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PASSIVE SOLAR DESIGN WORKBOOK

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BRET

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WHAT IS BRET?

The Botswana Renewable Energy Technology Project (BRET) works with individuals, institutions and government to use the abundant energy resources of people, animals, wind, and sun available in the country. BRET does research, development, and testing to find appropriate and reliable technologies that use these energy sources to meet demands.

BRET works to decrease dependency on imported petroleum-based fuels and to conserve existing energy sources, *particularly wood*. Thereby BRET strives to achieve these objectives listed in Botswana's National Energy Policy:

- to minimise dependence on imported oil because of its unreliable supply and rising price.
- to increase the energy available to the majority of rural people and to reduce the time and ecological damage involved in firewood collection.
- to minimise fossil energy consumption by designing buildings that require less heat and cooling, by substituting solar energy for electricity where this is economic,...[1]

BRET is a three-year pilot project that is funded by the government of Botswana and the United States Agency for International Development (USAID). It is implemented through the Ministry of Mineral Resources and Water Affairs by a staff of twenty-one people, fourteen Batswana and seven Americans.

The project operates on a community development basis. It works with people and institutions to develop and disseminate technologies and conservation approaches which are based upon locally perceived problems and needs. Community and organizational participation is crucial for the selection, pre-testing, and introduction of any renewable energy technology. BRET attempts to maximize this involvement in all of its work at the village level and at the institutional level.

VILLAGE LEVEL WORK

BRET is working in two villages, Ditshegwane in Kweneng District and Shoshong in Central District. This work began with a study of energy use patterns, including socio-economic factors. Firewood consumption data are being collected for three seasons of the year. Village discussions followed these studies to complete the needs assessment process. This resulted in a focus on firewood conserving technologies.

At BRET training facilities in Ditshegwane and Shoshong, demonstrations and workshops have been held in these technologies:

- earthen stoves
- sheet metal stoves
- retained heat cookers
- simple passive solar water heaters

In addition, BRET has designed and constructed improved rondavels and brick houses to illustrate how passive solar design can improve comfort in village housing, at minimal cost.

BRET engages in follow-up evaluation of each village technology to determine it longer term and broader scale suitability.

INSTITUTIONAL LEVEL WORK

BRET institutional level work revolves around substituting renewable energy for fuels in isolated areas. The sun generates electricity when it shines on photovoltaic panels. BRET has installed photovoltaic systems to provide lighting and refrigeration at the health clinics in Lentsweletau, Shoshong and Mabule. BRET is investigating possibilities of similar lighting for school rooms, community centres, or light posts in a village.

Water is an overwhelming need in Botswana, consequently, a major effort of BRET is water pumping technologies. Again the electricity from the sun is being used to pump water. Other renewable energy sources can also substitute for expensive diesel. BRET is developing, installing, and testing pumping systems powered by hand and human traction pumps, animal driven pumps, and wind pumps. BRET cooperates with Meteorological Services and the Department of Water Affairs to determine locations of potential wind energy for water pumping. Cooperatively, 34 anemometer wind speed data collection sites have been established.

PASSIVE SOLAR BUILDINGS

Homes and buildings can be built by passive solar design principles to provide comfortable temperatures in both summer and winter.

There are four BRET-designed demonstrations of these principles in Botswana; two in Gaborone. The first is a home completed in April, 1983, modeled after a standard BHC home. Comparisons of energy inputs and comfort will be made between the solar home and a similar standard BHC home from data collected

from sensors throughout both houses and recorded on microcomputers. The second Gaborone demonstration is a small office building, library, and workshop to house BRET and the Botswana Technology Centre. These buildings are scheduled for completion in May 1984, on a site across from the Polytechnic.

BRET constructed two village demonstrations at the training facilities in Ditshegwane and Shoshong which include rondavels and low cost block buildings. In addition, BRET has modified an existing rondavel in Shoshong. These four passive solar low and moderate cost demonstrations provide a basis for consultation with and design input to architects, builders and government policy makers, including the Self Help Housing Agency.

FUTURE ACTIVITIES

As a pilot project, BRET plans to see activities expand beyond the current efforts. With village level technologies, the experiences in the core villages will provide a basis for expanding dissemination efforts throughout the two districts. Eventually, there will be a national awareness campaign for energy conservation and technology dissemination. With institutional level technologies, BRET will make performance and economic comparisons between different technologies and make recommendations to government for future practices and policies in development programs. BRET offers its experience and knowledge to interested groups and agencies.

*Energy use studies are soon to be conducted in three (3) major population centres.

SERVICES AVAILABLE

BRET offers a wide range of services in Renewable Energy Technologies. Listed below are a few of those services.

INFORMATION AND WORKSHOPS

- Earthen stoves
- Sheet metal stoves
- Retained heat cookers
- Simple passive solar water heaters.

CONSULTATION ON INSTITUTIONAL RETS

- Photovoltaic electrification
- Wind energy potential
- Pumps
  - Photovoltaic
  - Hand
  - Human Traction
  - Animal driven
  - Windmills

CONSULTATION ON SOLAR BUILDING DESIGNS

RELATED RESOURCE MATERIALS AND REPORTS

WHERE TO FIND BRET

The BRET office is at Plot 2860 on Church Road, just behind the Y.W.C.A.

TEL: 52731 TELEX 2319 BRETP BD.

GABORONE PRINTING WORKS

PREFACE

This workbook contains reference material used in the two workshops on passive solar design held by the Botswana Renewable Energy Technology Project on February 27 - March 9, 1984. The workshops used verbal presentation, extensive visual aids, field trips and small-group application of concepts to design problems. Thus, the contents of this workbook represent only a small portion of the workshop program. It is not a comprehensive summary or text, but rather a collection of notes which were distributed as part of the workshop for use by the participants both during the workshop and in the future. This workbook and the workshops were held as part of the training component of the BRET project.

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

BRET PASSIVE SOLAR DESIGN WORKBOOK

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BRET PASSIVE SOLAR DESIGN WORKSHOP

FOR DESIGN PROFESSIONALS

SCHEDULE

DAY 1	7 MARCH 1984
7:30 - 12:30	• Registration • Introduction and Overview • Thermal Comfort • Climatic Factors • Passive Solar Cooling and Heating Strategies
14:00 16:00	• Integration of Energy Concerns into the Design Process • Siting for Passive Solar • Site Visit to Passive Solar Residence

DAY 2	8 MARCH 1984
7:30 - 12:30	• Building Form and Orientation • Thermal Design of the Building Envelope • Ventilation Design for Passive Solar Cooling • Selection of Building Energy Strategies • APPLICATION: Evaluation and Proposals for Improvement of the "Shakawe" Model House
14:00 - 16:00	• Building Energy Economics • Applying Passive Solar Design to Small Institutional Buildings • Site Visit to Passive Solar Office Building

C

BRET PASSIVE SOLAR DESIGN WORKSHOP

FOR DESIGN PROFESSIONALS

SCHEDULE (CONTINUED)

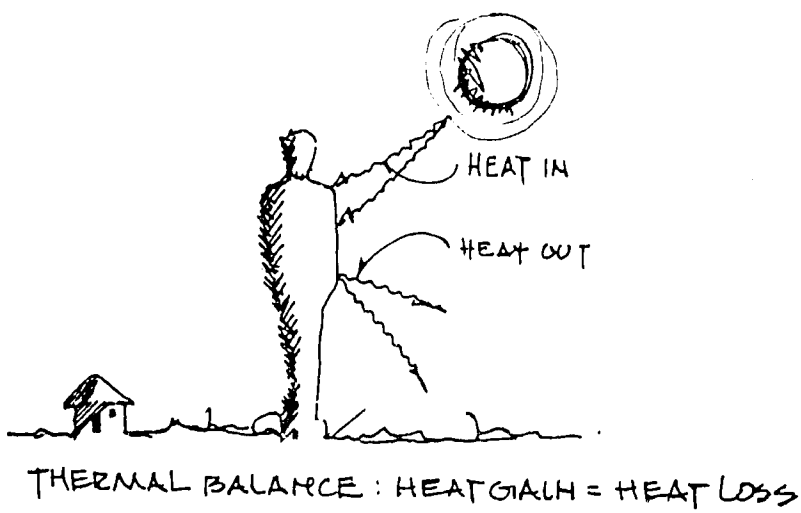
DAY 3	9 MARCH 1984
7:30 - 12:30	• Shading • Use of Vegetation • Water Collection and Conservation in Buildings • Applying Passive Solar Design to Large Institutional Buildings: - Daylighting - Environmental Control
14:00 - 16:00	• APPLICATION: Develop Design Guidelines for a Government Office Building • Resources - Literature, Calculation Aids and Organizations • Closing

1. ENERGY CONSERVATION IN BUILDING DESIGN:

A LOCAL PERSPECTIVE

ENERGY CONSERVATION IN BUILDING DESIGN: A LOCAL PERSPECTIVE

The human body seeks to remain at peace with the environment. For the body, peace is achieved when the amount of heat it gains from various internal and external sources is balanced by the amount of heat it loses back to the environment.



Thermal Balance: Heat Gain= Heat Loss

Without us being aware of it, this heat exchange with the surrounding environment is taking place continuously. Sweating, for instance,is an indication that the body has built up too much heat and needs to lose it. Shivering indicates that it has lost too much heat and needs to generate some of its own.

There is a limit to what the body can endure therm lly. Within that limit, though, there exists a narrow band of temperatures and other conditions where the body is not simply in a state of thermal balance, but in a state of thermal comfort. The body alone does not provide adequate protection against the harsh rays of

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the sun and when exposed to such conditions, humans seek the cool shelter of a hat, umbrella, tree or building.

1ST LEVEL SHELTER

2ND LEVEL SHELTER

THIRD LEVEL SHELTER

FOURTH LEVEL SHELTER.

As such, the building is not just a house, or a place to sleep, cook, converse, clean, think and work, but becomes an extension of our bodies into the environment, a sort of permanent tree over our heads or a permanent set of clothes that we wear which make it possible for us to survive and to create a small place or series of places where thermal comfort is achievable.

Botswana is a hot dry climate where it is cold for a few months of the year but hot most of the rest of the time and very hot for four months of the year. The priority,therefore, is how to keep the building cool inside.

Thermal comfort is a strong feature of the building tradition in Botswana. Building forms and materials have been developed over many centuries which seek to make the buildings cool inside.

The rondavel is such a building. The dispersed settlement form typical of the rural communities is good for air circulation. The low walls surrounding the family compound keep the dust out while permitting the cool breezes to circulate over top. The rondavel's cylindrical form reduces the building's surface area exposed to the sun's rays. The thatch roof is a much better insulator against the high overhead sun than the corrugated metal roof. Dense mud block walls keep the interior cool. Small window openings in the exterior walls don't let much sunlight, and therefore heat, into the interior.

Perhaps the most important lesson of the rondavel is the family compound's combination of interior and exterior and in between spaces. These establish an almost daily migratory pattern of the family is search of thermal comfort. At times it is deep inside the cool mud walls; at others in the shade of the overhang and still other under the stars.

The colonial era introduced the rectangular building form, which, if oriented correctly, is an energy efficient form. It also introduced the corrugated metal roof, which when installed without a ceiling , introduced a level of thermal discomfort unparalleled in the nation's history. The buildings had, nonetheless, deeply shaded overhangs and heavy block walls which kept the heat out.

These basic building forms were fine as long as traditional settlements did not require rapid expansion and maintained a primarily rural and agricultural focus. Gaborone changed all that with its commercial, governmental and industrial base which attracted large numbers of people very quickly with the hope of jobs and life in the city. Between 1971 and 1981, the population more than doubled and having reached an expansion rate of 13%, Gaborone is now one of the most rapidly growing cities of the world.

This has put enormous pressure on the government and others to provide an adequate number of decent housing units. This has led to the development of a low-income and other prototype houses which has as its reasonable top priority, shelter at moderate cost, but also plot layouts which make it difficult to orient the building to make it comfortable thermally, corrugated metal roofs which makes it very uncomfortable inside if there is no ceiling, and overhangs which don't shade windows adequately.

This has created thermal conditions of great discomfort in many dwellings. Last week, a staff member of the BRET project recorded a bedroom temperature of 42°C. Heat stress associated with such temperatures has been shown in other parts of the world to be linked to violent crimes, lower productivity of factory workers and heat stroke in old people and children.

Thermal comfort in buildings , therefore, is a critical issue which must be addressed by building designers and policy makers.

Thermal comfort and building energy use is also becoming an issue of economics. Botswana is not, like the western industrial economies of the early 70's, in the grips of an energy crisis. It is however, under increasing energy related stress(electrical costs!) and in a position to anticipate the long term economic effects of steadily rising fuel costs in the construction of its housing, schools and government buildings.

With both human physiology and economics in mind, this course will focus on the techniques of energy conservation in building which we believe should be a central part of Botswana's development policy for the following reasons:

1. GROWING DEPENDENCE ON IMPORTED SOURCES OF ENERGY

Imported energy is a major foreign exchange drain on the treasury of the government of Botswana, and it has been growing rapidly over the past five years. Money spent needlessly on energy imports is money not available for other government activities, such as new housing starts, health care centres, or drinking water installations.

2. ENERGY CONSUMPTION IN BUILDINGS IS EXPECTED TO RISE MORE RAPIDLY THAN ENERGY CONSUMPTION OVERALL

Expenditures for cooling and heating buildings in Botswana is expected to rise rapidly over the next decade, as private citizens and business have more discretionary income. The initiation of an energy-efficient building program now will moderate this increase, making money available for other investments.

3. ENERGY-EFFICIENT BUILDINGS ARE A GOOD INVESTMENT FOR BOTSWANA

The money invested in energy conserving design, insulation, etc., will be rapidly paid back in lower fuel costs, particularly where there is or will be airconditioning in use. Once the initial investment is paid back, Botswana will continue to enjoy the benefits of lower fuel costs for the life of the building.

4. ENERGY-EFFICIENT BUILDINGS ARE BETTER LIVING ENVIRONMENTS

By decreasing summer interior temperatures and increasing winter interior temperatures, energy-efficient design decreases the health problems of those using the building. This is particularly important for the poor, who often do not have funds to provide space heating or cooling for their homes. Young children, the elderly, and the infirm are the greatest immediate beneficiaries of these improved living conditions.

5. MANY OF THE BENEFITS OF ENERGY-EFFICIENCY CAN BE ACHIEVED WITH LITTLE ADDITIONAL COST

Using careful attention to design techniques, orientation to the sun, etc., a more comfortable building can be built.

6. WHERE THE GOVERNMENT IS BEARING THE COST BOTH OF CONSTRUCTING AND OPERATING A BUILDING - SCHOOLS, HOSPITALS, CLINICS, AND GOVERNMENT OFFICE SPACE - IT IS PARTICULARLY IMPORTANT THAT ENERGY EFFICIENCY IS INCLUDED IN THE DESIGN PHASE SO THAT THE OPERATING COSTS WILL BE LOWER THROUGHOUT THE LIFE OF THE STRUCTURE.

High energy costs for lighting, heating, and cooling often eat into the funds available for maintenance and for new equipment. This is particularly a problem for hospitals, clinics and schools. Careful energy-efficient design will prevent these unpleasant future surprises, and will make the building a more pleasant place for its workers as well.

2. THERMAL COMFORT

THERMAL COMFORT: THE BODY AND THE BUILDING

As discussed previously, the body undergoes a constant thermal exchange with its environment and in so doing, it seeks a thermal balance between the heat it loses and the heat it gains. There is a relatively narrow set of thermal conditions which make the body feel comfortable. If the body cannot achieve either thermal comfort or a state of thermal balance, it looks for another skin, such as a building, in order to do so. The key in all this is for the body to continue to balance the heat losses and the heat gains no matter what its level of physical activity or conditions of temperature, humidity and air movement. It is therefore critical to understand more precisely what the means of heat loss and gain are.

SOURCES OF HEAT GAIN

1. Heat generated by eating (basal metabolism) and by physical activity (muscular metabolism). The heat is a by-product of the process whereby the body converts food into work or physical activity. This food-to-work conversion mostly produces heat(80%) not work (20%) and this surplus heat must be lost to the environment.

2. Radiation. In this environment this is direct and indirect solar radiation heating up skin temperature.

3. Convection. This heat gain comes from the body being exposed to a flow of air which is hotter than the skin temperature.

4. Conduction. This heat gain requires physical contact between the body and a hotter surface or object.

SOURCES OF HEAT LOSS

1. Radiation. This requires that the body be in the presence of a surface or object whose surface temperature is lower than that of the skin. The night sky, dark and cold, is the most effective source of radiant heat loss in Botswana.

2. Convection. The process is the same as for heat gain except that now the flow of air is cooler rather than hotter than skin temperature.

3. Conduction. Contact with a surface or body with a temperature cooler than skin temperature.

4. Evaporation. As the body generates heat it is transported to the skin surface as sweat where, in contact with the dry air, it evaporates. As it does it cools the surface temperature of the skin.

Note that if thermal conditions are such that the body's efforts to lose heat by means of conduction, convection, radiation and evaporation are blocked,the core body temperature will rise and if it does so more than a few degrees one runs the risk of heat stroke, coma and possibly death.

THERMAL COMFORT

Thermal comfort is defined as that combination of temperature, humidity, radiation and air movement conditions which result in 80% of the people feeling comfortable. These factors can be combined into a single temperature, the Effective Temperature(ET).

In order to determine the ET first find the wet bulb temperature (WBT) by using the Psychometric Chart (Page 2-3). To do so you must know the dry bulb temperature (DBT), assumed here to be 30°C, and the relative humidity (RH), assumed to be 30%. Typically, both data can be obtained from meteorological charts. Start by locating the DBT on the horizontal axis, then rise vertically until you encounter the curved RG line. At their intersection, move diagonally to the upper left and read the WGT from the curbed scale.

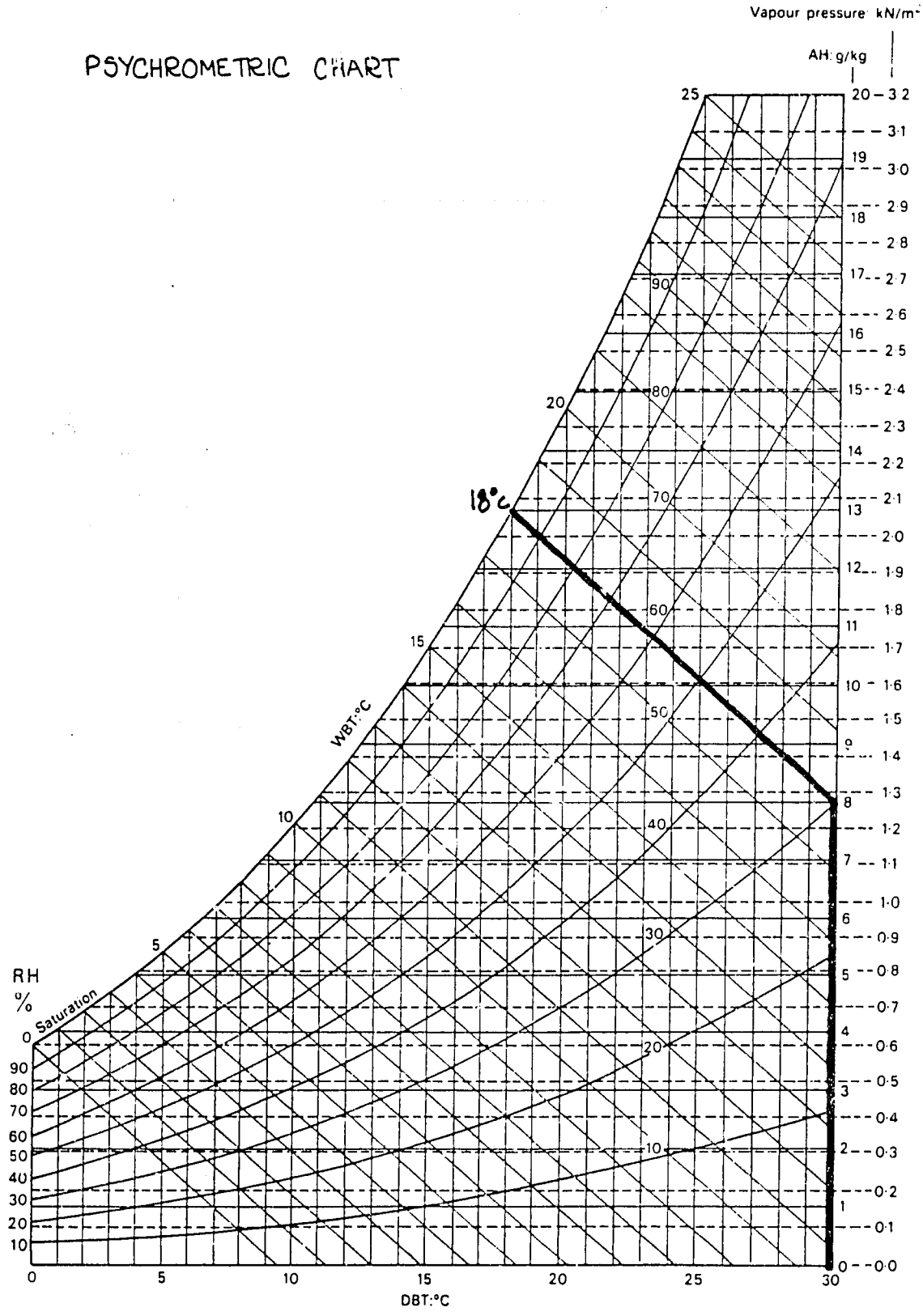
Move now to the Effective Temperature Nomogram (page 2.5) which accounts for the thermal effect of air movement in addition to those of DBT and WBT. Mark the DBT (30°C) on the vertical scale to the left and WBT (18°C) on the scale to the right. Connect the two points with a line and mark its intersection with the curved line representing air velocity, assumed here to be .5 meters per second. Read the ET from the outer scale. If the ET falls within the darkened zone on the nomogram, thermal comfort exists--at least statistically.

The above procedure is mostly important to point out the combination of factors affecting thermal comfort other than DBT. In Botswana, however, average humidity is negligible and air movement, though substantial, can be largely ignored for design purposes. Therefore, it is reasonable as well as simpler to link thermal comfort directly to the DBT. We can assume as such that thermal comfort in Botswana exists if the DBT is between 19° and 27° in winter and between 20° and 28° in summer. The seasonal shift assumes that the body adjusts its comfort zone to a range of higher temperatures in summer and lower ones in winter.

Other factors affecting thermal comfort include:

1. Clothing. A person wearing a business suit will require a comfortable temperature 9°C lower than a naked body.
2. Acclimatisation. Exposed to a new set of climatic conditions, the body will adjust in 30 days.
3. Age and Sex. Older people and women prefer higher temperatures because their base metabolism is lower.

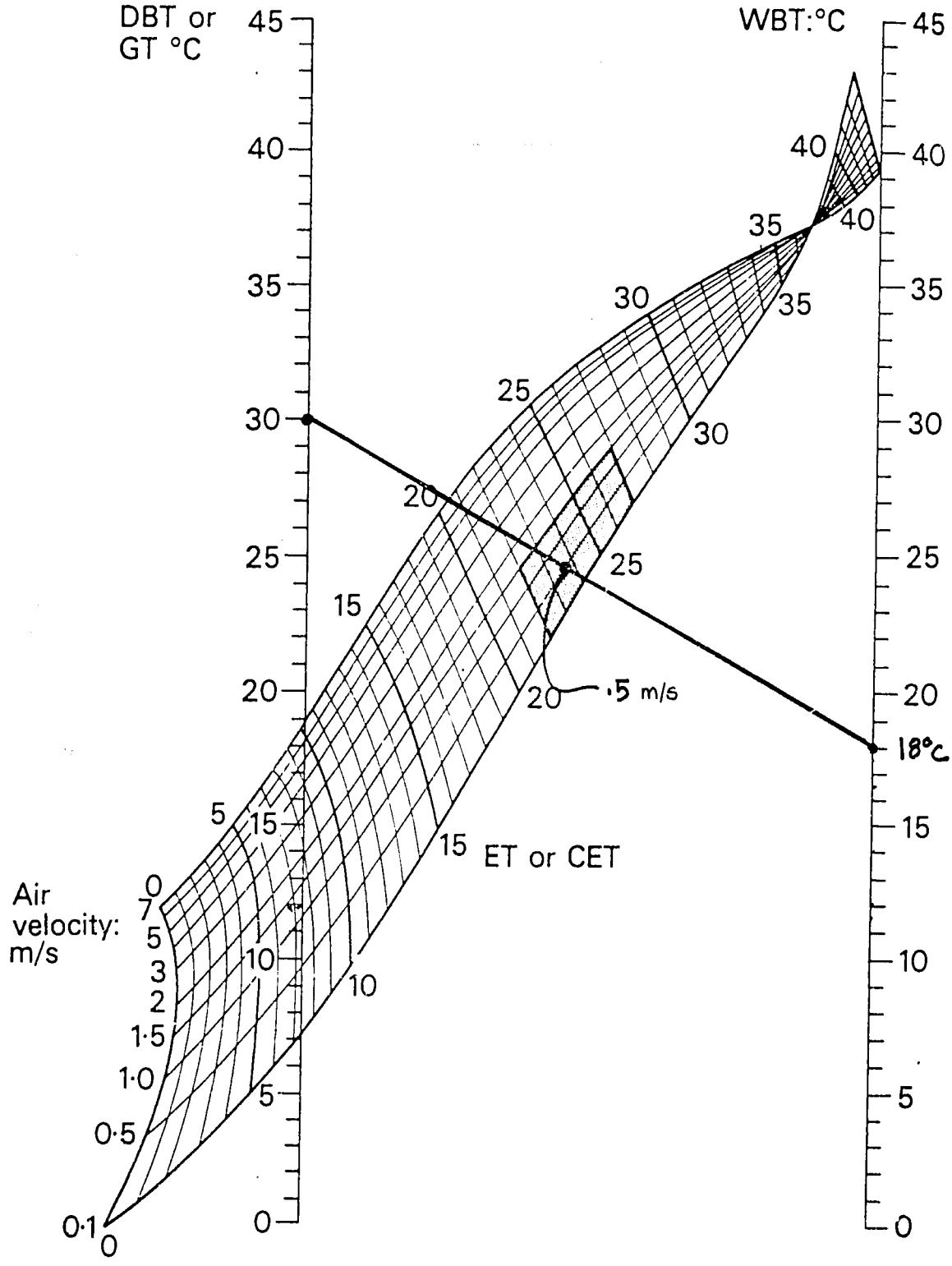
PSYCHROMETRIC CHART



(Source: ASHRAE)

Effective temperature nomogram for persons wearing normal business clothing (1 clo.)

(shaded area: comfort zone)



(Source: Koenigsberger)

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3. CLIMATIC FACTORS

CLIMATIC FACTORS AFFECTING BUILDING DESIGN IN BOTSWANA

Passive solar buildings are buildings designed to make the best possible use of the sun and other elements of the environment to help the building provide shelter and comfort. In order to design and build good passive solar buildings, it is important to understand the various factors in the environment which affect the building. In Botswana, the most important are:

1. SUN
2. AIR TEMPERATURE
3. WIND

Other factors to be considered are:

4. RAIN
5. GROUND TEMPERATURE
6. NIGHT SKY CLEARNESS

(1) SUN (Solar Radiation)

The amount of solar radiation available in Botswana is higher than most other places in the world. Over a year, the amount of solar radiation falling on a 1 m^2 piece of ground is 8.2 gigajoules (the same as 2300 kWh). This is the approximate amount of heat you would get burning 420 liters of fuel or a pile of wood 1m by 1m by 2m.

The amount of solar radiation available varies over the year, due to:

1. The amount of clouds blocking the sun.

   From November through March clouds block the sun 20 - 30% of the time. The rest of the year there are very few clouds.

2. The length of the day.

   The length of the day varies from about 14 hours in December to about 10 hours in June.

3. The angle of the sun in the sky.

   In December, the sun travels high overhead. In June, the sun never gets more than halfway (45°) to being directly overhead.

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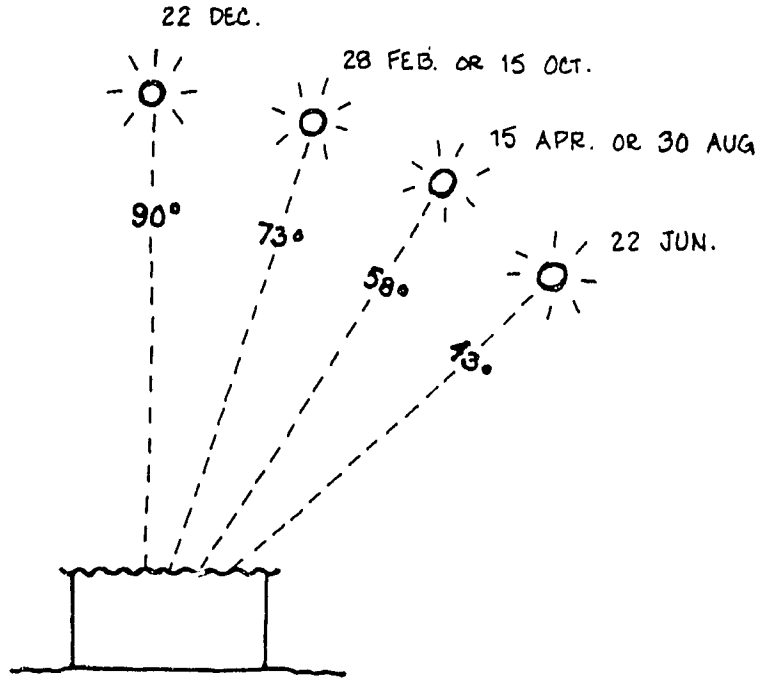

In Botswana, these three major factors all tend to balance each other:

- In winter, when the days are shorter and the sun is low in the sky, there are very few clouds.
- In summer, when the days are longer and the sun is high in the sky, there are more clouds.

The result is that the amount of solar radiation that falls on a surface facing the sun varies very little from month to month, with the average amount being about 6.5 kWh/m²/day.

A table of solar radiation data can be found on the next page. It contains data from the three closest meteorological stations where solar radiation has been measured long enough to establish average values. It also contains blank columns for locations in Botswana which can be filled in when data from these locations becomes available in the future. Until that time, if no other data source is available, the following is recommended:

-In the Southwest part of Botswana (west of Kanye and south of Ghanzi), use solar radiation data from Upington for the summer and an average of Upington and Windhoek data for the winter months.

SOLAR RADIATION DATA

($kWh/m^2/month$)

	PRETORIA*		UPINGTON*		WINDHOEK*	
	HORIZ.	26° TILT	HORIZ.	28° TILT	HORIZ.	22° TILT
JAN	203	187	236	209	200	184
FEB	169	164	187	180	185	180
MAR	170	178	179	192	185	192
APR	134	155	148	182	172	198
MAY	127	171	122	176	163	214
JUN	114	167	94	136	145	203
JUL	128	177	110	169	158	213
AUG	154	193	138	182	180	220
SEP	175	194	172	116	203	221
OCT	193	191	209	209	215	210
NOV	197	183	235	212	221	203
DEC	211	189	238	204	236	210
TOTAL	1975	2149	2068	2247	2263	2448

	GABARONE*		FRANCISTOWN*		MAUN*	
	HORIZ.	25° TILT	HORIZ.	21° TILT	HORIZ.	20° TILT
JAN						
FEB						
MAR						
APR						
MAY						
JUN						
JUL						
AUG						
SEP						
OCT						
NOV						
DEC						
TOTAL						

* from "Availability of Solar Radiation in South Africa", X/BOU 2-40, NBIR, 1978

SOLAR POSITION AND INSOLATION, 24° LATITUDE

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES: NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ. 14	24	34	54	90
JUL 21	7	5	4.8	65.6	71	10	17	21	25	28	31
	8	4	16.9	58.3	239	83	110	126	137	145	127
	9	3	27.9	48.8	288	151	188	207	221	228	176
	10	2	37.2	36.1	308	204	246	268	282	287	207
	11	1	43.6	19.6	317	237	283	306	319	324	226
	12		46.0	0.0	320	249	296	319	332	336	232
	SURFACE DAILY TOTALS				2756	1622	1984	2174	2300	2360	1766
AUG 21	7	5	9.3	74.6	158	35	44	49	53	56	46
	8	4	22.3	67.2	263	116	135	145	150	151	102
	9	3	34.4	57.6	298	187	213	225	230	228	141
	10	2	45.1	44.2	314	241	273	286	291	287	168
	11	1	53.0	25.0	321	276	310	324	328	323	185
	12		56.0	0.0	324	288	323	337	341	335	191
	SURFACE DAILY TOTALS				3036	1998	2276	2396	2446	2424	1476
SEP 21	7	5	13.7	83.8	194	60	63	64	62	59	27
	8	4	27.2	76.8	267	141	150	152	149	142	64
	9	3	40.2	67.9	295	212	226	229	225	214	95
	10	2	52.3	54.8	309	266	285	288	283	270	120
	11	1	61.9	33.4	315	300	322	326	320	305	135
	12		66.0	0.0	317	312	334	339	333	317	140
	SURFACE DAILY TOTALS				3078	2270	2428	2456	2412	2256	1022
OCT 21	6	6	4.7	100.6	40	7	5	4	4	3	2
	7	5	18.3	94.9	203	83	77	70	62	51	10
	8	4	32.0	89.0	256	160	157	149	137	122	16
	9	3	45.6	81.9	280	227	227	220	206	186	41
	10	2	59.0	71.8	292	278	282	275	259	232	61
	11	1	71.1	51.6	296	310	316	309	293	269	74
	12		77.6	0.0	299	321	328	321	305	280	79
	SURFACE DAILY TOTALS				3036	2454	2458	2374	2228	2016	488
NOV 21	6	6	8.0	108.4	86	22	15	10	9	9	5
	7	5	21.2	103.2	203	98	85	73	59	44	12
	8	4	34.6	98.5	248	171	159	145	127	106	15
	9	3	48.3	93.6	269	233	224	210	190	165	16
	10	2	62.0	87.7	280	281	275	261	239	211	22
	11	1	75.5	76.9	286	311	307	293	270	240	34
	12		86.0	0.0	288	322	317	304	281	250	37
	SURFACE DAILY TOTALS				3032	2556	2447	2286	2072	1800	246
DEC 21	6	6	9.3	111.6	97	29	20	12	12	11	7
	7	5	22.3	106.8	201	103	87	73	58	41	13
	8	4	35.5	102.6	242	173	158	142	122	99	16
	9	3	49.0	98.7	263	234	221	204	182	155	18
	10	2	62.6	95.0	274	280	269	253	229	199	18
	11	1	76.3	90.8	279	309	300	283	259	227	19
	12		89.4	0.0	281	319	310	294	269	236	22
	SURFACE DAILY TOTALS				2994	2574	2422	2230	1992	1700	204

DATE	SOLAR TIME AM	SOLAR TIME PM	SOLAR POSITION ALT	SOLAR POSITION AZM	BTUH/SQ. FT. TOTAL INSOLATION ON SURFACES: NORMAL	HORIZ.	SOUTH FACING SURFACE ANGLE WITH HORIZ. 14	24	34	54	90
JAN 21	6	6	8.2	109.0	81	23	16	11	10	9	6
	7	5	21.4	103.8	195	98	85	73	59	44	13
	8	4	34.8	99.2	239	169	157	143	125	104	16
	9	3	48.4	94.5	261	231	221	207	187	161	18
	10	2	62.1	88.0	272	278	270	256	235	206	21
	11	1	75.7	79.2	278	307	302	287	265	235	32
	12		86.6	0.0	280	317	312	298	275	245	36
	SURFACE DAILY TOTALS				2932	2526	2412	2250	2036	1766	246
FEB 21	6	6	5.0	101.3	35	7	5	4	4	4	2
	7	5	18.5	95.6	186	82	76	69	60	50	11
	8	4	32.2	89.7	241	158	154	146	134	118	16
	9	3	45.9	82.6	265	223	222	214	200	181	39
	10	2	59.3	73.0	278	273	275	268	252	230	58
	11	1	71.6	53.2	284	304	309	301	285	261	71
	12		76.3	0.0	286	315	320	313	296	272	75
	SURFACE DAILY TOTALS				2864	2408	2402	2316	2158	1958	470
MAR 21	7	5	13.7	83.8	173	57	60	60	59	56	26
	8	4	27.2	76.8	248	136	144	146	143	136	62
	9	3	40.2	67.9	278	205	218	221	217	206	93
	10	2	52.3	54.8	292	258	275	278	273	261	116
	11	1	61.9	33.4	299	291	311	315	309	295	131
	12		66.0	0.0	301	302	323	327	321	306	136
	SURFACE DAILY TOTALS				2878	2194	2342	2366	2322	2212	992
APR 21	7	5	9.1	74.1	138	32	40	45	48	50	42
	8	4	22.0	66.7	247	111	129	139	144	145	99
	9	3	34.1	57.1	284	180	206	217	223	221	138
	10	2	44.7	43.8	301	234	265	277	282	279	165
	11	1	52.5	24.7	309	268	301	315	319	314	182
	12		55.5	0.0	311	279	314	328	332	327	188
	SURFACE DAILY TOTALS				2868	1928	2198	2314	2364	2346	1442
MAY 21	7	5	4.9	65.8	67	10	16	20	24	27	29
	8	4	17.0	58.4	232	82	108	123	135	142	124
	9	3	28.0	48.9	282	150	186	205	217	224	172
	10	2	37.3	36.3	303	203	244	265	278	283	204
	11	1	43.8	19.7	312	236	280	302	316	320	222
	12		46.2	0.0	315	247	293	315	328	332	228
	SURFACE DAILY TOTALS				2706	1610	1962	2146	2268	2324	1730
JUN 21	7	5	3.2	62.6	30	3	7	9	11	12	14
	8	4	14.9	55.3	225	71	99	116	129	139	130
	9	3	25.5	46.0	281	137	176	198	214	223	184
	10	2	34.3	33.7	304	189	234	258	275	283	217
	11	1	40.4	18.2	314	221	270	295	312	320	236
	12		42.6	0.0	317	232	282	308	325	332	243
	SURFACE DAILY TOTALS				2624	1474	1852	2058	2204	2286	1808

Adapted from: Anderson & Riordan, The Solar Home Book, Brick House Pub., 1976.

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-In the southeast part of Botswana (east of Kanye and south of Palapye), use solar radiation data from Pretoria plus 5%.

-In the northern part of Botswana, use solar radiation data from Windhoek.

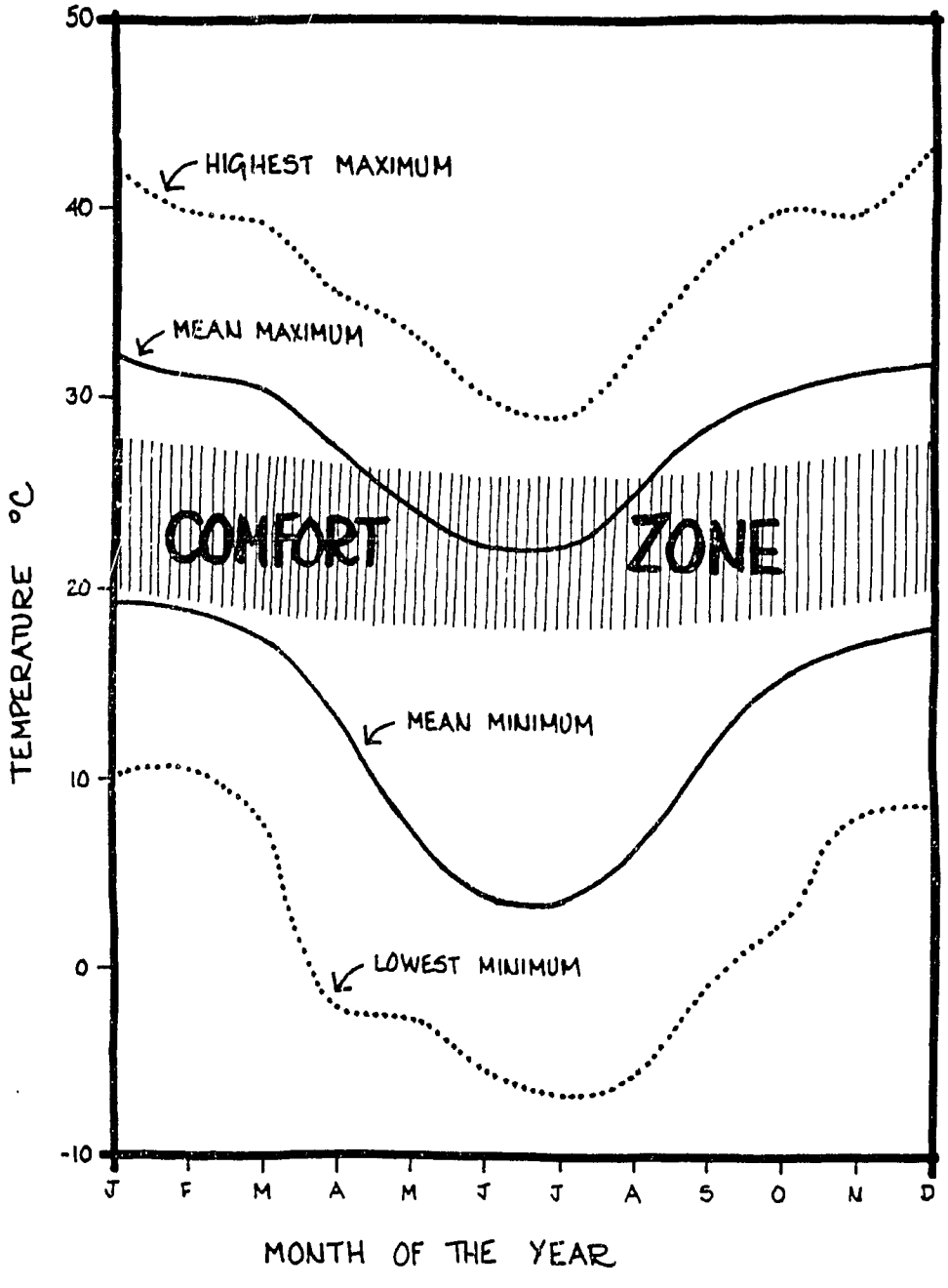
(2) AIR TEMPERATURE

The chart on the next page shows outdoor air temperatures for Gaborone, as well as the approximate limits of "comfortable" temperatures.

- The "mean maximum" is the average of the hottest temperatures it rises to each day.
- The "highest maximum" is the hottest temperature reached on the hottest day of the month.
- The "mean minimum" is the average of the coolest temperatures it falls to at night.
- The "lowest minimum" is the coldest temperature reached on the coldest night of the month.

The most notable feature about the pattern of outdoor air temperatures in Botswana is the very large difference between the high and low temperatures. In the summer, the average temperature difference from day to night is 16.3° and in the winter it is 20.0°. These differences are among the highest in the world and are a great resource for natural heating and cooling of buildings. As you can see in the following chart, even in the hottest month of the year, the temperature is usually inside the "comfort zone" for much of the time, usually at night. In the coldest months, the outdoor temperature will often rise to where it is very comfortable during the day.

Following the chart of Gaborone temperatures are tables of monthly temperatures for eight locations in Botswana.



ANNUAL TEMPERATURES IN GABORONE

MAXIMUM AND MINIMUM TEMPERATURES (C°)

	GABORONE				MAHALAPYE			
	Mean Maximum (1958-80)	Mean Minimum (1958-80)	Highest Maximum	Lowest Minimum	Mean Maximum (1961-80)	Mean Minimum (1961-79)	Highest Maximum	Lowest Minimum
JAN	32.6	19.7	42.5	10.4	30.9	19.1	40.5	12.5
FEB	31.2	19.0	39.7	10.9	30.2	19.2	36.6	13.5
MAR	31.1	18.0	39.7	8.0	28.6	16.6	36.5	9.8
APR	27.2	13.1	35.6	-2.2	26.5	13.2	34.6	4.5
MAY	24.6	7.6	33.9	-2.2	24.4	8.1	33.0	1.0
JUN	22.2	4.0	30.2	-5.0	22.1	4.9	28.9	-5.4
JUL	22.3	3.6	29.0	-6.5	22.3	3.9	29.8	-4.0
AUG	25.5	6.5	33.1	-5.5	25.1	7.1	34.1	-6.0
SEP	29.1	11.9	37.4	-0.6	29.2	12.6	37.6	1.7
OCT	30.7	15.5	40.6	2.8	29.8	15.6	39.3	6.2
NOV	31.2	17.5	39.7	8.5	30.4	18.0	38.6	8.6
DEC	32.1	18.4	43.9	8.5	30.6	19.0	37.9	11.6
ANNUAL	28.3	12.9	43.9 (30.12.)	-6.5 (19.7.54)	27.5	13.1	40.5 (14.1.69)	-6.0 (15.8.80)

	FRANCISTOWN				MAUN			
	Mean Maximum (1959-80)	Mean Minimum (1959-80)	Highest Maximum	Lowest Minimum	Mean Maximum (1959-80)	Mean Minimum (1959-80)	Highest Maximum	Lowest Minimum
JAN	30.7	19.0	40.6	10.6	31.6	19.5	40.0	9.2
FEB	29.5	18.2	38.4	10.5	31.4	18.9	37.2	10.6
MAR	29.3	16.9	38.8	4.0	31.3	17.8	39.5	6.2
APR	27.7	13.7	35.6	4.0	29.9	15.0	35.0	4.4
MAY	25.5	8.5	34.0	-1.0	27.5	9.6	33.0	-1.1
JUN	23.0	5.3	31.3	-4.5	25.0	6.9	30.6	-5.8
JUL	23.1	4.8	30.6	-5.0	25.1	6.9	31.1	-3.6
AUG	25.1	7.7	35.5	-4.2	28.3	9.8	35.2	3.5
SEP	29.8	12.3	37.0	1.5	32.2	14.8	38.6	3.9
OCT	31.5	16.2	40.2	4.0	34.1	18.6	41.4	9.0
NOV	31.0	16.9	41.1	4.1	33.0	19.4	41.7	9.4
DEC	30.3	18.5	39.5	8.8	32.1	19.4	40.6	8.4
ANNUAL	28.1	13.2	41.1 (30.11.51)	-5.0 (3.7.53)	30.1	14.7	41.7 (26.11.41)	-5.8 (15.6.62)

MAXIMUM AND MINIMUM TEMPERATURES (C°)

	SHAKAWE				GANTSI			
	Mean Maximum (1959-80)	Mean Minimum (1959-80)	Highest Maximum	Lowest Minimum	Mean Maximum (1959-80)	Mean Minimum (1959-80)	Highest Maximum	Lowest Minimum
JAN	30.4	19.3	39.2	10.6	31.6	19.0	40.3	6.5
FEB	30.4	19.2	36.6	11.3	31.3	18.3	39.6	5.5
MAR	30.2	18.5	36.4	8.8	30.9	16.8	38.8	3.5
APR	29.4	16.0	36.0	7.0	28.7	14.0	36.4	0.3
MAY	27.4	10.8	32.6	0.4	26.2	8.2	34.5	-2.2
JUN	25.0	6.5	30.6	-7.5	23.3	4.7	29.8	-8.1
JUL	24.8	6.0	31.9	-6.1	24.0	4.1	29.8	-8.5
AUG	28.6	8.6	34.7	-5.5	26.8	7.0	34.5	-5.4
SEP	32.3	12.5	38.0	2.0	30.8	11.5	37.2	-1.1
OCT	34.3	17.1	39.5	2.0	33.2	15.8	40.6	3.5
NOV	32.8	18.4	39.6	10.0	32.8	17.8	41.3	5.0
DEC	31.4	19.0	39.1	11.4	32.9	18.5	40.0	6.2
ANNUAL	29.7	14.3	39.6 (29-11-72)	-7.5 (15-6-68)	29.4	13.0	41.3 (29-11-66)	-8.5 (4-11-62)

	TSHANE				TSABONG			
	Mean Maximum (1959-80)	Mean Minimum (1959-80)	Highest Maximum	Lowest Minimum	Mean Maximum (1959-80)	Mean Minimum (1959-80)	Highest Maximum	Lowest Minimum
JAN	33.3	19.3	41.0	10.5	34.4	19.0	42.1	
FEB	32.0	18.6	38.7	11.0	33.2	17.9	41.3	
MAR	30.6	17.1	38.9	5.7	31.4	16.4	39.3	
APR	27.6	13.0	34.5	3.6	27.7	11.9	35.2	
MAY	24.5	7.0	34.5	-0.5	24.0	5.8	37.5	
JUN	21.6	3.9	29.5	-6.4	21.5	2.3	30.0	
JUL	22.2	3.5	31.9	-5.0	22.0	1.3	28.9	
AUG	25.2	6.0	32.6	-8.0	24.3	3.5	32.6	
SEP	29.4	11.2	37.8	-3.9	28.8	8.1	38.5	
OCT	31.6	14.2	39.9	4.9	31.2	12.3	39.6	
NOV	33.0	16.9	39.4	7.0	33.4	15.9	42.6	
DEC	33.7	18.3	40.8	6.0	34.5	17.7	41.1	
ANNUAL	28.7	12.4	41.0 (19-1-73)	-8.0 (15-6-8)	28.9	11.0	42.6 (19-11-61)	

(3) WIND

Wind is an important climatic factor for building design in Botswana because it can help cool both PEOPLE and BUILDINGS:

1. Wind-driven air movement over human skin can significantly affect thermal comfort in buildings.
2. Wind can provide ventilation of a building with outside air, bringing the inside temperature closer to the outside temperature. This can change the temperature not only of the air in the building, but also of the materials (mass) of which the building is made.

The size and placement of windows and other ventilation openings should be designed with consideration of both wind DIRECTION and wind VELOCITY.

WIND VELOCITY

Wind velocity is highly variable in Botswana. Depending on location it may be calm (no wind) anywhere from 20 - 50% of the time. Because of the calm periods, there is a substantial difference between the "average" wind velocity at all times and the actual velocity of the wind when the wind is blowing. The table below shows both this effect and the variability of wind at different locations in Botswana. The velocities reported are at a height of 2 meters, as this would be the the typical height at which wind would strike a building. Following this table is another, listing average wind velocities for eight locations in Botswana.

	Average Wind Over the Year (m/s)	%of Time Wind Blows	Design Wind Velocity (When Wind Blows) (m/s)
Gaborone	1.1	62%	1.8
Mahalapye	0.8	68%	1.2
Maun	1.8	75%	2.4
Francistown	1.8	76%	2.4
Ghanzi	1.7	61%	2.8
Tsabong	1.4	56%	2.5

MEAN MONTHLY WIND SPEED (KM/HOUR)

α (surface roughness coefficient) = 0.29

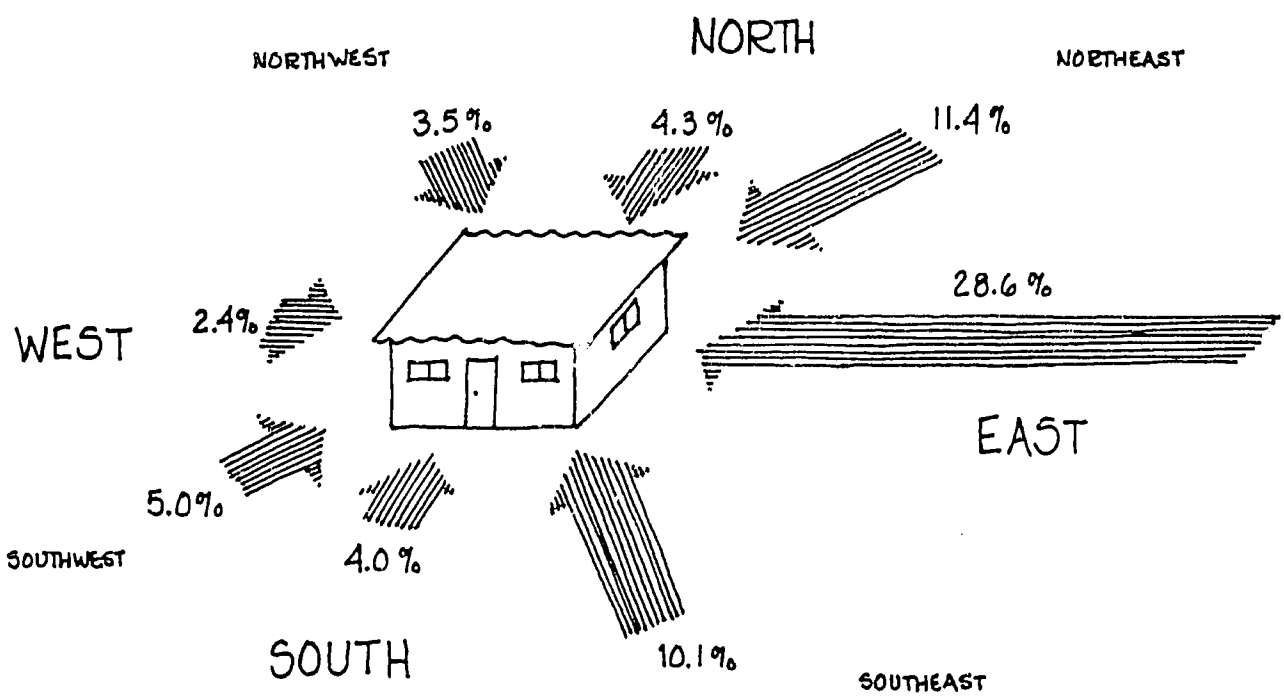
	GABORONE (1958-80)		MAHALAPYE (1959-80)		FRANCISTOWN (1958-80)		MAUN (1967-80)	
AT:	2m	10m	2m	10m	2m	10m	2m	10m
JAN	4.3	6.9	3.3	5.3	6.8	10.9	5.9	9.4
FEB	3.7	5.9	2.9	4.6	6.7	10.7	5.6	9.0
MAR	3.1	5.0	2.7	4.3	6.7	10.7	5.9	9.4
APR	3.0	4.8	2.4	3.8	5.7	9.1	5.5	8.9
MAY	3.2	5.1	2.1	3.4	4.9	7.8	5.4	8.6
JUN	3.0	4.8	2.4	3.8	4.9	7.8	5.7	9.1
JUL	3.1	5.0	2.2	3.5	5.4	8.6	6.0	9.6
AUG	4.0	6.4	2.9	4.6	6.4	10.2	6.5	10.4
SEP	4.9	7.8	3.7	5.9	8.0	12.8	7.7	12.3
OCT	3.7	9.1	4.3	6.9	9.0	14.4	8.6	13.8
NOV	5.1	8.2	3.9	6.2	7.9	12.6	7.5	12.1
DEC	4.5	7.2	3.5	5.6	7.1	11.4	6.7	10.7
ANNUAL	4.0	6.4	3.0	4.8	6.6	10.6	6.4	10.3

	SHAKAWE (1960-80)		GANTSI (1959-80)		TSHANE (1959-80)		TSABONG (1959-80)	
AT:	2m	10m	2m	10m	2m	10m	2m	10m
JAN	3.3	5.3	6.5	10.4	7.4	11.8	6.0	9.6
FEB	3.2	5.1	6.1	9.8	6.5	10.4	4.9	7.8
MAR	3.2	5.1	5.9	9.4	6.2	9.9	4.3	6.9
APR	2.7	4.3	4.7	7.5	5.3	8.5	3.4	5.4
MAY	2.4	3.8	4.7	7.5	4.9	7.8	3.0	4.8
JUN	2.3	3.7	4.9	7.8	4.9	7.8	3.3	5.3
JUL	2.2	3.5	5.6	9.0	5.2	8.3	3.9	6.2
AUG	3.1	5.0	6.0	9.6	6.1	9.8	5.2	8.3
SEP	3.3	5.3	7.0	11.2	7.0	11.2	5.7	9.1
OCT	3.5	5.7	7.9	12.6	7.5	12.0	6.5	10.4
NOV	3.1	5.0	7.8	12.5	7.7	12.3	5.8	9.3
DEC	3.4	5.4	7.0	11.2	7.6	12.2	6.4	10.2
ANNUAL	3.0	4.8	6.2	9.9	6.4	10.2	4.9	7.8

While the wind does no good for a building or its occupants when it is calm, there is enough wind at each of these locations to significantly help to cool both people and buildings.

WIND DIRECTION

Wind direction is important if you want to use the wind for natural ventilation to keep the building cool in summer. If the windows are not on the best side of the building, they will have to be much larger to provide the same amount of air moving through the building. This diagram shows how much of the time in January (the hottest month) the wind comes out of each direction in Gaborone:



The other 30.7% of the time there is no wind.

Over the year similar pattern of wind direction can be found in many locations in Botswana:

	Dominant Wind Direction	% of Time Wind Blows from Dominant Direction
Gaborone	east	24%
Mahalapye	northeast	26%
Maun	east	20%
Francistown	east	36%
Ghanzi	east	19%
Tsabong	north & south	23%

(4) RAIN

The amount of rainfall in Botswana is VERY small, but it often occurs in short, heavy showers. The primary considerations for building design are:

- Use of overhang to protect walls against driven rain.
- Use of roofs to gather rainwater for various uses.

(5) GROUND TEMPERATURE

The temperature of the ground just below the surface is relatively constant from day to day. It usually will have a temperature similar to the long-term (several months) average temperature of the outdoor air and is usually closer to the designed comfort temperature inside a building than the outside maximum and minimum air temperatures. Therefore thermal connection between a building and the ground can usually help to moderate temperature extremes in the building.

MEAN MONTHLY SOIL TEMPERATURES (C°)

GABORONE (1958-79)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0800 L.T.												
10 cm	26.1	25.5	24.2	19.9	15.3	12.2	11.3	14.0	18.8	22.0	24.5	25.2
20	28.6	27.3	26.4	22.3	17.8	14.4	13.8	16.5	21.2	24.4	26.7	27.6
30	29.9	29.1	27.9	23.7	19.8	16.5	15.8	17.7	22.4	25.9	28.5	28.7
60	30.7	30.4	29.1	25.5	21.8	17.9	17.5	19.0	22.9	26.4	28.5	29.5
120	30.7	28.7	27.4	26.3	23.5	20.4	19.8	19.5	22.5	25.2	27.3	27.9
1400 L.T.												
10 cm	33.2	33.1	31.7	26.8	22.4	18.1	18.0	21.0	26.3	30.5	32.5	33.1
20	31.6	30.7	29.3	24.6	20.3	16.1	15.7	18.6	23.2	27.5	30.1	31.0
30	30.4	29.8	28.4	24.1	19.7	16.1	16.1	18.3	23.0	26.6	28.8	29.9
60	30.3	29.9	28.4	25.0	21.0	16.0	16.8	18.7	23.2	26.2	28.0	29.2
120	29.2	28.8	28.6	26.2	23.0	18.3	[illegible].0	19.5	22.2	25.0	26.9	28.2
2000 L.T.												
10 cm	32.5	31.6	30.8	26.0	21.6	18.1	17.7	21.5	25.6	29.3	30.9	31.5
20	30.4	32.8	31.5	26.5	22.3	18.4	17.8	21.1	26.0	29.5	31.9	33.9
30	32.3	31.7	29.8	25.9	21.7	17.8	17.1	20.0	24.8	28.2	30.6	31.4
60	30.4	30.1	29.1	25.3	21.5	17.8	16.9	18.9	23.4	26.3	28.5	29.5
120	29.1	29.3	28.1	26.3	22.9	20.8	18.9	19.6	22.2	24.8	26.9	27.4

(6) NIGHT SKY CLEARNESS

The clearness of the night sky affects how much heat can be lost from the earth and various objects on it by "radiation" to the night sky. If there are clouds, dust, pollution or a lot of moisture in the air, it will prevent heat from radiating up to the night sky.

While no measurements have been taken to quantify this resource, it is obvious that Botswana has extremely clear skies and should offer excellent potential for cooling buildings by radiating to to the night sky.

DESIGN WEATHER CONDITIONS

The remainder of this section contains tables of "design weather conditions" for Maun, Upington and Windhoek, taken from the South African NBRI publication "Climatic and Other Design Data for Evaluating Heating and Cooling Requirements of Buildings" (CSIR Research Report 300, Pretoria, 1971). For each location, the tables contain values for numerous climatic factors presented by probability of occurance at the 0.05%, 2.5%, 5% and 10% levels. What this means, for example, is that the maximum temperatures listed on the 2.5% probability table will be exceeded only 2.5% of the time. Thus, if you wanted to use a maximum temperature for determining peak cooling loads at a particular location and time, you could choose a value on any one of the four probability tables. If you wanted to design for the worst case conditions you would use the 0.05% probability table. If, on the other hand, you could accept that 5% of the time (for each hour of the day under consideration) the temperature would be greater than what you have designed for, you would use the 5% table.

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10%	DB	22,0	21,5	21,0	20,6	20,1	19,6	21,2	24,7	27,8	30,1	31,9	33,2	34,2	34,7	34,7	34,5	33,6	32,6	30,6	28,0	26,2	25,0	24,1	23,2
	RH	59,7	62,1	66,1	65,5	70,6	75,1	68,0	51,8	41,4	34,1	30,5	26,8	23,7	22,4	24,3	26,5	23,4	26,2	31,2	35,5	43,4	53,9	49,4	[illegible]
	WB	16,5	16,2	16,6	16,0	16,1	16,5	17,0	17,6	18,1	18,4	18,6	19,0	18,8	18,8	19,2	19,6	18,4	18,4	18,0	17,1	17,3	18,1	16,6	17,1
	DP	12,8	12,7	13,6	12,8	13,4	14,4	14,5	13,5	12,7	11,8	12,0	11,0	9,9	9,4	10,6	11,9	9,3	10,0	10,2	9,9	11,6	14,2	11,6	13,1
	PV	15,84	15,80	16,53	15,85	16,38	17,15	17,12	16,12	15,40	14,55	14,54	13,65	12,74	12,47	13,26	14,31	12,21	12,88	13,66	12,38	14,84	17,09	14,81	[illegible]
	W	11,03	11,00	11,51	11,03	11,41	11,95	11,92	11,22	10,70	10,10	10,09	9,47	8,83	8,64	9,26	9,93	8,45	8,93	9,50	9,30	10,33	11,91	10,30	11,30
	H	50,24	49,44	50,41	48,70	49,10	50,06	51,64	53,44	55,22	56,10	57,89	57,73	57,02	57,17	58,63	59,95	55,55	55,69	55,07	51,90	52,79	55,50	50,44	52,14
	S	207,4	204,9	208,5	202,6	204,3	208,0	212,8	217,4	222,2	224,1	229,5	228,3	225,5	225,8	230,8	235,5	220,7	221,6	220,3	210,4	214,3	224,5	207,1	213,5
	V	0,950	0,940	0,939	0,937	0,936	0,936	0,941	0,951	0,960	0,967	0,972	0,976	0,278	0,979	0,980	0,979	0,975	0,973	0,967	0,958	0,954	0,953	0,947	0,940
	WS	1,31	2,35	2,27	1,92	2,06	1,97	2,59	3,11	3,55	3,92	4,06	3,12	2,95	2,82	2,96	2,87	2,75	2,80	2,06	4,32	2,83	3,69	2,28	2,55
	G						0,021	0,157	0,393	0,591	0,802	0,948	0,999	0,960	0,918	0,772	0,554	0,354	0,137	0,020					
	G (N)						0	0,043	0,095	0,159	0,210	0,260	0,273	0,278	0,236	0,195	0,149	0,105	0,043	0					
	G (E)						0	0,475	0,689	0,707	0,654	0,500	0,293	0,188	0,193	0,167	0,140	0,096	0,043	0					
	G (S)						0	0,164	0,200	0,184	0,191	0,193	0,193	0,195	0,219	0,209	0,205	0,181	0,136	0					
	G (W)						0	0,044	0,093	0,124	0,149	0,173	0,183	0,292	0,484	0,605	0,601	0,588	0,430	0					

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5%	DB	22,9	22,4	22,0	21,5	20,9	20,4	22,2	25,6	28,8	31,1	33,0	34,3	35,2	35,9	35,9	35,7	35,0	33,5	31,9	28,9	27,1	25,8	24,9	24,0
	RH	59,4	59,5	65,8	70,7	67,3	57,9	70,1	60,3	55,3	44,1	36,5	35,3	32,5	29,3	34,2	29,4	26,0	30,8	31,5	36,6	43,8	45,1	53,8	60,7
	WB	17,2	16,7	17,8	17,4	16,5	14,7	18,0	19,6	21,7	21,4	21,2	21,9	21,9	21,4	22,5	21,2	20,3	21,5	18,9	17,9	18,0	17,1	17,9	18,3
	DP	12,8	12,4	15,2	14,8	13,5	9,8	15,1	16,1	18,6	16,8	15,5	16,2	15,6	14,4	16,3	13,4	12,3	14,7	11,2	10,9	12,0	11,0	13,3	14,6
	PV	16,73	16,10	18,27	17,96	16,60	13,98	18,71	19,78	22,04	20,04	18,51	19,20	18,67	17,29	20,16	17,33	15,78	19,53	14,90	14,48	15,75	14,97	16,97	18,19
	W	11,08	11,22	12,75	12,53	11,57	9,73	13,08	13,84	15,44	14,01	12,92	13,42	13,04	12,06	14,16	12,13	1,02	13,74	10,39	10,08	10,98	10,43	11,85	12,71
	H	52,54	51,08	54,59	53,34	50,37	45,31	55,54	61,00	68,53	67,24	66,40	69,00	69,11	67,05	72,50	67,17	62,49	69,39	58,68	54,77	55,37	52,52	55,27	56,56
	S	216,1	210,2	222,9	218,8	208,4	190,5	226,2	243,6	268,1	262,3	258,3	266,6	266,4	259,1	277,7	259,5	287,1	268,2	232,2	220,1	223,0	213,6	223,7	228,8
	V	0,950	0,944	0,945	0,942	0,940	0,936	0,945	0,957	0,970	0,975	0,981	0,985	0,987	0,988	0,991	0,988	0,984	0,984	0,972	0,963	0,958	0,953	0,952	0,951
	WS	2,01	1,79	1,79	1,79	2,36	1,94	1,88	3,05	3,31	3,13	3,20	2,78	2,91	2,59	2,76	2,50	2,76	2,95	3,05	4,56	3,28	3,87	2,46	3,43
	G						0,017	0,125	0,376	0,623	0,788	0,904	1,006	0,972	0,817	0,600	0,456	0,353	0,130	0,017					
	G (N)						0	0,043	0,091	0,139	0,188	0,195	0,254	0,258	0,241	0,171	0,134	0,107	0,042	0					
	G (E)						0	0,376	0,692	0,739	0,613	0,466	0,318	0,213	0,206	0,155	0,133	0,098	0,044	0					
	G (S)						0	0,111	0,158	0,193	0,217	0,212	0,232	0,222	0,224	0,181	0,199	0,193	0,142	0					
	G (W)						0	0,043	0,091	0,131	0,166	0,182	0,220	0,307	0,430	0,442	0,529	0,559	0,354	0					

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - MAUN (SUMMER)

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2,5%	DB	22,8	22,1	21,8	21,3	20,8	20,3	22,3	26,2	29,6	31,9	33,7	35,0	35,9	36,5	36,9	36,1	35,5	34,4	32,3	29,5	27,7	26,5	25,7	24,6
	RH	62,2	76,2	76,3	69,1	70,3	78,5	76,0	65,6	57,3	48,5	34,9	28,3	33,8	29,8	37,0	31,9	33,9	27,8	23,3	37,1	34,1	42,3	46,1	62,6
	WB	17,4	18,9	18,9	17,3	17,0	17,7	19,0	21,0	22,5	22,9	21,2	20,6	22,5	21,6	23,3	21,9	22,0	19,9	17,4	18,2	16,6	17,4	17,3	19,1
	DP	14,4	17,4	17,4	14,9	14,8	16,3	17,4	18,7	19,3	19,1	15,0	13,2	16,5	14,5	16,7	14,6	14,7	11,5	7,8	10,9	9,2	12,2	12,0	16,2
	PV	17,14	20,01	20,11	17,58	17,36	18,80	20,26	22,1	23,7	23,10	18,18	15,99	19,94	17,55	22,54	19,04	19,69	15,24	11,25	15,26	12,70	14,68	15,30	19,30
	W	11,95	13,97	14,04	12,25	20,10	13,11	14,15	15,47	16,67	16,22	12,69	11,13	13,96	12,25	15,95	13,39	13,86	10,65	7,79	10,67	8,81	10,19	10,66	13,49
	H	53,16	57,56	57,75	52,65	51,72	53,80	9,25	65,59	72,31	73,72	66,41	63,89	71,87	68,12	77,59	70,71	71,44	62,10	52,52	56,85	50,37	52,70	53,11	59,07
	S	217,5	233,6	234,2	216,3	213,3	221,0	235,9	259,6	280,9	284,2	258,1	248,7	275,6	262,5	294,8	271,5	274,3	242,8	210,8	227,1	205,2	213,9	215,7	237,[illegible]
	V	0,948	0,946	0,946	0,942	0,939	0,939	0,948	0,963	0,975	0,983	0,982	0,984	0,991	0,989	0,995	0,990	0,990	0,982	0,971	0,967	0,959	0,955	0,954	0,955
	WS	0,0	0,0	0,0	2,53	2,01	2,24	2,68	2,83	3,31	2,24	4,92	3,04	3,01	2,93	2,85	1,92	1,98	2,12	2,24	0,0	0,0	0,0	0,0	0,0
	G						0,016	0,123	0,328	0,496	0,753	0,941	0,948	0,987	0,811	0,524	0,449	0,288	0,134	0,017					
	G (N)						0	0,046	0,069	0,140	0,177	0,212	0,247	0,262	0,239	0,161	0,138	0,097	0,042	0					
	G (E)						0	0,285	0,595	0,532	0,582	0,493	0,284	0,234	0,205	0,159	0,136	0,097	0,043	0					
	G (S)						0	0,103	0,174	0,168	0,185	0,185	0,192	0,242	0,214	0,177	0,167	0,159	0,128	0					
	G (W)						0	0,046	0,071	0,137	0,160	0,165	0,185	0,326	0,442	0,353	0,470	0,402	0,374	0					

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0,05%	DB	20,8	23,0	22,7	22,3	19,1	18,9	23,2	27,5	31,3	33,6	35,5	37,4	37,9	38,5	38,9	38,7	38,5	37,9	35,3	29,9	29,2	31,0	29,0	28,6
	RH	73,0	53,0	53,0	57,0	75,0	73,0	57,0	44,0	36,0	32,0	29,0	23,0	18,0	17,0	17,0	17,0	17,0	16,0	17,0	21,0	22,0	25,0	25,0	28,0
	WB	17,4	16,5	16,2	16,5	16,1	15,7	17,3	18,6	19,9	20,6	21,2	20,8	19,5	19,5	19,8	19,7	19,5	18,8	17,6	15,3	15,1	17,1	15,7	16,1
	DP	15,8	12,9	12,6	13,4	14,6	14,0	14,2	14,2	14,5	14,6	14,8	12,8	9,5	9,1	9,5	9,3	9,1	7,8	6,6	5,2	5,3	8,7	7,0	8,3
	PV	17,93	14,89	14,62	15,34	16,58	15,93	16,21	16,16	16,46	16,65	16,77	14,76	11,87	11,58	11,83	11,71	11,58	10,55	9,72	8,81	8,92	11,24	10,02	10,56
	W	12,45	10,33	10,14	10,65	11,52	11,07	11,26	11,22	11,44	11,58	11,66	10,24	8,21	8,00	8,18	8,09	8,00	7,28	6,71	6,07	6,15	7,76	6,91	7,57
	H	52,62	49,42	48,63	49,52	48,45	47,09	51,99	56,31	60,76	63,48	65,[illegible]	63,96	59,26	59,35	60,21	59,78	59,35	56,88	52,74	45,51	45,09	51,06	46,84	48,12
	S	216,5	204,0	201,3	204,7	202,4	197,7	213,0	226,1	239,8	248,0	254,5	247,8	231,6	231,7	234,4	233,1	231,7	223,5	210,4	187,4	186,1	206,2	192,3	196,9
	V	0,934	0,945	0,945	0,949	0,935	0,932	0,946	0,966	0,977	0,975	0,979	0,999	0,996	1,001	1,006	1,001	0,990	0,987	0,976	0,962	0,957	0,972	0,972	0,970
	WS	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,24	1,34	0,0	1,79	2,24	1,34	1,79	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	G						0,023	0,198	0,442	0,674	0,860	1,000	1,069	1,116	1,035	0,802	0,663	0,430	0,221	0,023					
	G (N)						0	0,038	0,068	0,100	0,135	0,151	0,158	0,192	0,189	0,141	0,114	0,082	0,052	0					
	G (E)						0	0,640	0,820	0,816	0,667	0,497	0,278	0,192	0,189	0,141	0,114	0,082	0,057	0					
	G (S)						0	0,253	0,288	0,275	0,248	0,226	0,207	0,240	0,263	0,246	0,274	0,278	0,263	0					
	G (W)						0	0,040	0,072	0,101	0,135	0,151	0,156	0,311	0,523	0,616	0,754	0,737	0,645	0					

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - MAUN (SUMMER)

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10%	DB	8,8	7,7	6,5	5,6	4,8	4,6	4,5	8,0	15,0	19,6	22,3	24,0	25,0	25,8	26,3	26,2	25,6	23,3	18,0	14,6	13,1	12,4	11,5	10,5
	RH	48,4	55,5	56,4	62,0	66,7	68,2	69,2	57,6	43,3	34,8	30,2	25,0	23,7	19,6	21,6	21,9	21,9	22,3	25,1	30,9	35,0	39,3	44,8	39,5
	WB	4,1	3,8	3,0	2,6	2,4	2,1	2,3	4,2	8,5	11,0	12,0	12,4	12,8	12,4	13,1	13,1	12,8	11,4	8,3	6,6	5,1	6,0	4,0	4,5
	DP	-1,6	-0,8	-1,6	-1,2	-0,9	-1,0	-0,8	-0,3	2,4	3,5	3,7	2,6	2,8	0,6	2,0	2,3	1,8	0,3	-2,2	-2,4	-2,2	-1,4	-0,2	-2,8
	PV	5,46	5,80	5,49	5,63	5,78	5,74	5,87	6,11	7,31	7,99	8,08	7,51	7,54	6,48	7,36	7,43	7,24	6,41	5,21	5,12	5,29	5,66	6,10	4,96
	W	3,74	3,97	3,76	3,85	3,96	3,93	4,02	4,19	5,01	5,48	5,55	5,15	5,17	4,44	5,05	5,10	4,96	4,39	3,57	3,50	3,62	3,87	4,18	3,40
	I	18,27	17,68	16,08	15,32	14,90	14,42	14,76	18,45	27,66	33,75	36,47	37,40	38,43	37,23	39,28	39,31	38,51	34,74	27,26	23,53	22,40	22,24	22,24	19,02
	S	95,2	93,4	87,7	85,2	83,8	82,1	83,3	96,2	127,9	148,4	157,2	159,9	163,2	158,8	165,8	166,0	163,3	150,7	125,5	112,9	109,2	108,8	109,1	97,5
	V	0,886	0,883	0,880	0,876	0,874	0,873	0,874	0,884	0,908	0,923	0,931	0,937	0,940	0,941	0,943	0,943	0,942	0,934	0,916	0,904	0,900	0,898	0,896	0,891
	WS	1,43	1,79	1,79	1,70	1,45	2,11	1,79	2,11	2,63	2,54	2,44	2,78	2,12	2,38	2,01	2,46	2,46	1,79	2,09	1,94	1,61	0,00	1,34	1,49
	G						0,012	0,025	0,204	0,415	0,577	0,693	0,756	0,765	0,693	0,553	0,380	0,167	0,017						
	G (N)						0	0	0,360	0,524	0,641	0,741	0,762	0,745	0,712	0,616	0,493	0,336	0						
	G (E)						0	0	0,678	0,735	0,625	0,452	0,242	0,126	0,105	0,093	0,064	0,032	0						
	G (S)						0	0	0,041	0,070	0,090	0,100	0,125	0,126	0,107	0,093	0,063	0,031	0						
	G (W)						0	0	0,042	0,071	0,090	0,099	0,126	0,242	0,446	0,592	0,675	0,602	0						

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5%	DB	7,6	6,6	5,5	4,4	3,6	3,4	3,3	6,7	13,9	18,6	21,4	23,0	24,0	24,9	25,4	25,4	24,8	22,6	17,0	13,6	12,2	11,7	10,8	9,7
	RH	43,7	51,5	59,1	64,7	68,2	69,3	69,0	64,7	40,5	32,8	27,7	24,8	25,7	26,3	23,9	21,6	23,3	27,3	28,0	32,5	33,1	34,1	43,9	40,7
	WB	2,8	2,5	2,2	1,7	1,4	1,0	0,8	3,9	7,4	9,8	11,1	11,7	12,5	13,2	13,1	12,6	12,4	11,7	8,0	6,2	5,4	5,0	5,4	4,3
	DP	-3,6	-2,7	-2,0	-1,7	-1,6	-1,9	-2,1	0,5	0,7	1,8	1,8	1,5	3,0	4,1	3,1	1,5	2,1	2,6	-1,5	-2,5	-3,2	-3,4	-1,0	-2,7
	PV	4,60	4,97	5,28	5,40	5,42	5,31	5,25	6,38	6,45	7,01	7,08	7,00	7,72	8,27	7,82	7,04	7,23	7,44	5,41	5,06	4,78	4,70	5,74	4,98
	W	3,15	3,40	3,61	3,69	3,71	3,66	3,60	4,37	4,42	4,80	4,85	4,80	5,30	5,68	5,36	4,83	4,96	5,10	3,70	3,47	3,27	3,21	3,93	3,41
	I	15,72	15,08	14,47	13,65	13,03	12,49	12,13	17,83	25,21	30,91	33,91	35,48	37,75	39,52	39,38	37,88	37,42	35,63	26,45	22,47	20,80	19,95	20,97	18,64
	S	86,0	81,0	82,0	79,2	77,1	75,2	73,9	94,2	119,3	138,5	148,3	153,4	161,1	167,1	166,4	161,2	159,8	154,1	122,8	109,3	103,5	100,6	104,5	96,2
	V	0,882	0,879	0,875	0,872	0,870	0,869	0,868	0,881	0,904	0,919	0,928	0,933	0,937	0,940	0,942	0,940	0,938	0,932	0,912	0,901	0,897	0,895	0,894	0,890
	WS	2,24	0,00	0,00	0,00	1,3	1,31	2,01	1,79	2,35	2,91	3,04	2,77	2,33	1,92	1,92	1,68	1,68	0,00	0,00	0,00	0,00	1,45	1,34	1,34
	G						0,012	0,024	0,196	0,420	0,596	0,711	0,783	0,754	0,668	0,549	0,373	0,158	0,015						
	G (N)						0	0	0,395	0,565	0,687	0,772	0,802	0,768	0,708	0,649	0,527	0,324	0						
	G (E)						0	0	0,712	0,766	0,655	0,463	0,237	0,117	0,105	0,082	0,061	0,031	0						
	G (S)						0	0	0,035	0,065	0,085	0,099	0,108	0,116	0,107	0,082	0,060	0,030	0						
	G (W)						0	0	0,036	0,066	0,085	0,098	0,109	0,236	0,434	0,606	0,688	0,569	0						

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - MAUN (WINTER)

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2.5%	DB	1.2	5.4	4.0	2.8	2.0	2.7	2.7	6.4	12.9	17.8	20.6	22.4	23.5	24.4	25.0	25.0	24.4	22.4	16.5	12.6	10.8	10.7	9.9	9.2
	RH	48.3	0	58.5	51.8	52.7	52.0	51.8	71.0	0.0	41.0	0.0	0	0	0	26.0	19.5	25.0	26.3	28.0	35.6	44.3	50.5	0	0
	WB	2.2	0	0.8	-0.5	-1.4	-0.9	-0.8	4.0	0.0	10.7	0.0	0	0	0	13.2	11.9	12.6	11.5	7.6	5.7	5.3	5.8	0	0
	DP	-3.3	0	-3.4	-5.5	-6.1	-6.2	-5.8	1.4	0.0	4.5	0	0	0	0	4.1	-0.2	2.9	2.0	-2.5	-3.0	-1.1	0.6	0	0
	PV	4.71	0	4.68	3.94	3.71	3.81	3.85	6.78	0.0	8.48	0	0	0	0	8.26	6.18	7.60	7.13	5.23	5.19	5.71	6.41	0	0
	W	3.22	0	3.20	2.70	2.53	2.60	2.63	4.65	0.0	5.82	0	0	0	0	5.63	4.24	5.22	4.89	3.58	3.56	3.94	4.42	0	0
	H	11.46	0	11.86	9.84	8.35	9.16	9.41	18.03	0.0	32.93	0	0	0	0	39.39	35.96	37.76	35.00	25.58	21.63	20.80	21.76	0	0
	S	81.7	0	72.6	65.1	59.8	62.7	63.6	95.1	0.0	146.0	0	0	0	0	166.7	154.5	161.1	152.0	119.8	106.6	104.0	107.6	0	0
	V	0.875	0	0.870	0.867	0.864	0.865	0.866	0.880	0.0	0.919	0	0	0	0	0.940	0.938	0.938	0.931	0.910	0.898	0.893	0.893	0	0
	WS	0.00	0	0.00	0.00	0.00	1.79	2.46	0.00	0.0	0.00	0	0	0	0	2.24	2.01	1.56	0.00	0.00	0.00	0.00	0.00	0	0
	G						0	0.027	0.221	0.0	0.581	0	0	0	0	0.448	0.386	0.166	0.017						
	G (N)						0	0	0.417	0.0	0.716	0	0	0	0	0.504	0.520	0.320	0						
	G (E)						0	0	0.786	0.0	0.650	0	0	0	0	0.095	0.061	0.032	0						
	G (S)						0	0	0.038	0.0	0.083	0	0	0	0	0.095	0.060	0.031	0						
	G (W)						0	0	0.040	0.0	0.083	0	0	0	0	0.464	0.703	0.585	0						

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0.05%	DB	-0.7	0.5	-0.1	-1.4	2.8	3.6	2.9	4.5	9.8	14.1	16.4	18.0	19.7	20.7	21.4	20.9	20.3	17.6	11.2	6.9	6.0	9.1	4.2	6.0
	RH	57.0	59.0	63.0	63.0	53.0	50.0	53.0	49.0	36.0	29.0	21.0	17.0	16.0	14.0	13.0	12.0	12.0	14.0	19.0	27.0	34.0	29.0	35.0	40.0
	WB	-3.5	-2.2	-2.4	-3.6	-0.7	-0.3	-0.6	0.6	3.7	6.1	6.6	7.0	7.9	8.1	8.4	7.9	7.5	6.2	2.8	0.6	0.6	2.4	-1.0	1.1
	DP	-7.3	-5.8	-5.6	-6.8	-5.2	-5.2	-5.1	-4.7	-4.0	-3.2	-5.3	-6.6	-6.0	-6.9	-7.2	-8.5	-8.9	-9.1	-10.3	-9.6	-7.7	-7.1	-8.8	-5.8
	PV	3.28	3.74	3.82	3.43	3.96	3.95	3.98	4.12	4.36	4.66	3.91	3.51	3.67	3.42	3.31	2.96	2.86	2.82	2.52	2.68	3.18	3.35	2.88	3.74
	W	2.24	2.55	2.61	2.34	2.70	2.70	2.72	2.82	2.98	3.19	2.67	2.39	2.51	2.33	2.26	2.02	1.95	1.92	1.72	1.83	2.17	2.29	1.97	2.55
	H	4.93	6.91	6.44	4.46	9.61	10.41	9.76	11.62	17.38	22.26	23.29	24.20	26.20	26.77	27.29	26.18	25.39	22.60	15.63	11.57	11.51	14.93	9.19	12.47
	S	47.1	54.7	53.0	45.8	64.4	67.2	64.9	71.5	91.6	108.4	111.5	114.4	121.2	123.0	124.7	120.8	118.2	108.7	84.8	70.7	70.7	82.7	62.4	74.3
	V	0.854	0.859	0.857	0.852	0.866	0.869	0.866	0.872	0.888	0.902	0.909	0.914	0.919	0.922	0.924	0.922	0.920	0.912	0.891	0.878	0.875	0.885	0.870	0.876
	WS	0.00	0.00	0.00	0.00	0.00	1.34	0.00	2.24	3.13	4.02	4.47	4.02	3.13	1.79	2.24	1.34	1.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G						0	0.012	0.139	0.384	0.535	0.686	0.732	0.744	0.686	0.535	0.314	0.163	0.012						
	G (N)						0	0.007	0.039	0.071	0.100	0.116	0.127	0.128	0.122	0.100	0.075	0.041	0.007						
	G (E)						0	0.007	0.208	0.431	0.409	0.344	0.205	0.128	0.122	0.100	0.075	0.041	0.007						
	G (S)						0	0.007	0.088	0.159	0.165	0.167	0.158	0.160	0.172	0.165	0.138	0.103	0.007						
	G (W)						0	0.007	0.039	0.071	0.100	0.116	0.127	0.207	0.346	0.409	0.332	0.253	0.007						

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - MAUN (WINTER)

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10	DB	24,3	23,4	22,5	21,7	20,8	20,1	21,9	25,0	28,1	30,7	33,0	34,6	35,9	36,7	37,1	37,0	36,6	35,9	34,7	32,3	30,5	28,9	27,5	26,4
	RH	26,3	31,9	33,8	33,5	38,2	40,5	33,7	36,7	31,3	26,4	23,0	20,3	17,5	15,5	13,3	14,3	13,0	13,2	14,2	15,3	17,0	20,3	22,2	26,1
	WB	12,9	13,2	12,9	12,2	12,3	12,2	12,4	15,2	16,4	17,1	17,8	18,2	18,1	18,0	17,5	17,7	17,1	16,8	16,4	15,4	14,7	14,5	14,1	14,2
	DP	3,3	5,2	4,8	4,3	5,4	5,6	4,4	8,4	8,8	8,4	8,4	7,9	6,8	5,7	3,8	4,3	3,0	2,9	3,0	2,1	2,2	3,0	3,3	4,5
	PV	8,10	9,19	9,26	8,70	9,38	9,54	8,84	11,62	11,93	11,64	11,60	11,20	10,37	9,66	8,46	8,98	7,96	7,87	7,90	7,42	7,43	8,09	8,18	9,00
	W	5,53	6,28	6,34	5,94	6,42	6,53	6,04	7,97	8,19	7,98	7,96	7,68	7,10	6,61	5,79	6,15	5,44	5,38	5,40	5,07	5,07	5,53	5,59	6,16
	H	38,73	39,37	38,88	36,95	37,24	36,85	37,36	45,42	49,21	51,34	53,59	54,57	54,41	54,04	52,26	53,05	50,84	50,03	48,88	45,55	43,66	13,24	41,99	42,32
	S	162,9	166,4	164,1	157,6	158,9	157,8	159,0	186,4	198,4	204,8	211,7	214,4	213,4	211,8	205,6	208,3	200,9	198,4	194,8	184,2	178,2	177,3	173,4	174,9
	V	0,934	0,931	0,929	0,925	0,923	0,921	0,926	0,939	0,949	0,957	0,964	0,969	0,972	0,974	0,974	0,974	0,972	0,969	0,966	0,958	0,952	0,947	0,943	0,941
	WS	3,58	2,11	1,79	2,15	2,15	2,24	2,62	3,20	3,99	4,10	4,47	4,44	4,79	3,90	4,02	4,67	4,73	4,51	4,50	4,38	4,14	4,55	4,11	3,36
	G						0,032	0,223	0,460	0,681	0,864	0,996	1,072	1,076	1,005	0,869	0,680	0,452	0,217	0,031					
	G (N)						0	0,051	0,077	0,117	0,203	0,295	0,324	0,308	0,267	0,190	0,120	0,077	0,050	0					
	G (E)						0	0,611	0,830	0,833	0,720	0,527	0,285	0,150	0,139	0,125	0,101	0,077	0,051	0					
	G (S)						0	0,210	0,204	0,148	0,128	0,140	0,148	0,150	0,142	0,129	0,148	0,190	0,201	0					
	G (W)						0	0,052	0,078	0,104	0,124	0,138	0,150	0,285	0,526	0,719	0,833	0,828	0,603	0					

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5	DB	24,5	23,5	22,5	21,7	20,7	20,0	22,0	25,4	28,8	31,5	33,8	35,3	36,6	37,4	37,7	37,5	37,2	36,6	35,3	32,9	31,0	29,5	28,1	27,1
	RH	31,7	38,5	42,7	35,2	34,0	38,5	37,2	36,4	31,3	29,4	21,4	19,2	18,3	15,5	15,1	15,7	15,8	17,0	11,4	15,1	19,0	25,7	28,0	29,7
	WB	13,9	14,4	12,7	12,4	11,6	11,8	13,0	15,4	17,0	18,4	18,0	18,3	18,8	18,3	18,5	18,4	18,2	18,1	16,8	15,6	15,5	16,0	15,6	15,2
	DP	5,8	7,5	4,9	4,5	4,0	4,8	6,0	8,8	9,7	10,7	8,1	7,8	8,0	6,3	6,2	6,0	5,7	5,6	3,5	2,3	3,5	6,1	5,7	6,3
	PV	9,79	11,21	8,96	9,12	8,34	9,00	9,82	11,76	12,47	13,63	11,32	11,04	11,25	9,91	9,90	10,12	10,00	10,35	8,26	7,55	8,59	10,58	10,75	10,92
	W	6,70	7,69	6,13	6,25	5,70	6,16	6,72	8,07	8,56	9,38	7,77	7,57	7,72	6,78	6,78	6,94	6,87	7,12	5,64	5,15	5,88	7,27	7,41	7,29
	H	41,75	43,27	38,30	37,70	35,36	35,78	39,23	46,06	50,96	55,69	54,08	55,01	56,67	54,99	55,46	55,63	55,04	55,06	50,03	46,38	46,34	48,23	47,38	45,78
	S	173,6	179,4	162,0	160,2	152,2	154,0	165,6	188,5	204,2	219,6	213,0	215,6	220,8	214,8	216,2	216,9	215,1	215,4	198,6	186,8	187,3	194,5	192,0	186,8
	V	0,935	0,934	0,928	0,926	0,922	0,920	0,927	0,940	0,952	0,961	0,967	0,971	0,975	0,976	0,977	0,977	0,975	0,974	0,968	0,959	0,955	0,952	0,948	0,944
	WS	4,47	4,74	4,16	4,84	3,13	3,82	2,58	4,84	5,63	3,68	3,79	4,47	4,30	4,23	4,17	4,79	4,89	5,31	4,96	5,29	3,55	3,51	3,81	3,46
	G						0,034	0,215	0,450	0,689	0,870	1,005	1,079	1,081	1,007	0,868	0,676	0,453	0,215	0,035					
	G (N)						0	0,048	0,079	0,112	0,198	0,242	0,292	0,310	0,260	0,197	0,115	0,080	0,048	0					
	G (E)						0	0,596	0,798	0,811	0,711	0,515	0,284	0,153	0,143	0,128	0,107	0,080	0,050	0					
	G (S)						0	0,202	0,195	0,162	0,131	0,146	0,153	0,152	0,145	0,131	0,148	0,200	0,199	0					
	G (W)						0	0,059	0,080	0,109	0,129	0,143	0,153	0,286	0,520	0,711	0,807	0,805	0,605	0					

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - UPINGTON (SUMMER)

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Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2,5%	DB	25,0	24,1	23,0	22,0	21,0	20,3	22,6	26,3	29,8	32,6	35,1	36,5	37,8	38,3	38,6	38,5	38,2	37,8	36,6	33,9	32,1	30,5	29,2	28,1
	RH	26,9	28,7	36,9	31,7	40,8	46,0	47,8	44,9	32,0	35,4	26,2	22,2	18,8	17,6	14,6	14,0	16,7	14,2	16,6	13,1	13,1	22,5	31,5	30,5
	WB	13,3	13,1	13,8	12,1	12,8	13,2	15,2	17,8	17,8	20,7	20,0	19,8	19,7	19,6	18,8	18,5	19,0	18,1	18,1	15,5	14,6	15,9	17,0	16,1
	DP	3,9	3,9	7,0	3,8	6,7	7,9	10,6	12,9	10,7	15,0	12,1	10,9	9,2	9,0	6,5	5,5	6,5	4,7	6,0	0,8	0,1	5,2	8,5	7,4
	PV	8,49	8,68	10,34	8,34	10,06	11,00	13,06	15,39	13,47	17,47	14,74	13,51	12,32	11,88	10,05	9,51	11,19	9,26	10,16	6,86	6,27	9,82	12,79	11,62
	W	5,80	5,94	7,08	5,70	6,88	7,54	8,97	10,60	9,26	12,06	10,15	9,29	8,46	8,15	6,88	6,51	7,71	6,34	6,96	4,69	4,27	6,74	8,82	8,00
	H	39,86	39,42	41,12	36,58	38,50	39,69	45,48	53,54	53,70	63,78	61,27	60,48	59,83	59,55	56,62	55,44	58,24	54,28	54,62	45,96	43,28	47,84	51,84	48,71
	S	166,8	165,5	172,0	156,2	163,4	167,9	187,6	214,4	213,4	247,0	237,2	233,9	231,1	229,9	219,9	216,0	225,6	212,3	213,8	185,1	176,4	192,8	207,2	196,7
	V	0,935	0,933	0,931	0,926	0,924	0,924	0,932	0,947	0,956	0,969	0,974	0,977	0,980	0,981	0,980	0,979	0,980	0,976	0,973	0,961	0,956	0,954	0,953	0,949
	WS	1,17	4,58	4,47	2,98	3,58	2,91	3,35	5,30	4,15	4,73	3,95	3,61	4,25	3,63	3,82	4,49	5,26	5,31	5,23	4,37	2,51	3,32	5,19	4,19
	G						0,035	0,220	0,451	0,683	0,870	1,006	1,079	1,078	1,008	0,877	0,682	0,445	0,203	0,031					
	G (N)						0	0,050	0,081	0,114	0,151	0,242	0,261	0,280	0,254	0,183	0,117	0,081	0,048	0					
	G (E)						0	0,598	0,780	0,802	0,688	0,513	0,282	0,155	0,144	0,129	0,108	0,081	0,049	0					
	G (S)						0	0,209	0,203	0,167	0,134	0,147	0,156	0,155	0,146	0,132	0,161	0,194	0,187	0					
	G (W)						0	0,051	0,081	0,108	0,131	0,145	0,155	0,283	0,519	0,713	0,805	0,776	0,553	0					

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0,15%	DB	27,5	27,0	26,2	25,5	25,0	21,7	25,3	28,3	30,2	32,3	35,6	37,6	38,7	40,2	40,6	40,4	40,4	39,7	39,7	37,8	35,7	35,7	34,9	33,5
	RH	19,0	18,0	19,0	19,0	20,0	24,0	22,0	22,0	16,0	15,0	12,0	10,0	7,0	5,0	5,0	5,0	5,0	5,0	5,0	6,0	5,0	11,0	9,0	8,0
	WB	13,4	12,8	12,6	12,1	12,0	10,6	12,6	14,6	14,3	15,3	16,2	16,6	16,1	15,9	16,1	16,0	16,0	15,7	15,7	15,2	15,0	16,0	14,9	13,8
	DP	1,8	0,7	0,8	0,2	0,5	0,3	2,1	4,6	1,6	2,4	1,8	0,8	-2,8	-5,9	-5,6	-5,7	-5,7	-6,2	-6,2	-5,2	-3,2	0,7	-2,3	-4,6
	PV	6,98	6,42	6,46	6,20	6,34	6,23	7,09	8,46	6,87	7,26	6,98	6,49	4,82	3,73	3,81	3,77	3,77	3,63	3,63	3,93	4,68	6,43	5,04	4,14
	W	4,76	4,37	4,40	4,22	4,32	4,24	4,84	5,78	4,68	4,95	4,76	4,42	3,28	2,53	2,59	2,56	2,56	2,47	2,47	2,67	3,18	4,38	3,42	2,81
	H	39,82	38,33	37,60	36,43	36,16	32,63	37,79	43,24	42,37	45,18	48,05	49,22	47,39	47,00	47,54	47,27	47,27	46,32	46,32	44,93	44,11	47,19	43,92	40,93
	S	165,8	160,7	158,4	154,5	153,7	142,1	159,3	177,5	173,8	182,9	191,7	195,1	188,6	186,8	188,6	187,7	187,7	184,7	184,7	180,4	178,2	188,7	177,8	167,9
	V	0,942	0,940	0,937	0,935	0,933	0,923	0,935	0,946	0,950	0,957	0,967	0,973	0,975	0,978	0,980	0,979	0,979	0,977	0,977	0,971	0,965	0,967	0,963	0,958
	WS	0,00	0,00	1,79	1,34	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,34	1,34	1,34	1,79	1,79	1,34	1,79	1,34	0,00	0,00	2,24	2,68	1,79
	G						0,033	0,235	0,473	0,699	0,887	1,022	1,092	1,092	1,022	0,887	0,699	0,473	0,235	0,033					
	G (N)						0	0,055	0,078	0,108	0,136	0,211	0,252	0,252	0,211	0,136	0,108	0,078	0,055	0					
	G (E)						0	0,603	0,827	0,827	0,713	0,522	0,285	0,152	0,140	0,127	0,106	0,080	0,055	0					
	G (S)						0	0,228	0,235	0,186	0,133	0,146	0,153	0,153	0,146	0,133	0,186	0,235	0,228	0					
	G (W)						0	0,055	0,080	0,106	0,127	0,140	0,152	0,285	0,522	0,713	0,827	0,827	0,603	0					

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - UPINGTON (SUMMER)

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10%	DB	2,8	2,0	1,3	0,7	0,0	-0,4	0,9	0,2	6,2	9,9	13,3	15,6	17,2	18,3	19,0	19,2	18,9	16,9	12,9	9,8	8,2	6,8	5,8	4,8
	RH	61,1	67,1	66,9	72,8	70,0	74,9	76,6	72,7	60,5	45,7	39,8	31,0	29,8	25,7	21,6	19,4	19,5	19,9	30,8	35,0	40,8	45,8	44,2	54,6
	WB	-0,05	-0,3	-0,8	-0,9	-1,9	-1,9	-2,2	-1,4	3,0	4,7	6,8	7,4	8,4	8,6	8,4	8,2	8,0	6,9	5,4	3,7	2,9	2,3	1,4	1,3
	DP	-4,1	-5,3	-4,2	-3,6	-4,6	-4,1	-4,9	-3,9	-1,0	-1,3	-0,8	-1,8	-0,6	-1,7	-3,3	-4,6	-4,7	-6,2	-4,1	-4,7	-4,5	-4,2	-5,2	-3,8
	PV	4,52	4,74	4,53	4,73	4,27	4,42	4,38	4,53	5,70	5,54	6,02	5,48	5,83	5,37	4,72	4,32	4,28	3,87	4,57	4,27	4,42	4,52	4,11	4,70
	W	3,07	3,20	3,06	3,19	2,85	2,99	2,96	3,06	3,86	3,74	4,07	3,70	3,94	3,63	3,19	2,91	2,89	2,61	3,05	2,85	2,99	3,05	2,78	3,17
	H	10,52	10,05	9,11	8,85	7,24	7,09	6,58	7,94	15,88	19,31	23,56	26,02	27,26	27,56	27,19	26,70	25,36	22,80	20,72	17,26	15,76	14,57	13,00	12,82
	S	64,1	62,6	59,1	58,3	52,3	51,9	50,1	55,0	83,4	95,1	109,7	114,3	122,0	122,8	121,2	119,4	118,3	109,5	99,8	87,4	82,3	78,2	72,6	72,2
	V	0,855	0,853	0,851	0,850	0,846	0,845	0,844	0,848	0,867	0,878	0,889	0,896	0,901	0,904	0,906	0,906	0,905	0,899	0,887	0,877	0,872	0,868	0,865	0,862
	WS	1,68	1,89	1,97	1,61	1,92	2,09	1,88	2,24	1,85	2,73	3,30	3,50	2,79	2,11	2,68	2,76	3,51	2,86	3,03	2,87	3,13	2,83	2,61	1,66
	G								0,096	0,280	0,462	0,580	0,664	0,644	0,560	0,433	0,267	0,090							
	G (N)								0,206	0,465	0,634	0,745	0,792	0,801	0,750	0,640	0,468	0,208							
	G (E)								0,374	0,589	0,568	0,417	0,217	0,095	0,053	0,069	0,019	0,024							
	G (S)								0,024	0,050	0,073	0,087	0,097	0,095	0,085	0,070	0,049	0,023							
	G (W)								0,023	0,051	0,073	0,085	0,095	0,213	0,409	0,547	0,575	0,364							

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5%	DB	,4	0,6	-0,4	-1,0	-1,4	-2,2	-2,7	-1,5	5,1	8,9	12,2	14,7	16,4	17,4	18,1	18,3	18,0	15,9	11,8	8,7	7,0	5,6	4,6	3,6
	RH	59,2	63,1	66,3	60,7	67,2	72,1	72,1	82,5	56,0	43,3	35,4	30,5	23,9	23,1	18,9	17,9	17,0	20,0	31,3	-	39,1	49,5	44,7	46,7
	WB	-1,2	-2,3	-2,1	-1,1	-3,4	-3,6	-4,2	-2,6	1,5	3,6	5,8	6,9	7,0	7,6	7,4	7,5	7,1	6,1	4,7	-	1,5	0,8	0,2	-0,4
	DP	-6,4	-7,6	-5,4	-10,4	-7,0	-6,6	-6,9	-3,9	-3,1	-3,0	-2,2	-2,2	-4,4	-4,0	-6,0	-6,6	-7,2	-1,3	-4,3	-	-6,0	-6,9	-6,8	-6,0
	PV	4,06	3,64	4,04	2,80	3,61	3,71	3,54	4,47	4,86	4,85	5,14	5,22	4,44	4,61	3,94	3,81	3,61	4,60	4,32	-	3,92	3,72	3,79	3,72
	W	2,74	2,38	2,72	1,89	2,44	2,50	2,38	3,02	3,28	3,28	3,47	3,52	2,99	3,12	2,66	2,57	2,35	3,43	2,92	-	2,64	2,61	2,55	2,51
	H	5,92	6,67	6,78	3,67	4,34	4,18	3,30	6,08	13,22	16,95	21,40	23,90	24,95	25,43	25,02	25,18	24,30	22,11	19,26	-	13,70	11,53	11,07	10,07
	S	54,5	50,0	50,6	35,5	42,4	41,1	37,9	48,3	73,7	86,6	102,0	110,5	110,6	115,3	113,6	114,1	111,0	103,7	94,3	-	75,0	68,5	65,7	62,1
	V	0,851	0,848	0,846	0,842	0,841	0,840	0,838	0,842	0,862	0,874	0,886	0,894	0,898	0,901	0,903	0,904	0,902	0,895	0,883	-	0,868	0,863	0,860	0,858
	WS	2,12	1,94	2,34	1,56	2,01	1,24	1,56	0,00	0,00	1,79	2,91	3,73	3,95	3,67	3,58	4,02	4,35	0,00	2,77	-	2,86	2,24	0,00	0,00
	G								0,092	0,297	0,493	0,582	0,650	0,656	0,589	0,483	0,304	0,112							
	G (N)								0,210	0,468	0,624	0,746	0,800	0,795	0,743	0,625	0,463	0,216							
	G (E)								0,371	0,611	0,585	0,418	0,214	0,097	0,080	0,075	0,054	0,028							
	G (S)								0,023	0,052	0,077	0,088	0,096	0,096	0,085	0,076	0,053	0,020							
	G (W)								0,023	0,053	0,076	0,086	0,096	0,215	0,421	0,581	0,617	0,418							

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - UPINGTON (WINTER)

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2,57	DB	-0,4	-1,2	-2,1	-2,7	-3,2	-3,7	-4,1	-2,8	4,2	7,7	11,3	13,6	15,1	16,2	17,2	17,5	17,2	15,2	10,7	7,8	5,8	4,2	3,2	2,8
	RH	61,5	51,0	64,6	39,5	62,3	66,0	70,3	73,0	55,5	-	35,5	31,3	25,0	-	-	-	17,0	20,5	24,0	26,7	-	23,3	28,0	36,5
	WB	-2,4	-4,1	-4,1	-6,2	-5,2	-5,3	-5,6	-4,0	1,1	-	5,0	6,0	6,1	-	-	-	6,4	5,8	3,1	1,1	-	-1,9	-2,3	-2,0
	DP	-6,3	-9,5	-7,7	-13,7	-8,8	-8,5	-8,8	-6,4	-3,4	-	-2,9	-2,8	-4,5	-	-	-	-7,4	-6,4	-8,6	-10,0	-	-13,8	-13,1	-11,0
	PV	3,76	2,82	3,32	1,89	2,90	3,01	3,03	3,61	4,63	-	4,81	4,86	4,21	-	-	-	3,28	3,57	3,09	2,81	-	1,94	2,16	2,72
	W	2,54	1,90	2,24	1,27	1,95	2,03	2,04	2,44	3,13	-	3,25	3,28	2,84	-	-	-	2,21	2,40	2,08	1,90	-	1,30	1,46	1,83
	H	6,35	3,54	3,52	0,28	1,60	1,51	0,95	3,54	12,27	-	19,78	21,93	22,08	-	-	-	22,66	21,54	16,13	12,64	-	7,62	6,92	7,32
	S	18,9	38,4	38,6	26,2	31,5	31,2	29,2	38,8	70,2	-	96,3	103,6	103,8	-	-	-	105,4	101,7	83,0	70,7	-	52,7	50,3	52,0
	V	0,846	0,841	0,839	0,835	0,833	0,834	0,832	0,838	0,860	-	0,883	0,889	0,892	-	-	-	0,895	0,894	0,879	0,869	-	0,858	0,855	0,85[illegible]
	WS	2,32	0,00	0,00	0,00	0,00	0,00	1,79	0,00	2,46	-	3,13	1,79	2,01	-	-	-	0,00	0,00	0,00	2,24	-	0,00	0,00	0,00
	G								0,111	0,293	-	0,644	0,640	0,642	-	-	-	0,079							
	G (N)								0,227	0,465	-	0,723	0,801	0,802	-	-	-	0,199							
	G (E)								0,427	0,605	-	0,444	0,212	0,093	-	-	-	0,023							
	G (S)							-	0,026	0,052	-	0,095	0,095	0,093	-	-	-	0,021							
	G (W)								0,028	0,053	-	0,093	0,095	0,212	-	-	-	0,332							

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0,057	DB	-3,1	-3,7	-5,8	-6,7	-6,8	-7,7	-7,8	-7,2	0,8	4,7	8,3	10,6	12,5	13,6	14,6	15,2	14,5	12,5	7,6	4,7	5,0	0,9	1,1	0,1
	RH	64,0	67,0	63,0	68,0	70,0	74,0	77,0	77,0	60,0	47,0	41,0	31,0	24,0	21,0	19,0	15,0	14,0	15,0	21,0	25,0	26,0	35,0	39,0	41,0
	WB	-5,5	-5,4	-7,5	-8,1	-8,1	-8,7	-8,7	-8,2	-1,8	0,7	3,1	3,8	4,4	4,7	5,1	5,0	4,4	3,2	0,6	-1,5	-1,2	-3,5	-3,0	-3,7
	DP	-10,2	-8,4	-11,1	-11,1	-10,8	-11,1	-10,8	-10,2	-5,4	-5,0	-3,7	-5,2	-6,7	-7,4	-7,8	-10,0	-11,3	-12,0	-11,9	-12,2	-11,5	-11,4	-10,1	-10,3
	PV	2,55	3,00	2,36	2,36	2,41	2,35	2,43	2,56	3,88	4,01	4,48	3,96	3,48	3,27	3,16	2,59	2,31	2,17	2,19	2,13	2,27	2,28	2,58	2,52
	W	1,72	2,02	1,59	1,59	1,62	1,58	1,63	1,72	2,62	2,71	3,03	2,67	2,34	2,20	2,13	1,74	1,56	1,46	1,47	1,44	1,52	1,54	1,74	1,69
	H	1,18	1,35	-1,85	-2,77	-2,78	-3,78	-3,76	-2,94	7,38	11,54	15,98	17,41	18,51	19,26	20,08	19,72	18,54	16,28	11,37	8,35	8,88	4,77	5,47	4,37
	S	29,8	30,6	18,6	15,2	15,2	11,5	11,6	14,7	52,6	67,4	83,1	87,8	91,3	93,8	96,6	95,1	91,0	83,2	66,0	55,4	57,3	42,6	45,3	41,3
	V	0,835	0,834	0,827	0,824	0,824	0,821	0,821	0,823	0,849	0,861	0,872	0,879	0,885	0,888	0,891	0,892	0,890	0,883	0,868	0,859	0,860	0,848	0,848	0,845
	WS	0,00	1,34	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,24	2,68	2,68	1,34	1,34	1,34	0,00	1,34	0,00	1,79	0,00	0,00	0,00
	G								0,069	0,248	0,412	0,533	0,597	0,597	0,533	0,412	0,248	0,069							
	G (N)								0,024	0,053	0,075	0,119	0,145	0,145	0,119	0,075	0,053	0,024							
	G (E)								0,086	0,264	0,314	0,267	0,162	0,097	0,089	0,074	0,053	0,024							
	G (S)								0,037	0,076	0,074	0,089	0,097	0,097	0,089	0,074	0,076	0,037							
	G (W)								0,024	0,053	0,074	0,089	0,097	0,162	0,267	0,314	0,264	0,086							

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - UPINGTON (WINTER)

43

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10%	DB	20,2	19,5	19,0	18,4	17,9	17,5	18,3	21,3	24,0	26,0	27,6	29,0	30,0	30,5	30,7	30,5	30,1	29,4	28,0	25,8	24,2	23,0	22,1	21,2
	RH	34,1	33,9	38,0	36,1	36,8	32,3	34,0	31,5	30,7	24,2	20,3	18,6	16,3	16,1	14,6	13,7	12,5	13,1	15,7	16,9	21,3	24,5	27,1	31,0
	WB	11,4	10,3	10,5	9,8	9,5	8,6	9,4	11,1	12,9	12,9	13,2	13,5	13,6	13,8	13,5	13,2	12,7	12,4	12,3	11,2	11,1	11,1	10,9	11,0
	DP	1,3	2,0	2,8	2,1	2,2	-0,04	1,2	2,4	4,7	3,2	2,1	2,0	1,0	0,9	-0,1	-1,1	-2,4	-1,3	-1,0	-1,7	-0,4	0,8	1,1	2,2
	PV	8,95	7,69	8,37	7,70	7,55	6,47	7,19	7,98	9,09	8,06	7,51	7,37	6,89	7,01	6,40	5,99	5,39	5,36	5,96	5,62	6,40	6,91	7,21	7,83
	W	7,80	5,84	6,37	5,85	5,72	4,90	5,45	6,06	6,90	6,13	5,70	5,59	5,22	5,31	4,84	4,53	4,07	4,06	4,51	4,25	4,84	5,23	5,47	5,85
	H	37,52	34,50	35,33	33,48	32,52	30,08	32,32	36,82	41,66	41,70	42,38	43,33	43,50	44,26	43,18	42,36	40,90	40,02	39,82	36,81	36,61	36,52	36,15	36,51
	S	189,9	179,3	183,5	176,0	172,7	164,0	171,9	187,0	203,3	202,7	204,5	207,4	207,6	210,1	206,3	203,4	198,4	195,6	195,3	185,5	185,3	185,3	184,3	186,0
	V	1,022	1,019	1,018	1,015	1,013	1,010	1,014	1,025	1,036	1,042	1,047	1,051	1,054	1,056	1,056	1,055	1,053	1,050	1,046	1,038	1,033	1,030	1,027	1,025
	WS	4,09	2,42	2,17	2,51	2,29	3,34	3,26	4,50	4,30	4,30	3,76	3,75	3,90	4,29	4,40	5,01	4,73	4,60	5,60	5,32	5,03	4,04	2,54	2,26
	G						0,037	0,246	0,500	0,753	0,933	1,051	1,125	1,060	0,980	0,818	0,632	0,433	0,217	0,039					
	G (N)						0	0,045	0,081	0,117	0,155	0,195	0,222	0,230	0,223	0,193	0,145	0,095	0,047	0					
	G (E)						0	0,815	0,925	0,908	0,750	0,541	0,315	0,200	0,198	0,183	0,143	0,097	0,050	0					
	G (S)						0	0,277	0,272	0,244	0,211	0,188	0,195	0,205	0,214	0,216	0,216	0,231	0,236	0					
	G (W)						0	0,048	0,084	0,117	0,150	0,168	0,189	0,312	0,513	0,632	0,706	0,739	0,670	0					

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1%	DB	20,7	20,0	19,5	19,0	18,4	18,0	18,8	21,8	24,6	26,5	28,1	29,4	30,4	30,9	31,1	31,0	30,5	29,9	28,6	26,2	24,6	23,5	22,4	21,6
	RH	34,8	37,8	37,8	43,5	43,4	43,3	39,4	30,9	25,0	23,2	20,2	17,0	15,0	16,3	16,3	14,4	15,3	15,2	17,6	21,9	23,4	21,5	26,1	23,2
	WB	11,1	11,1	10,9	11,3	10,7	10,4	10,6	11,5	12,2	13,1	13,4	13,5	13,5	14,0	14,2	13,6	13,5	13,2	12,9	12,5	11,8	10,7	11,0	9,9
	DP	4,3	3,9	4,5	5,1	4,3	3,8	3,6	2,9	2,6	2,9	2,2	1,0	-0,1	0,6	0,5	-1,0	-0,7	-0,4	-0,6	0,4	0,4	-1,0	0,9	-0,9
	PV	8,26	8,74	8,58	9,51	9,08	8,81	8,59	8,13	7,74	8,05	7,66	7,00	6,53	7,27	7,41	6,50	6,72	6,39	6,88	7,44	7,28	6,22	7,11	5,95
	W	6,27	6,61	6,52	7,26	6,91	6,70	6,53	6,17	5,87	6,11	5,81	5,31	4,95	5,53	5,64	4,93	5,12	4,85	5,21	5,66	5,53	4,71	5,40	4,52
	H	36,75	36,52	36,26	37,57	35,89	34,92	35,57	37,74	39,72	42,26	43,12	43,25	43,30	45,23	45,84	43,91	43,80	42,43	42,15	40,90	38,96	38,66	36,43	33,24
	S	187,0	187,0	186,6	190,0	181,8	181,4	183,4	190,1	196,2	201,4	206,9	206,9	206,8	213,3	215,3	208,7	208,4	203,9	203,3	199,7	193,4	189,1	185,2	174,1
	V	1,021	1,021	1,020	1,019	1,016	1,014	1,018	1,028	1,036	1,044	1,049	1,053	1,055	1,058	1,059	1,058	1,056	1,053	1,049	1,042	1,036	1,031	1,029	1,024
	WS	2,34	2,57	2,55	2,88	3,17	3,13	3,66	5,29	3,90	4,95	3,51	3,49	3,50	4,43	4,05	3,81	4,97	4,75	4,97	4,26	3,74	3,31	3,00	2,32
	G						0,032	0,228	0,501	0,758	0,915	1,062	1,104	1,097	0,944	0,814	0,585	0,448	0,201	0,042					
	G (N)						0	0,049	0,087	0,116	0,159	0,183	0,213	0,214	0,207	0,177	0,134	0,095	0,049	0					
	G (E)						0	0,684	0,901	0,914	0,727	0,544	0,311	0,196	0,189	0,169	0,133	0,096	0,051	0					
	G (S)						0	0,258	0,283	0,247	0,216	0,193	0,197	0,203	0,208	0,213	0,211	0,239	0,214	0					
	G (W)						0	0,051	0,089	0,116	0,153	0,167	0,190	0,314	0,490	0,635	0,647	0,778	0,612	0					

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - WINDHOEK (SUMMER)

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2,5%	DB	21,2	20,7	20,2	19,6	19,0	18,5	19,3	22,3	25,0	27,0	28,8	30,0	31,0	31,4	31,5	31,2	30,8	30,0	28,7	26,5	24,9	23,8	22,7	21,9
	RH	27,1	37,8	48,7	31,3	31,5	35,5	30,9	24,1	28,1	20,9	19,8	14,8	13,3	11,4	13,0	20,4	13,8	14,8	13,2	15,9	16,2	19,4	21,5	21,8
	WB	9,4	11,7	13,1	10,4	10,0	9,8	9,7	10,5	13,2	[illegible],9	13,7	13,3	12,4	13,0	13,4	15,0	13,2	13,0	12,1	11,4	10,9	10,5	10,2	9,7
	DP	-2,0	1,5	7,9	2,4	1,6	1,6	0,8	0,2	4,6	1,7	2,3	-0,4	-1,6	-3,1	-3,4	0,7	-2,7	-4,8	-4,0	-2,6	-2,0	-1,9	-1,1	-1,4
	PV	5,51	9,19	11,52	7,89	7,67	7,63	6,97	6,46	8,94	7,44	7,82	6,36	6,06	5,25	6,03	9,23	6,03	6,36	5,32	5,52	5,71	5,73	5,92	5,66
	W	4,19	7,00	8,79	5,99	5,82	5,79	5,29	4,89	6,79	5,64	5,94	4,82	4,54	3,97	4,58	7,09	4,57	4,84	4,03	4,18	4,32	4,34	4,48	4,28
	H	42,00	38,55	42,78	35,04	34,06	33,50	32,93	34,86	42,53	41,62	44,14	42,75	42,85	41,81	43,53	49,51	42,40	42,52	39,41	37,37	36,00	35,03	34,20	32,71
	S	189,8	193,4	208,8	181,2	177,8	176,0	173,7	179,7	205,9	202,0	210,2	204,9	205,0	201,3	207,2	228,1	203,6	204,1	193,6	187,2	182,9	179,8	177,2	172,2
	V	1,032	1,025	1,020	1,020	1,018	1,016	1,017	1,027	1,040	1,045	1,051	1,054	1,057	1,057	1,059	1,062	1,055	1,053	1,048	1,040	1,035	1,031	1,027	1,024
	WS	5,87	1,88	2,16	2,24	2,76	4,77	2,75	2,24	2,77	5,07	3,77	4,14	3,84	3,58	0,0	4,17	0,0	5,51	4,92	4,32	5,28	3,46	3,30	2,24
	G				-		0,029	0,223	0,482	0,756	0,950	1,034	1,109	1,007	0,930	0,713	0,469	0,424	0,211	[illegible],048					
	G (S)						0	0,046	0,085	0,117	0,145	0,187	0,196	0,223	0,209	0,168	0,105	0,075	0,047	0					
	G (E)						0	0,679	0,856	0,914	0,769	0,536	0,304	0,211	0,198	0,163	0,165	0,077	0,049	0					
	G (S)						0	0,258	0,276	0,240	0,201	0,191	0,190	0,216	0,213	0,200	0,179	0,221	0,229	0					
	G (W)						0	0,048	0,087	0,116	0,137	0,170	0,182	0,311	0,484	0,553	0,514	0,790	0,646	0					

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0,05%	DB	22,8	21,0	20,1	19,1	18,2	18,0	20,3	23,9	25,3	26,8	28,2	30,5	31,3	31,7	27,9	27,4	27,3	27,2	26,7	25,4	25,1	24,5	23,8	23,7
	RH	29,0	32,0	36,0	37,0	37,0	39,0	36,0	32,0	28,0	26,0	23,0	19,0	16,0	12,0	18,0	20,0	21,0	20,0	21,0	22,0	24,0	27,0	30 0	32,0
	WB	11,9	11,1	11,2	10,6	9,9	10,0	11,3	13,2	13,4	14,0	14,2	14,7	14,4	13,4	12,8	13,0	13,2	12,9	12,8	12,2	12,2	12,6	12,8	13,1
	DP	3,9	3,7	4,6	4,1	3,3	3,8	4,8	6,2	5,5	5,7	5,1	4,3	2,5	-1,0	1,4	2,5	3,1	2,3	2,6	2,2	2,5	1,3	5,2	[illegible]
	PV	8,05	7,96	8,47	8,18	7,73	8,05	8,57	9,49	9,03	9,16	8,80	8,30	7,32	5,61	6,77	7,30	7,02	7,22	7,36	7,14	7,33	8,30	8,54	9,28
	W	6,10	6,03	6,42	6,20	5,86	6,10	6,50	7,20	6,85	6,95	6,67	6,29	5,54	4,24	5,12	5,53	5,77	5,46	5,57	5,40	5,55	6,29	6,71	7,12
	H	38,48	36,47	36,55	34,97	33,18	33,59	36,95	42,41	42,94	44,72	45,44	46,80	45,69	42,78	41,17	41,70	42,22	41,33	41,10	39,35	39,42	40,70	41,05	41,98
	S	192,4	185,8	186,4	181,2	175,0	176,6	187,8	205,9	207,3	213,0	215,0	218,9	214,8	204,5	200,1	202,2	204,0	200,9	200,3	194,6	194,9	199,6	201,1	204,5
	V	1,031	1,024	1,022	1,018	1,014	1,014	1,023	1,036	1,041	1,046	1,050	1,058	1,059	1,059	1,047	1,046	1,046	1,045	1,043	1,039	1,038	1,037	1,035	1,0[illegible]
	WS	9,9	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	G						0,035	0,244	0,511	0,756	0,942	1,011	0,953	1,314	1,023	0,256	0,267	0,256	0,116	0,012					
	G (S)						0	0,043	0,076	0,105	0,137	0,158	0,239	0,319	0,258	0,144	0,157	0,144	0,065	0					
	G (E)						0	0,777	0,936	0,907	0,758	0,503	0,321	0,319	0,258	0,144	0,157	0,144	0,065	0					
	G (S)						0	0,295	0,307	0,267	0,230	0,193	0,246	0,330	0,286	0,147	0,166	0,155	0,079	0					
	G (W)						0	0,045	0,079	0,105	0,133	0,158	0,239	0,436	0,533	0,160	0,170	0,156	0,106	0					

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - WINDHOEK (SUMMER)

45

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
10	DB	6,9	6,2	5,7	5,2	4,7	4,2	4,0	4,6	8,1	11,0	13,4	15,3	16,8	17,8	18,4	18,4	17,9	16,4	13,9	12,0	10,9	9,7	8,9	8,2
	RH	32,7	34,4	36,7	38,9	39,9	44,7	45,0	43,8	37,8	24,8	23,2	20,4	17,9	15,8	12,2	9,6	9,6	13,5	14,9	16,9	9,4	20,8	26,6	25,9
	WB	0,6	0,3	0,1	-0,1	-0,4	-0,3	-0,6	-0,2	2,2	3,0	4,4	5,2	5,8	6,1	5,9	5,4	5,1	4,8	3,6	2,4	2,1	1,4	1,5	0,8
	DP	-8,3	-8,0	-7,9	-7,5	-8,0	-6,8	-6,9	-6,6	-5,4	-8,7	-7,2	-7,4	-8,4	-10,0	-12,4	-16,1	-15,3	-12,9	-13,4	-13,5	-12,1	-12,0	-9,6	-10,1
	PV	3,27	3,28	3,37	3,45	3,41	3,71	3,66	3,71	4,10	3,28	3,54	3,51	3,40	3,20	2,59	2,04	1,97	2,50	2,40	2,36	2,50	2,18	3,03	2,79
	W	2,45	2,46	2,53	2,59	2,56	2,79	2,75	2,79	3,08	2,47	2,66	2,63	2,56	2,40	1,95	1,53	1,48	1,88	1,80	1,70	1,48	1,36	2,27	2,09
	H	13,19	12,50	12,16	11,78	11,18	11,35	10,94	11,62	15,98	17,47	20,22	21,93	23,32	24,04	23,54	22,50	21,78	21,26	18,72	16,36	15,61	14,15	14,73	13,47
	S	103,9	101,5	100,4	99,1	97,0	97,7	96,2	98,7	114,0	118,8	128,3	134,1	138,8	141,1	139,1	135,3	132,9	131,3	122,6	114,5	112,0	108,0	109,2	104,7
	V	0,966	0,964	0,962	0,960	0,959	0,958	0,956	0,958	0,971	0,981	0,989	0,995	1,000	1,004	1,005	1,005	1,002	0,998	0,990	0,982	0,979	0,975	0,973	0,970
	WS	2,53	2,53	2,65	2,11	2,53	1,94	2,46	2,17	3,40	4,53	3,50	3,98	3,65	3,16	3,82	3,07	3,28	3,35	2,73	2,15	3,11	2,68	2,20	2,48
	G						0	0,030	0,204	0,411	0,619	0,719	0,782	0,782	0,710	0,589	0,384	0,187	0,016	0					
	G (N)						0	0	0,419	0,587	0,697	0,760	0,786	0,805	0,761	0,693	0,555	0,423	0	0					
	G (E)						0	0	0,783	0,778	0,688	0,473	0,248	0,117	0,110	0,069	0,063	0,033	0	0					
	G (S)						0	0	0,036	0,067	0,089	0,117	0,123	0,116	0,111	0,089	0,062	0,032	0	0					
	G (W)						0	0	0,037	0,068	0,090	0,115	0,124	0,244	0,468	0,660	0,730	0,759	0	0					

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
50	DB	5,1	4,6	4,2	3,6	3,2	2,7	2,4	2,9	6,4	9,3	11,7	13,8	15,4	16,5	17,1	17,2	16,7	15,1	12,5	10,6	9,1	8,4	7,6	6,9
	RH	45,3	21,8	43,6	41,5	42,4	54,1	53,7	41,8	42,7	32,6	29,9	21,4	16,2	19,7	9,2	13,4	11,0	13,0	14,7	18,4	16,2	20,9	24,8	24,2
	WB	0,7	-2,1	-0,7	-1,1	-1,3	-1,0	-1,	-1,9	1,4	2,6	4,2	4,4	4,7	6,0	4,7	5,4	4,7	4,8	2,6	1,8	0,5	0,1	0,1	-0,4
	DP	-4,8	-10,1	-9,6	-9,6	-8,0	-6,0	-5,8	-9,2	-4,9	-5,7	-5,8	-8,7	-9,4	-6,8	-20,0	-12,7	17,4	-14,2	-14,4	-12,7	-11,9	-12,8	-11,0	-11,8
	PV	4,21	1,50	3,51	3,36	3,27	3,97	3,89	3,09	4,10	3,81	4,13	3,40	2,84	3,73	1,82	2,66	2,12	2,19	2,11	2,35	1,90	2,29	2,62	2,42
	W	3,17	1,37	3,66	2,48	2,46	2,98	2,92	2,32	3,08	2,86	3,11	2,55	2,13	2,80	1,37	2,00	1,59	1,65	1,60	1,56	1,42	1,72	1,96	1,81
	H	13,11	7,78	10,71	10,04	9,56	10,12	9,85	8,54	14,26	16,55	19,78	20,12	20,87	23,76	20,93	22,49	21,0	19,05	16,69	15,12	12,99	12,74	12,86	11,54
	S	103,1	84,2	96,4	92,9	91,2	93,5	92,4	87,5	108,1	115,8	127,1	128,9	130,2	140,4	129,9	135,6	130,3	124,7	115,5	110,2	102,6	101,9	102,4	97,8
	V	0,961	0,965	0,956	0,955	0,951	0,952	0,951	0,951	0,965	0,975	0,984	0,990	0,995	1,000	1,000	1,001	0,999	0,992	0,981	0,976	0,973	0,970	0,965	0,965
	WS	1,73	4,69	1,97	1,53	2,35	3,87	3,53	2,46	1,56	3,84	2,68	3,86	5,66	4,92	6,93	4,40	4,10	1,92	4,09	2,46	2,01	1,79	2,83	3,24
	G						0	0,020	0,201	0,435	0,629	0,714	0,782	0,758	0,682	0,596	0,390	0,166	0,015	0					
	G (N)						0	0	0,442	0,609	0,712	0,809	0,855	0,797	0,507	0,716	0,592	0,366	0	0					
	G (E)						0	0	0,794	0,826	0,700	0,477	0,241	0,129	0,095	0,088	0,060	0,035	0	0					
	G (S)						0	0	0,036	0,066	0,090	0,100	0,109	0,128	0,097	0,088	0,059	0,031	0	0					
	G (W)						0	0	0,038	0,067	0,089	0,098	0,110	0,248	0,461	0,674	0,762	0,636	0	0					

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - WINDHOEK (WINTER)

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2,5 %	DB	4,1	3,5	3,1	2,5	2,2	1,6	1,6	2,0	5,5	8,4	10,7	12,8	14,5	15,6	16,2	16,4	15,9	14,2	11,6	9,7	8,5	7,8	7,1	6,4
	RH	44,[illegible]	48,6	43,4	53,0	54,4	53,8	55,7	57,1	38,3	32,2	20,4	16,0	17,6	17,0	19,2	16,3	21,5	14,3	15,2	21,9	21,6	29,4	32,6	26,0
	WB	-0,6	-0,7	1,3	-1,0	-1,1	-1,8	-1,6	-1,2	-0,1	1,9	2,2	3,1	4,3	4,8	5,6	5,3	5,7	3,7	2,2	1,7	1,0	0,9	0,9	-0,5
	DP	-7,6	-6,4	-8,4	-6,4	-6,9	-7,5	-7,0	-6,1	-8,3	-7,3	-10,6	-12,9	-10,3	-10,1	-7,1	-9,4	-5,8	-13,2	-13,7	-10,7	-10,6	-9,4	-8,7	-11,7
	PV	3,54	3,79	3,34	3,92	3,56	3,67	3,83	4,04	3,39	3,58	2,61	2,38	2,89	2,96	3,50	3,03	3,82	2,32	2,08	2,65	2,75	3,09	3,29	2,50
	W	2,65	2,85	2,51	2,95	2,90	2,76	2,88	3,04	2,55	2,69	1,96	1,78	2,17	2,22	2,63	2,27	2,87	1,74	1,56	1,99	2,06	2,32	2,47	1,88
	H	10,75	10,67	9,54	10,11	9,14	8,55	8,94	9,69	11,76	15,42	15,70	17,52	20,00	21,13	22,89	22,12	23,05	18,86	15,75	14,94	13,92	13,71	13,15	11,38
	S	95,[illegible]	95,4	91,2	93,4	91,6	87,8	89,2	92,0	99,0	111,8	112,4	118,5	127,2	131,1	137,3	134,5	138,0	123,1	112,3	109,7	106,1	105,6	104,8	97,2
	V	0,956	0,955	0,953	0,952	0,950	0,948	0,949	0,950	0,961	0,972	0,978	0,986	0,992	0,995	0,998	0,998	0,997	0,991	0,981	0,976	0,971	0,969	0,967	0,964
	WS	2,86	2,24	3,13	2,79	2,93	2,68	3,95	3,07	6,15	3,58	4,81	2,91	2,77	4,17	3,80	0,00	0,00	4,62	3,73	3,20	2,95	2,46	3,24	3,46
	G						0	0,015	0,194	0,423	0,593	0,739	0,774	0,761	0,687	0,558	0,399	0,180	0,017	0					
	G (N)						0	0	0,465	0,624	0,760	0,811	0,867	0,863	0,796	0,721	0,626	0,447	0	0					
	G (E)						0	0	0,837	0,820	0,684	0,490	0,240	0,109	0,089	0,082	0,062	0,031	0	0					
	G (S)						0	0	0,033	0,064	0,086	0,104	0,108	0,109	0,101	0,082	0,061	0,030	0	0					
	G (W)						0	0	0,035	0,064	0,085	0,102	0,109	0,235	0,461	0,645	0,789	0,767	0	0					

Probability level	Element	Hour of day																							
		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0,0 %	DB	0,7	-0,4	-0,9	-1,5	-1,1	-1,1	-2,0	-1,5	3,4	8,6	10,8	12,5	14,5	14,5	15,0	15,2	14,2	11,9	8,9	7,7	6,3	4,0	2,1	3,4
	RH	12,0	15,0	19,0	22,0	25,6	27,0	28,0	30,0	28,0	13,0	10,0	8,0	7,0	6,0	5,0	6,0	7,0	8,0	10,0	12,0	13,0	15,0	18,0	20,0
	WB	-5,7	-6,2	-6,2	-6,5	-6,0	-5,8	-6,4	-5,9	-2,5	-0,6	1,0	1,7	2,7	2,6	2,72	3,0	2,6	1,4	-0,8	-1,4	-2,0	-3,3	-4,2	-3,2
	DP	-23,0	-21,6	-19,6	-18,5	-16,8	-16,0	-16,4	-15,2	-12,0	-16,4	-17,6	-18,[illegible]	-18,8	-20,4	-22,0	-20,0	-19,0	-19,2	-19,0	-17,9	-18,1	-18,5	-17,7	-15,6
	PV	0,77	0,89	1,05	1,19	1,39	1,50	1,45	1,62	2,18	1,45	1,29	1,16	1,15	0,99	0,85	1,04	1,13	1,11	1,14	1,26	1,24	1,22	1,28	1,56
	W	0,58	0,66	0,81	0,89	1,04	1,13	1,08	1,21	1,64	1,09	0,97	0,87	0,86	0,74	0,64	0,78	0,85	0,83	0,85	0,94	0,93	0,91	0,96	1,17
	H	2,20	1,31	1,16	0,76	1,55	1,76	0,75	1,57	7,57	11,43	13,35	14,81	16,82	16,50	16,74	17,30	16,47	14,12	11,15	10,16	8,72	6,36	4,56	6,39
	S	63,7	60,5	60,0	58,6	61,6	62,1	58,7	61,8	83,6	96,9	103,6	108,6	115,6	114,4	115,2	117,2	114,4	106,2	95,8	92,4	87,3	78,9	72,4	79,1
	V	0,942	0,938	0,937	0,935	0,936	0,936	0,933	0,935	0,953	0,970	0,977	0,983	0,990	0,990	0,991	0,992	0,989	0,981	0,970	0,966	0,962	0,954	0,947	0,952
	WS	0,00	0,00	0,00	0,00	0,00	1,34	0,00	1,34	0,00	0,00	0,00	1,34	2,24	2,68	3,58	4,92	4,47	3,58	1,34	0,00	0,00	0,00	0,00	1,34
	G						0	0,023	0,198	0,430	0,581	0,709	0,767	0,767	0,697	0,546	0,325	0,116	0,012	0					
	G (N)						0	0	0,033	0,065	0,087	0,101	0,113	0,113	0,106	0,083	0,059	0,024	0	0					
	G (E)						0	0	0,345	0,497	0,450	0,351	0,199	0,113	0,106	0,083	0,059	0,024	0	0					
	G (S)						0	0	0,117	0,152	0,140	0,127	0,121	0,121	0,130	0,133	0,121	0,069	0	0					
	G (W)						0	0	0,033	0,065	0,087	0,101	0,113	0,199	0,346	0,423	0,364	0,190	0	0					

DB DRY-BULB TEMPERATURE °C
DP DEW-POINT TEMPERATURE °C
H ENTHALPY OF MOIST AIR kJ/kg OF DRY AIR
WS WIND SPEED m/s
G(E) TOTAL SOLAR RADIATION ON E-FACING VERT. SURFACE kW/m²

RH RELATIVE HUMIDITY %
PV VAPOUR PRESSURE mb
S ENTROPY OF DRY AIR J/kg OF DRY AIR
G GLOBAL SOLAR RADIATION ON HOR. SURFACE kW/m²
G(S) TOTAL SOLAR RADIATION ON S-FACING VERT. SURFACE kW/m²

WB WET-BULB TEMPERATURE °C
W HUMIDITY RATIO g/kg
V SPECIFIC VOLUME OF MOIST AIR m³/kg OF DRY AIR
G(N) TOTAL SOLAR RADIATION ON N-FACING VERT. SURFACE kW/m²
G(W) TOTAL SOLAR RADIATION ON W-FACING VERT. SURFACE kW/m²

DESIGN WEATHER DATA - WINDHOEK (WINTER)

4. PASSIVE SOLAR COOLING AND HEATING STRATEGIES

WHY USE PASSIVE SOLAR COOLING AND HEATING?

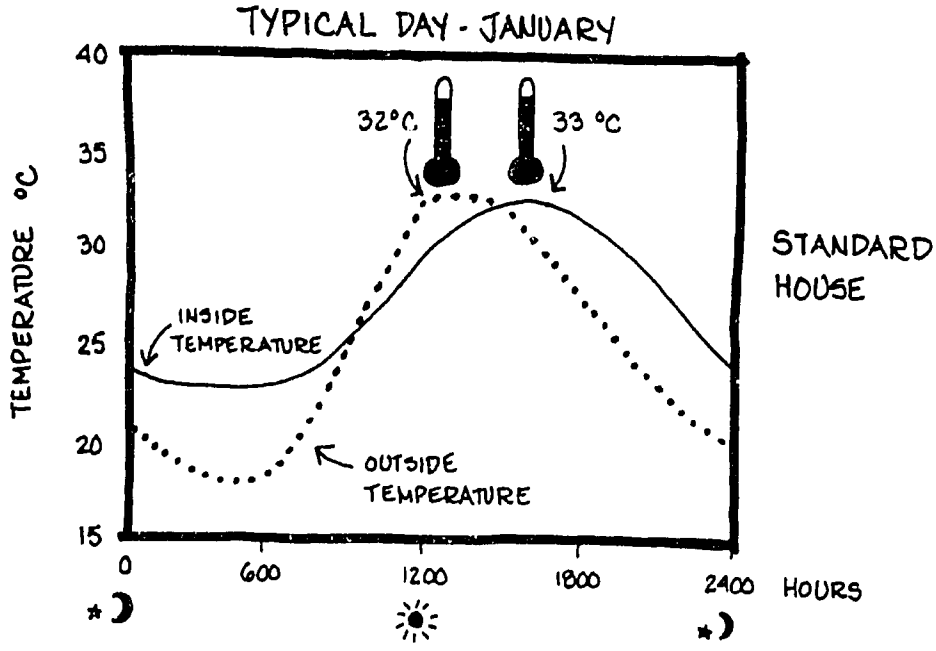
As described in the last section, the outdoor temperature in Botswana varies greatly from day to night as well as from winter to summer. At the same time, the desired temperature to achieve indoor comfort conditions is a fairly narrow band. While one of the primary functions of a building is to provide comfort on the inside by sheltering us from the outdoor climate, conventional building design is only moderately successful in achieving this goal. The graphs at the top of the following two pages show the average summer and winter temperatures found inside and outside a typical new house in Botswana (block walls, metal roof, un-insulated ceiling, etc.). As you can see, while the temperature swing inside the house is less than it is outdoors, the swing is still substantial and needs to be further reduced to make the house comfortable.

The graphs on the lower left side of the two following pages show how the indoor temperature can be made warmer in winter and cooler in summer by the conventional solution, where electricity or fuel is consumed to artificially heat or cool the building. Obviously, this costs money and it is not an option for most homeowners. It also depletes precious natural resources.

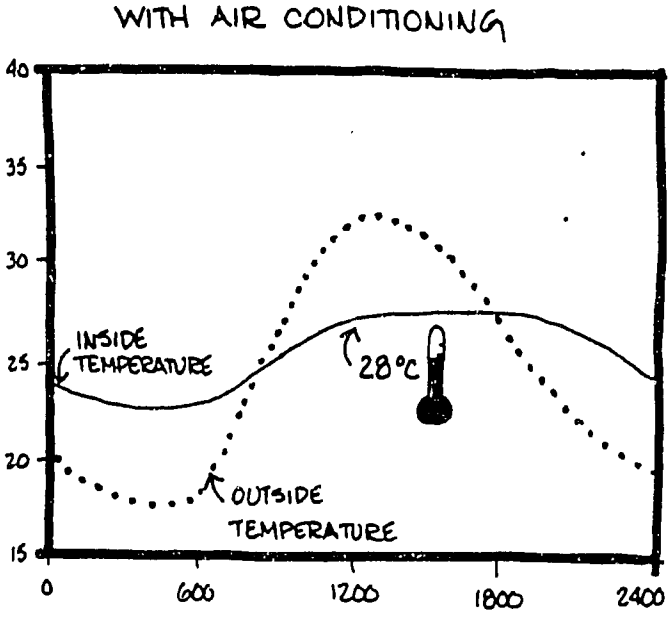
The other choice, which can achieve almost the same level of comfort in a house, is illustrated on the bottom right side of the following pages. These graphs show the typical performance of a house which incorporates both energy conservation and passive solar features in its design. Many of the design elements which result in this performance cost nothing over conventional construction. Others have some additional cost, but much less than the cost of artificially heating and cooling the building to achieve the same results.

The remainder of this section will catalogue the strategies which can be used to achieve this "natural" heating and cooling of buildings with passive solar techniques.

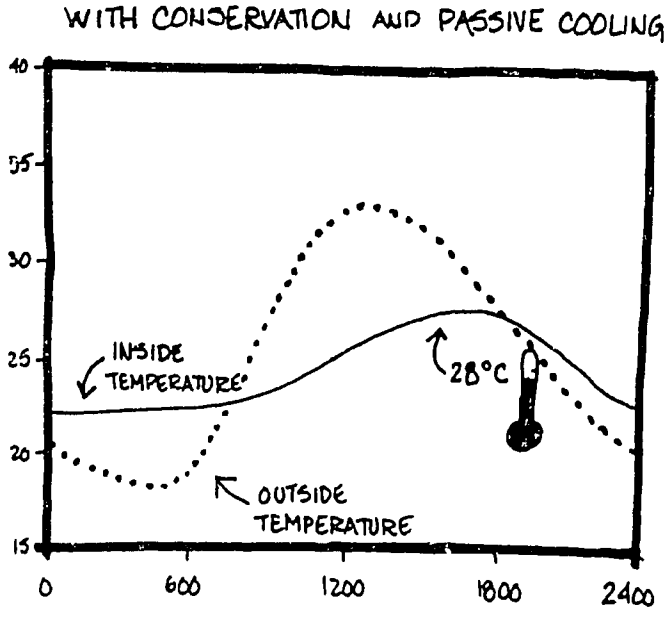
THE BASIC CHOICE ON HOW TO COOL A HOUSE IN SUMMER



OR

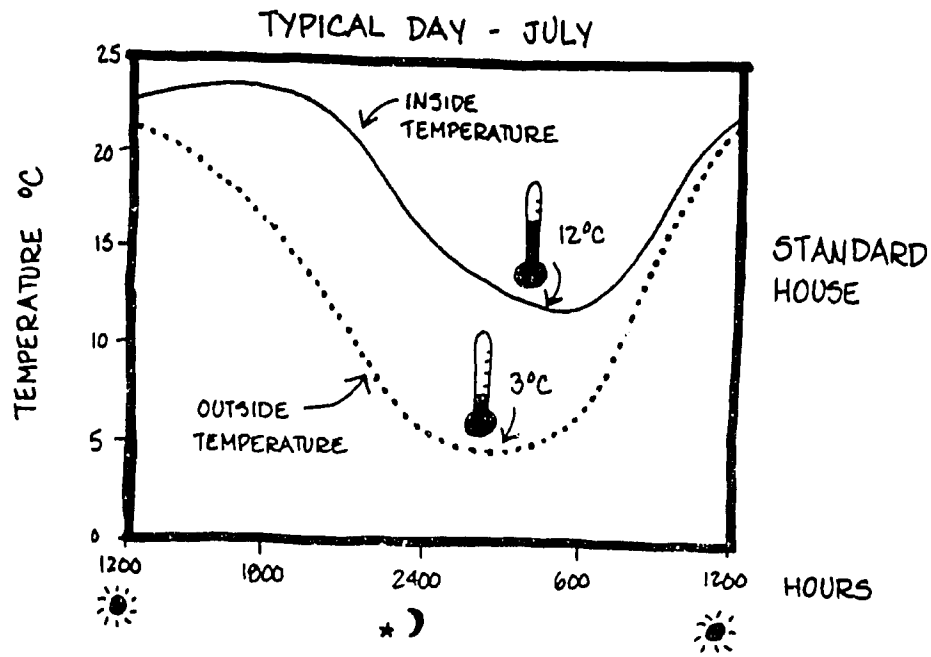


HIGH COST

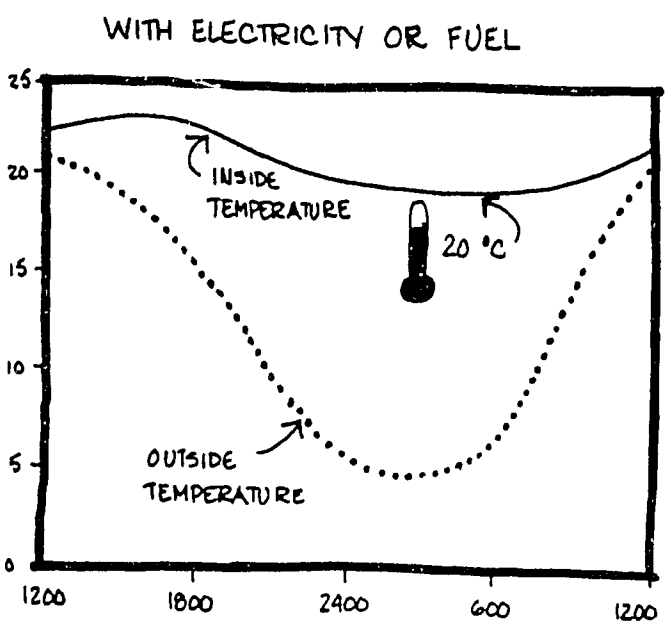


LOW COST

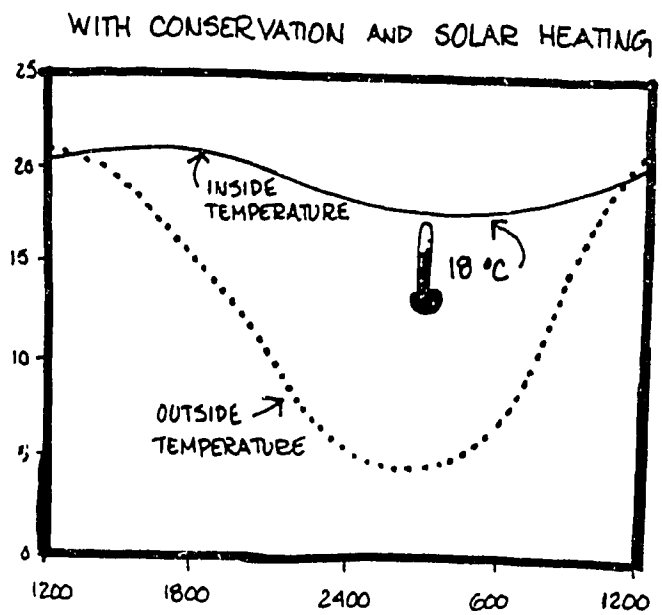
THE BASIC CHOICE ON HOW TO HEAT A HOUSE IN WINTER



OR



HIGH COST



LOW COST

OVERVIEW OF HEATING AND COOLING STRATEGIES

The purpose of this section is to survey the appropriate heating and cooling strategies which can be used is building design in Botswana and explain how they work.

In previous sections we have talked about requirements for thermal comfort and the outdoor enviroment to which buildings are exposed in Botswana. In passive solar building design, these outdoor conditions should be seen not as weather which the building should be trying to keep out, but rather as resources which can be used to help achieve thermal comfort. This can be done by promoting energy exchanges with some elements of the environment while resisting exchange with other elements. Cooling strategies try to resist heat gain to the building while promoting heat loss. Heating strategies try to promote heat gains to the building while resisting heat losses.

COOLING STRATEGIES 1 - MINIMIZE SOLAR GAIN

1A - Minimize the amount of solar radiation directly entering the building.

1B - Minimize the amount of solar radiation absorbed on the outside of the building which can be transmitted through the walls and roof to the inside.

COOLING STRATEGY 2 - PROMOTE VENTILATION

2A - Promote wind-driven ventilation.

2B - Promote stack-driven ventilation.

2C - Use forced ventilation with a fan.

COOLING STRATEGY 3 - MINIMIZE CONDUCTIVE HEAT FLOW FROM OUTSIDE

3A - Insulate roof.

3B - Insulate walls.

COOLING STRATEGY 4 - PROMOTE EARTH COUPLING

4A - Use higher conductivity to ground.

4B - Use higher surface area of building in contact with ground.

COOLING STRATEGY 5 - LOWER INFILTRATION

5A - Lower uncontrolled air leakage through house.

COOLING STRATEGY 6 - PROMOTE RADIANT COOLING

6A - Use roof material which is a good radiator.

6B - Use radiant roof to cool ventilation air.

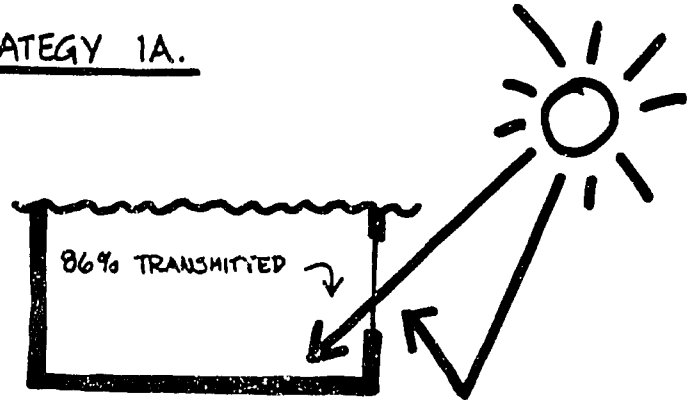
COOLING STRATEGY 7 - USE THERMAL MASS

7A - Maximize thermal mass to reduce indoor temperature extremes.

7B - Design to cool thermal mass with night ventilation air.

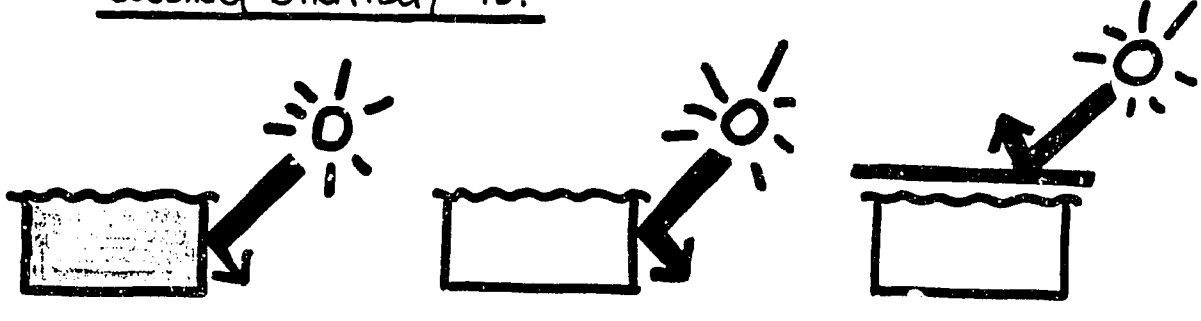
7C - Use massive walls and/or roof to retard heat gain.

COOLING STRATEGY 1A.



MINIMIZE THE AMOUNT OF SOLAR RADIATION DIRECTLY ENTERING THE HOUSE

COOLING STRATEGY 1B.



DARK COLOR | LIGHT COLOR | REFLECTIVE BARRIER

MINIMIZE THE AMOUNT OF SOLAR RADIATION ABSORBED ON THE OUTSIDE OF THE BUILDING WHICH CAN BE TRANSMITTED THROUGH THE WALLS AND ROOF TO THE INSIDE

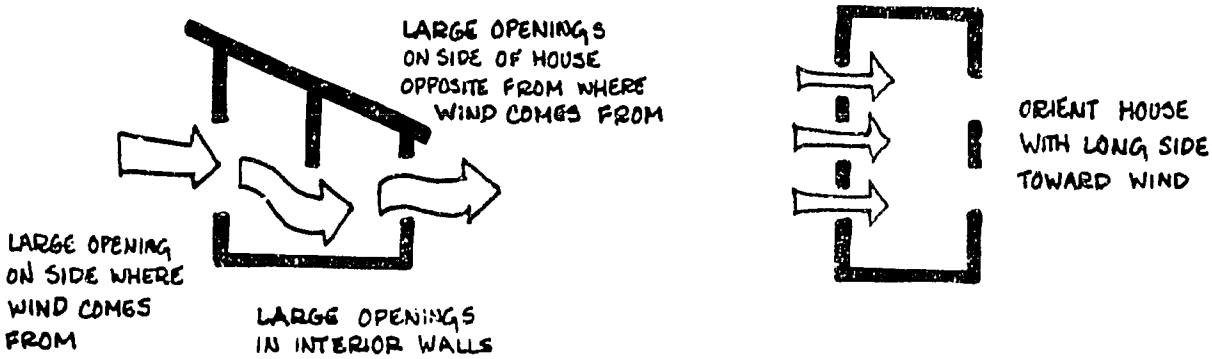
ABSORPTIVITY OF DIFFERENT SURFACES

MATERIAL	SOLAR ENERGY ABSORBED
aluminum sheet (new)	15%
white wash (new)	20%
white paint	30%
aluminum paint	40%
cream-coloured paint	45%
light blue, green or pink paint	50%
galvanized sheet (new)	55%
light-coloured brick	50%
concrete	65%
red clay tiles	70%
red or green paint	70%
red brick	70%
galvanized sheet (old)	75%
light brown paint	80%
dark brown or blue paint	88%
black paint	90%
flat black paint	95%

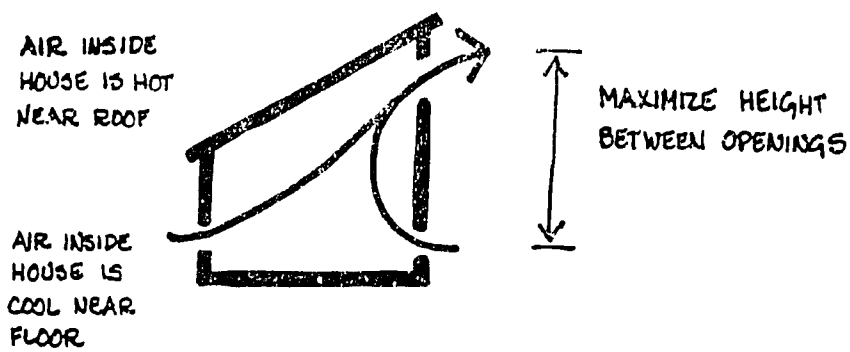
SUMMER DAY TEMPERATURES OF GALVANIZED STEEL ROOFS

COLOUR	ABSORPTIVITY	TEMPERATURE
black	90%	70°
unpainted	75%	65°
red	74%	63°
cream	40%	48°
white	30%	44°

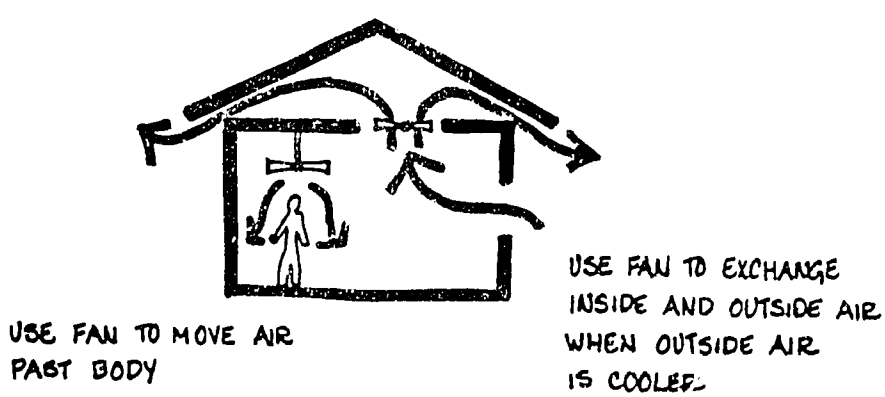
COOLING STRATEGY 2A. PROMOTE WIND-DRIVEN VENTILATION



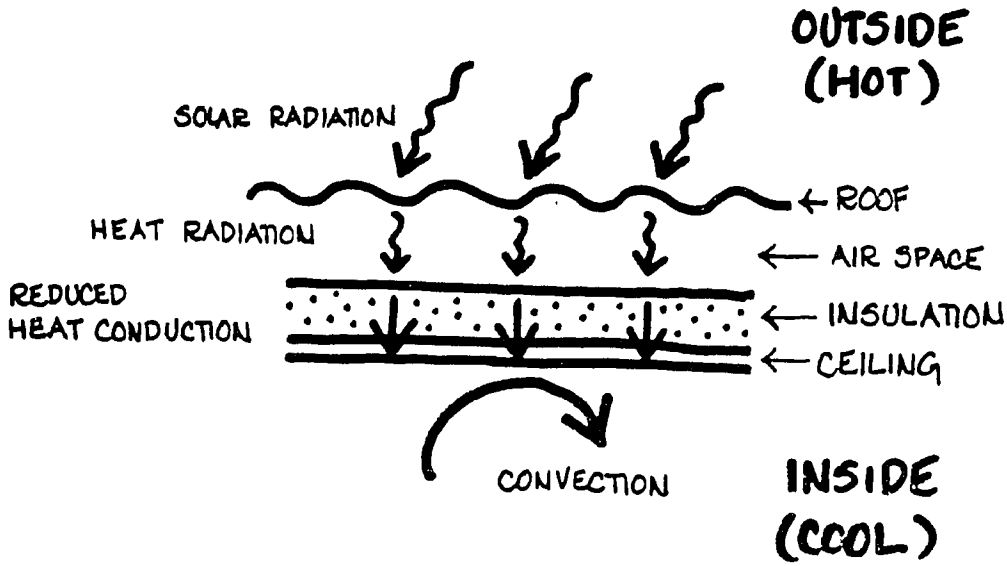
COOLING STRATEGY 2B. PROMOTE STACK-DRIVEN VENTILATION



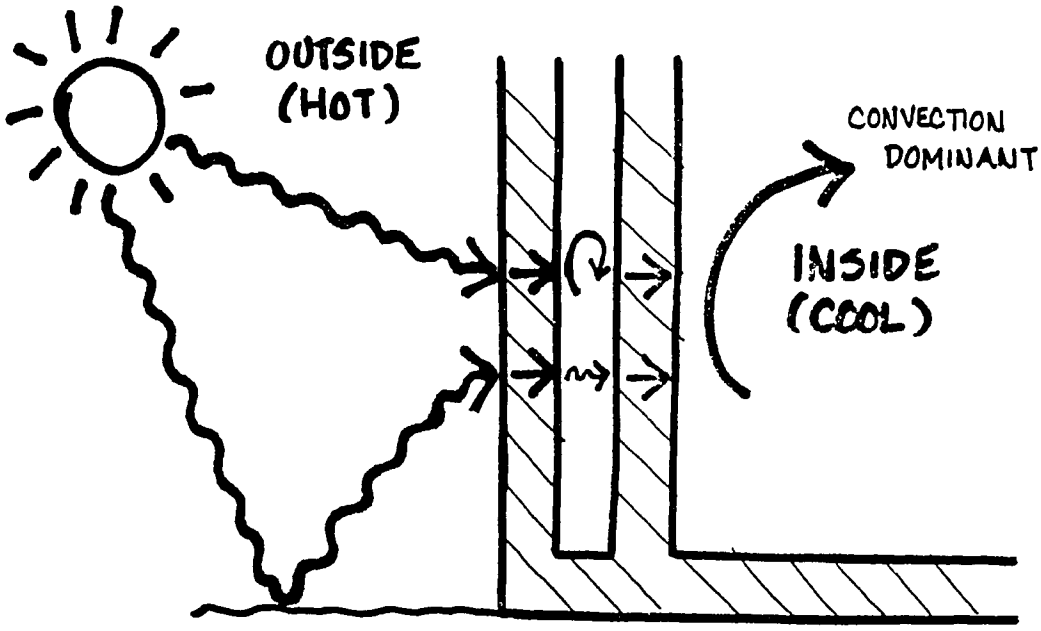
COOLING STRATEGY 2C. FORCED VENTILATION WITH A FAN



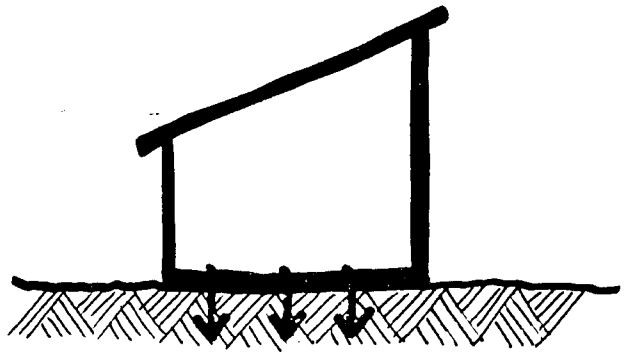
COOLING STRATEGY 3A. INSULATE ROOF



COOLING STRATEGY 3B. INSULATE WALLS

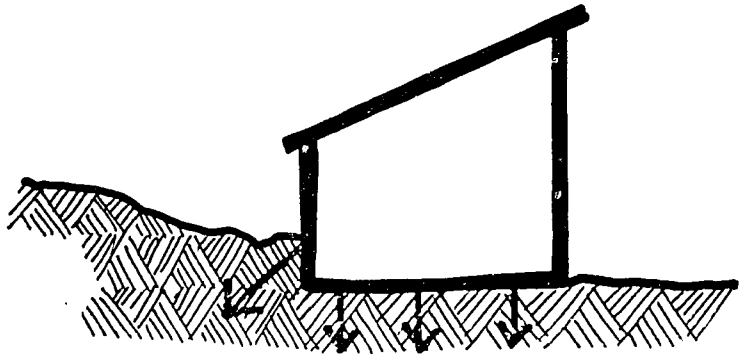


COOLING STRATEGY 4A.



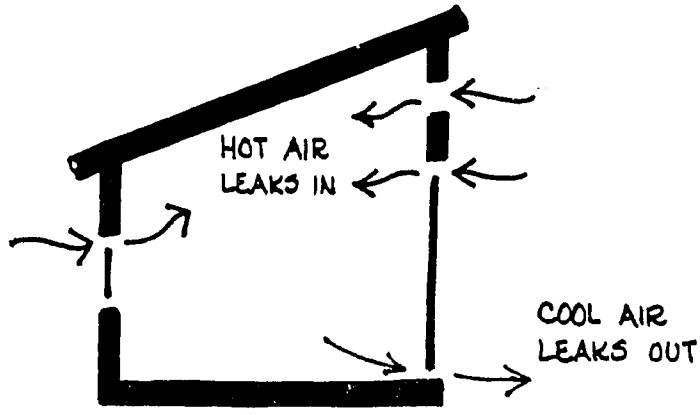
HIGH CONDUCTIVITY TO THE GROUND

COOLING STRATEGY 4B.

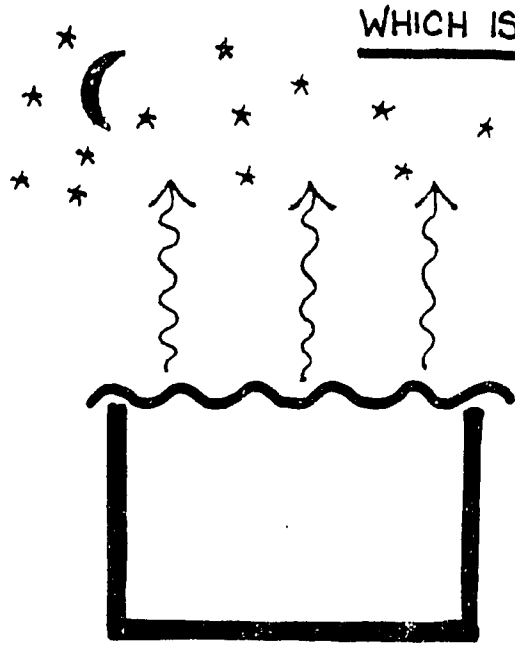


HIGH AMOUNT OF SURFACE AREA
IN CONTACT WITH GROUND

COOLING STRATEGY 5A. LOWER INFILTRATION



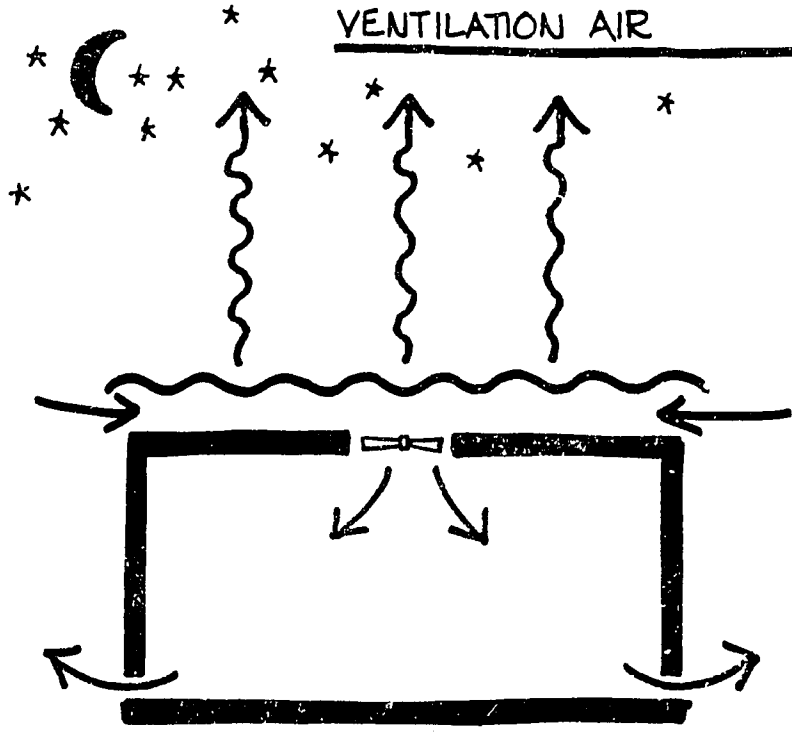
COOLING STRATEGY 6A. USE ROOF MATERIAL WHICH IS GOOD RADIATOR



GOOD AND BAD RADIATORS

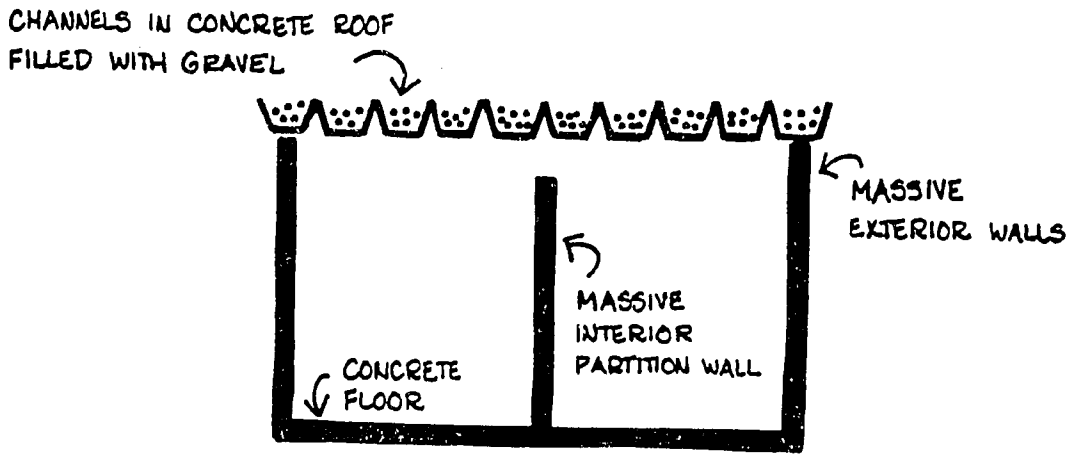
MATERIAL	"EMISSIVITY"	
as[illegible]	.93	Good Radiators
asb[illegible]tos cement board	.93	
paint, any color	.90	
earth or sand	.90	
concrete	.90	
red clay tiles	.90	
white-washed galvanized sheet	.79	
aluminum paint	.55	Poor Radiators
galvanized sheet	.25	
stainless steel	.22	
aluminum sheet	.09	

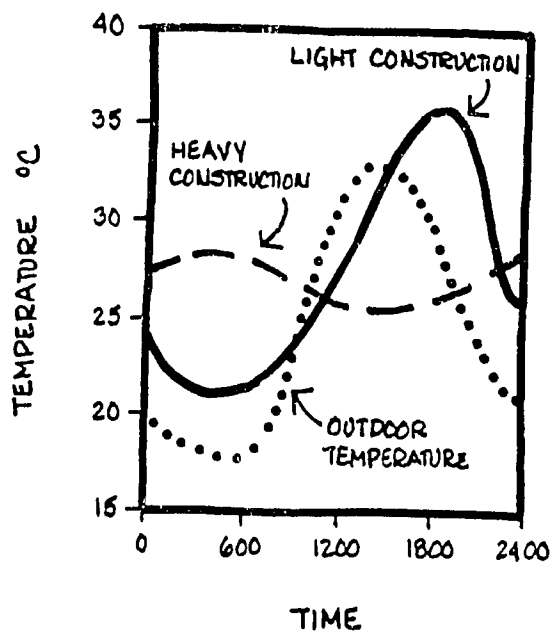
COOLING STRATEGY 6B. USE RADIANT ROOF TO COOL VENTILATION AIR



60

COOLING STRATEGY 7A. MAXIMIZE THERMAL MASS TO REDUCE INDOOR TEMPERATURE EXTREMES

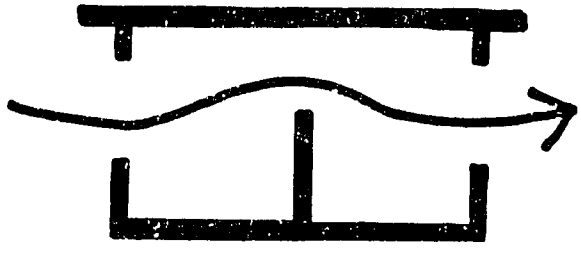




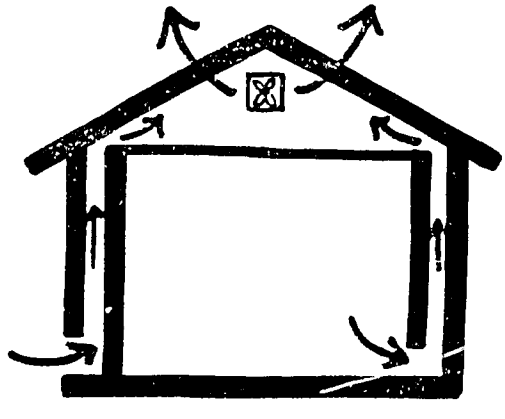
COMPARISON OF INDOOR TEMPERATURES
FOR HEAVY AND LIGHTWEIGHT CONSTRUCTION
IN JANUARY

COOLING STRATEGY 7B. DESIGN TO COOL THERMAL MASS WITH NIGHT VENTILATION

STACK DRIVEN



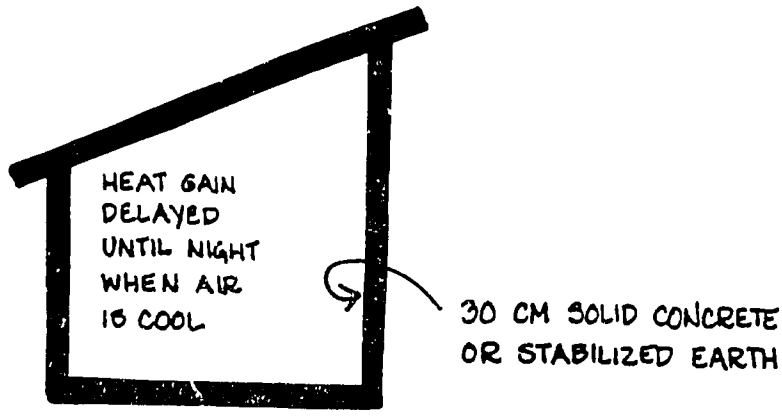
WIND DRIVEN



FAN DRIVEN

62

COOLING STRATEGY 7C. USE MASSIVE WALLS AND/OR ROOF TO RETARD HEAT GAIN



TIME LAG FOR HEAT TRANSMISSION THROUGH WALLS

MATERIAL	TIME LAG (hours)
wood 5 cm thick	1.3
brick 10 cm thick	2.3
solid concrete 15 cm thick	3.8
hollow concrete block 20 cm thick	7.5
solid concrete 30 cm thick	7.8
stone 30 cm thick	8.0

HEATING STRATEGY 1 - MINIMIZE CONDUCTIVE HEAT FLOW TO OUTSIDE

1A - Insulate roof.

1B - Insulate walls.

HEATING STRATEGY 2 - MINIMIZE INFILTRATION

2A - Lower uncontrolled air leakage through house.

HEATING STRATEGY 3 - PROMOTE SOLAR GAIN

3A - Increase the amount of solar radiation directly entering the building.

3B - Increase the amount of solar radiation absorbed on the outside of the building which can be transmitted through the walls and roof to the inside.

3C - Minimize the conductivity of the north wall and/or roof to transmit solar heat into the building.

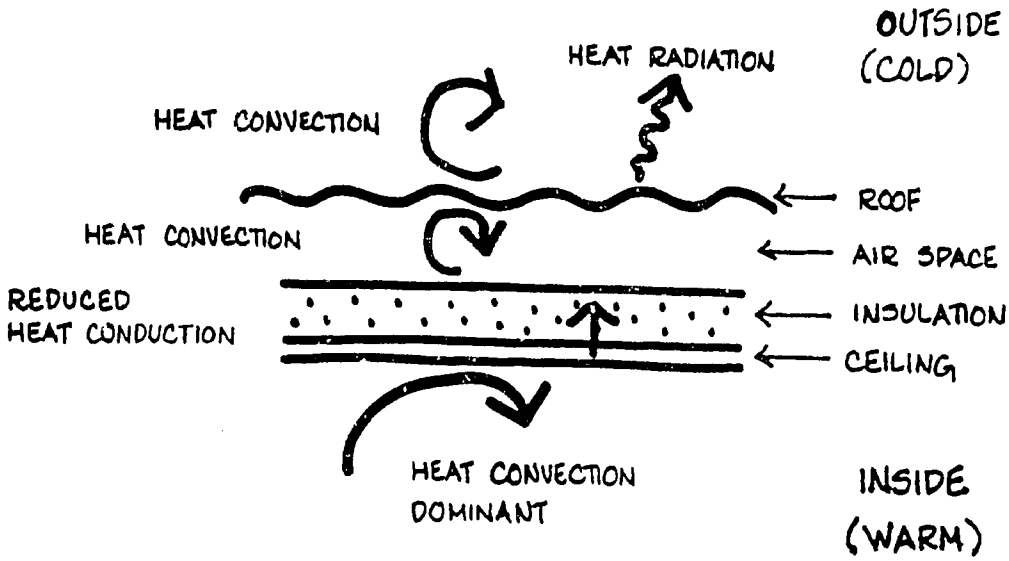
3D - Use wall or roof as solar air heater.

HEATING STRATEGY 4 - USE THERMAL MASS

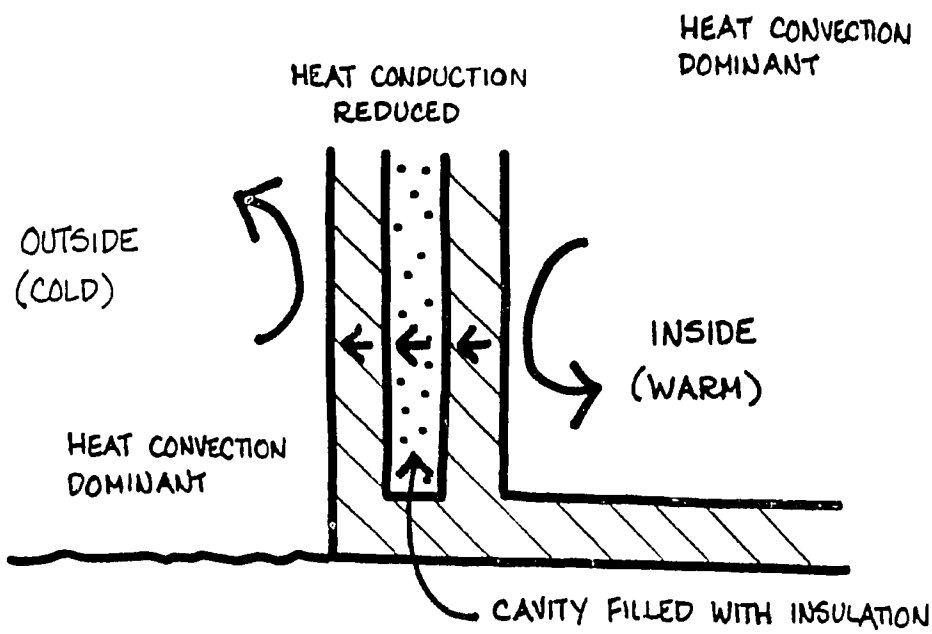
4A - Use thermal mass inside house for heat storage of solar gains.

4B - Use thermal mass in walls and/or roof to store heat gains and release heat to inside at night.

HEATING STRATEGY 1A. INSULATE ROOF

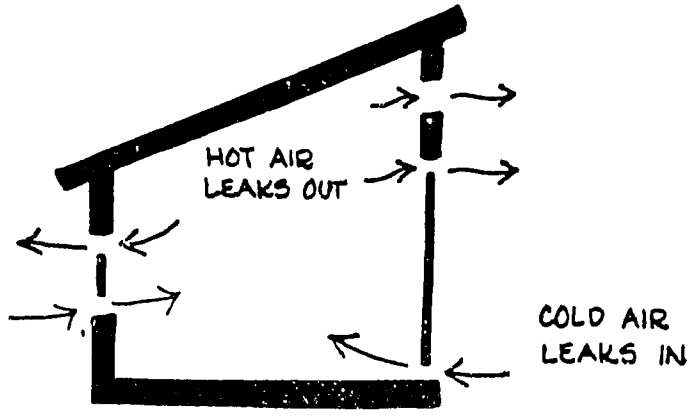


HEATING STRATEGY 1B. INSULATE WALLS

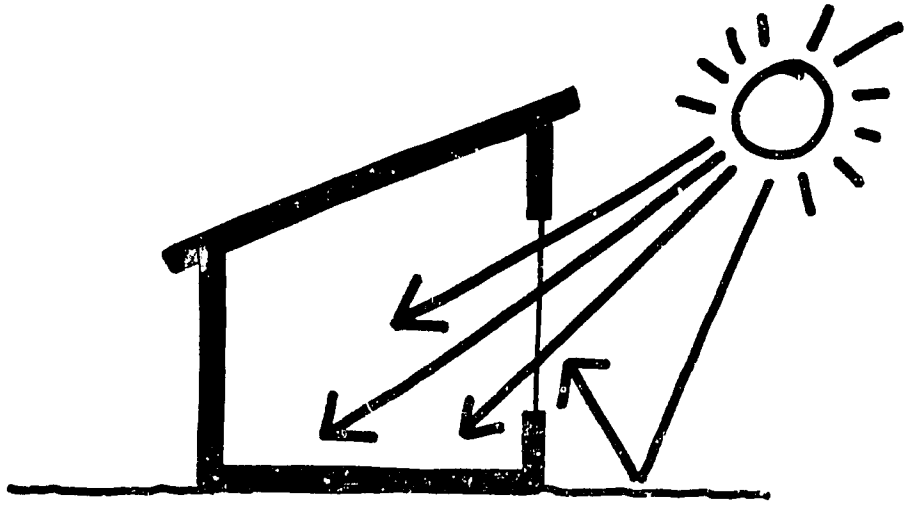


65

HEATING STRATEGY 2A. MINIMIZE INFILTRATION



HEATING STRATEGY 3A. INCREASE AMOUNT OF SOLAR RADIATION DIRECTLY ENTERING HOUSE



USE LARGE WINDOWS PLACED SO THAT SUN SHINES IN DURING THE WINTER

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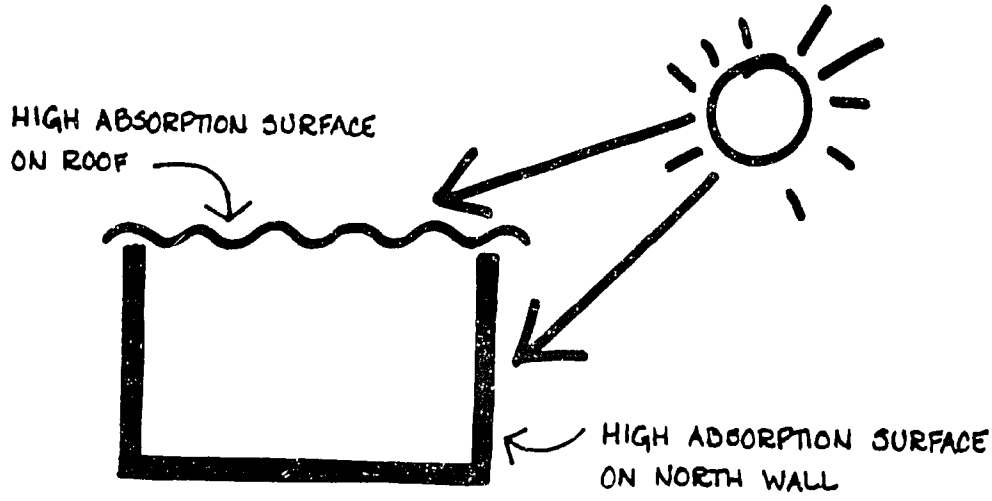
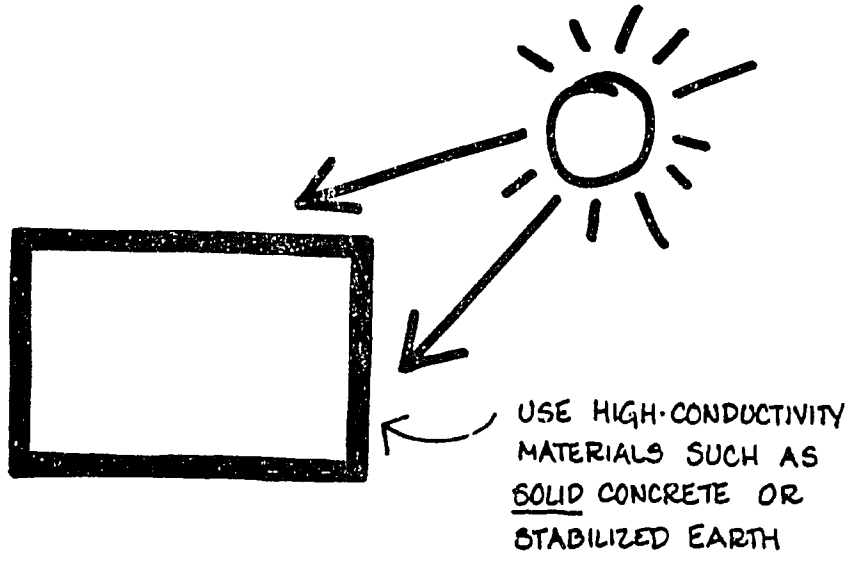
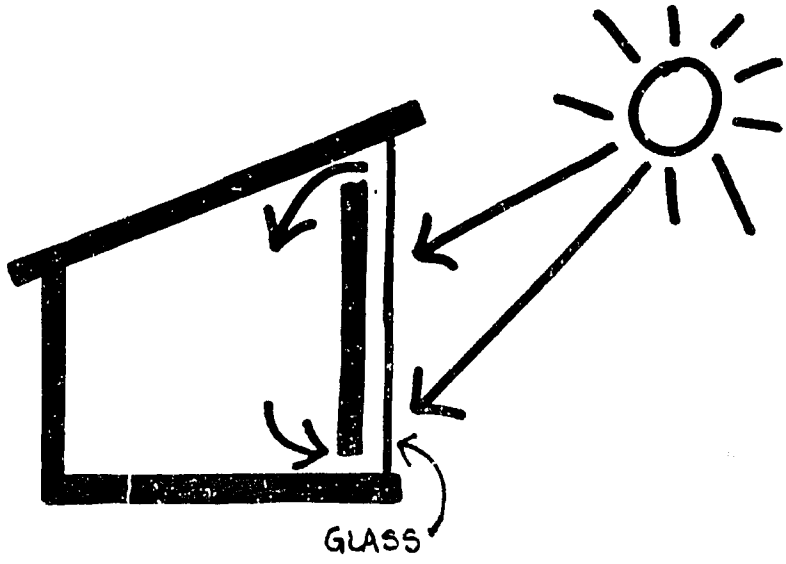
HEATING STRATEGY 3B. INCREASE AMOUNT OF SOLAR RADIATION ABSORBED ON OUTSIDE OF BUILDING

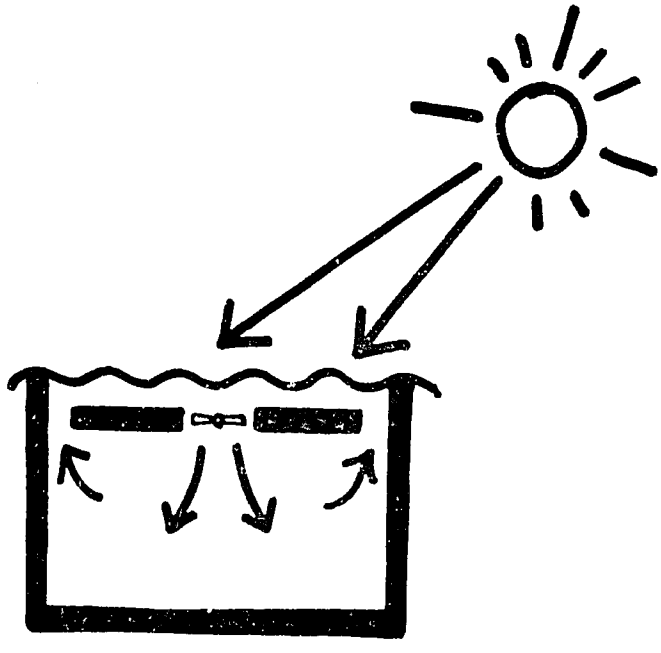


HEATING STRATEGY 3C. MAXIMIZE CONDUCTIVITY OF ROOF AND/OR NORTH WALL TO TRANSMIT ABSORBED SOLAR HEAT



HEATING STRATEGY 3D. USE WALL OR ROOF AS SOLAR AIR HEATER





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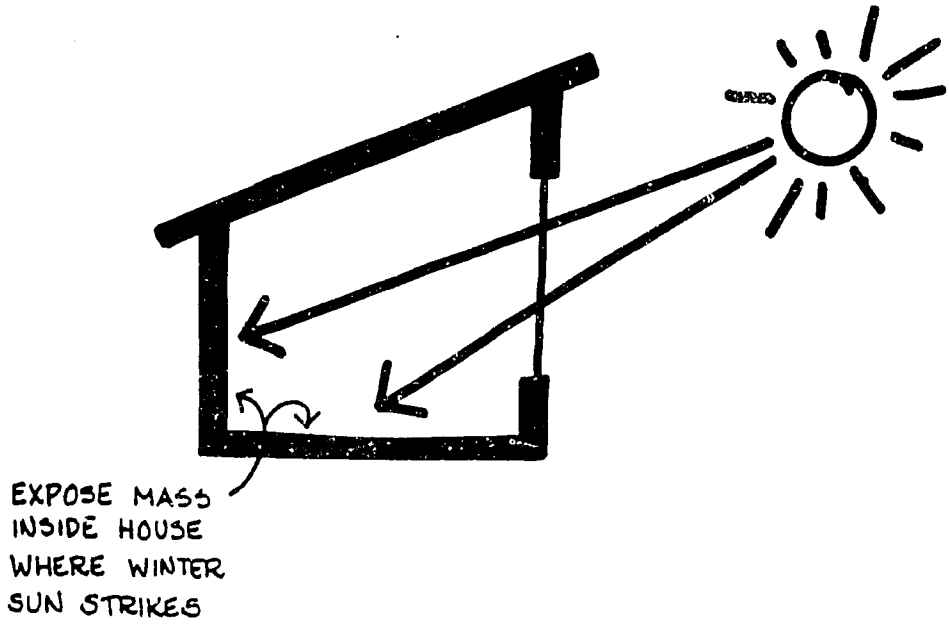
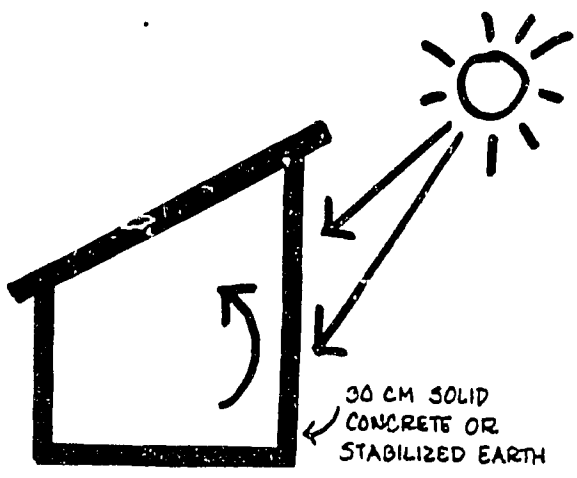
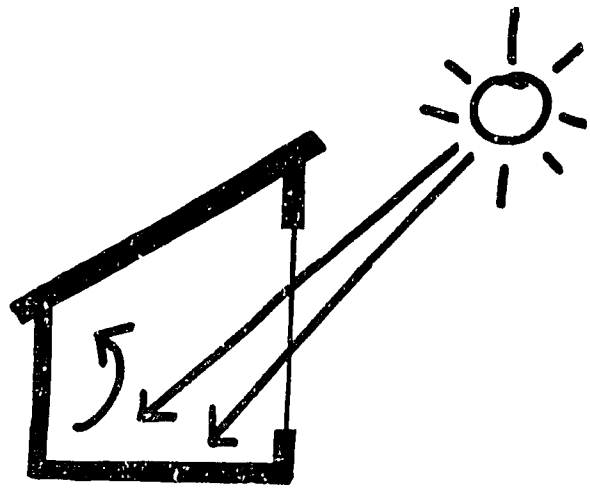
HEATING STRATEGY 4A. USE THERMAL MASS INSIDE HOUSE FOR HEAT STORAGE OF SOLAR GAINS



HEATING STRATEGY 4B. USE THERMAL MASS IN WALLS AND/OR ROOF TO STORE HEAT GAINS FROM DAY UNTIL NIGHT



HEAT RELEASED INSIDE
8 HOURS LATER (NIGHT)



HEAT RELEASED INSIDE
DURING DAY AND EVENING

LARGE BUILDINGS

The focus for thermal environmental control for most large buildings in Botswana can be stated very simply: COOLING

Strategies for achieving cooling by passive means can be broadly grouped in two categories:

1. Reduce Heat Gains
2. Promote Heat Losses

Many of the strategies previously discussed for smaller buildings can be appropriate for large buildings. Others are particular to the thermal characteristics of large buildings. In summary:

Strategies to Reduce Heat Gains

- orient building with long axis east-west
- place windows on north and south sides
- shade windows, walls, roof
- use reflective surfaces on walls and roof
- use ground cover of plants outside
- insulate roof (and walls in some situations)
- use less artificial lighting (more daylighting)
- use energy-efficient lighting

Strategies to Promote Heat Loss

- use large amount of mass with large surface area to absorb daytime heat gains
- use night ventilation to pre-cool building mass

5. SITING FOR PASSIVE SOLAR

SITE SELECTION AND ANALYSIS

The purpose of passive solar site analysis is to identify those features of the site which provide possible thermal benefits as well as those which may be liabilities in order to determine the best location for the structure.

The following is a check list of site factors affecting thermal comfort of which solar, wind and vegetation are the most important. To accumulate the information below, one need only a single site visit if the site is a relatively simple one and no special instruments, though a compass would be helpful.

1. Using either a compass and compensating for the variation between magnetic and true north, or the sundial technique (page 5-3), determine where true, i.e. solar, north is located.

2. Using a compass and protractor, or the fist method (page 5-4), locate the annual extreme positions of the sun. This can be carried out jointly with the Solar Access Analysis, should such analysis be required.

3. Obstacles such as hills, trees, other building, etc., may be high enough and wide enough to block out sunlight. If such obstacles exist, the more detailed survey (page 5-6) should be undertaken.

4. Leafy trees can shade the building and help cool it. Ground level vegetation can reduce reflected solar radiation and reduce ground temperatures. Review the contents of Chapter 12 and inventory the site's existing vegetation.

5. In Botswana, the reflection of sunlight off of surrounding vertical and horizontal surfaces can add significantly to the solar gain of a neighboring building. Use the table on page 5-9 to evaluate sources of reflected gain.

6. Wind can help to ventilate and cool the building. Though the wind's general pattern may be predicted by meteorological data, its actual performance is altered by site factors such as topography, other structures and vegetation (pages 5-10 and 5-11). Observe and note such factors and evaluate their impact. Obtain a rough, site specific wind velocity reading by using the Beaufort Scale on page 5-12.

7. Visually survey the site's slope to evaluate potential for cooling the building through contact of the walls with the earth. Observe erosion patterns to see if there are locations where water gathers which might suggest a natural place to grow trees and therefore to locate and shade a building.

Once all of the site's energy related features are enumerated, compile them on a site map such as on page 5-14, and evaluate them along with other factors such as access, service views and the like.

HOW TO DETERMINE SOLAR NORTH

1. Punch a 500 mm nail through the center of a 300 x 500 mm piece of cardboard (drawing 1).

2. Punch two sheets of paper down on the nail and tape the bottom sheet firmly to the carboard (1).

3. At about 11 in the morning, place the sundial down on flat ground approximately where the building will be (1). Secure the sundial with rocks on two sides. From here on out it cannot move.

4. With a sharp pencil point, locate the end of the shadow cast by the nail point and punch through the top sheet (2).

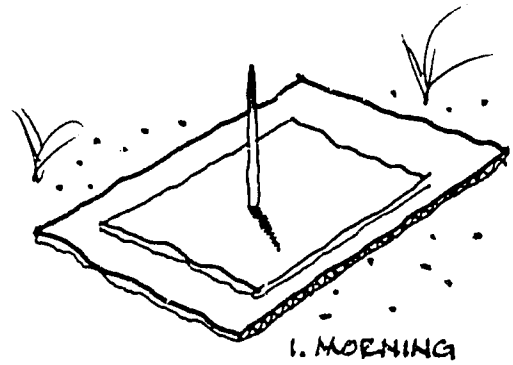
5. Rotate a full turn around the nail, drawing a circle on the bottom sheet. Now remove the top sheet taking care not to move the nail.

6. Wait until about 2 in the afternoon. Return to the sundial. At the precise moment the sun again touches the circle line, mark the intersection (4).

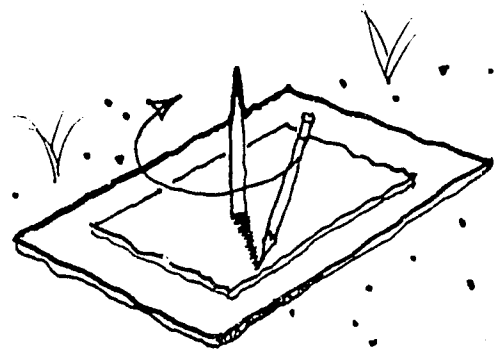
7. Draw a straight line between the morning and afternoon intersection points using the edge of sheet no. 1 (4).

8. With sheet no. 1, mark the length of the line between the two points. Fold the marked off length in half and mark the midpoint of the line (4).

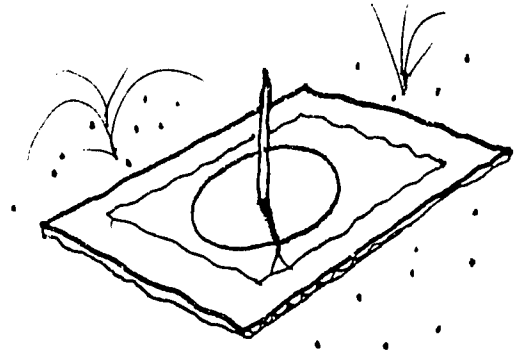
9. Draw a line from the nail to the midpoint. Solar north is at the nail end of the line.



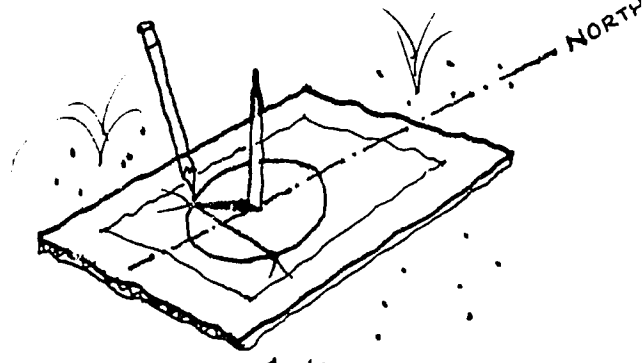
1. MORNING



2. MORNING



3. MORNING

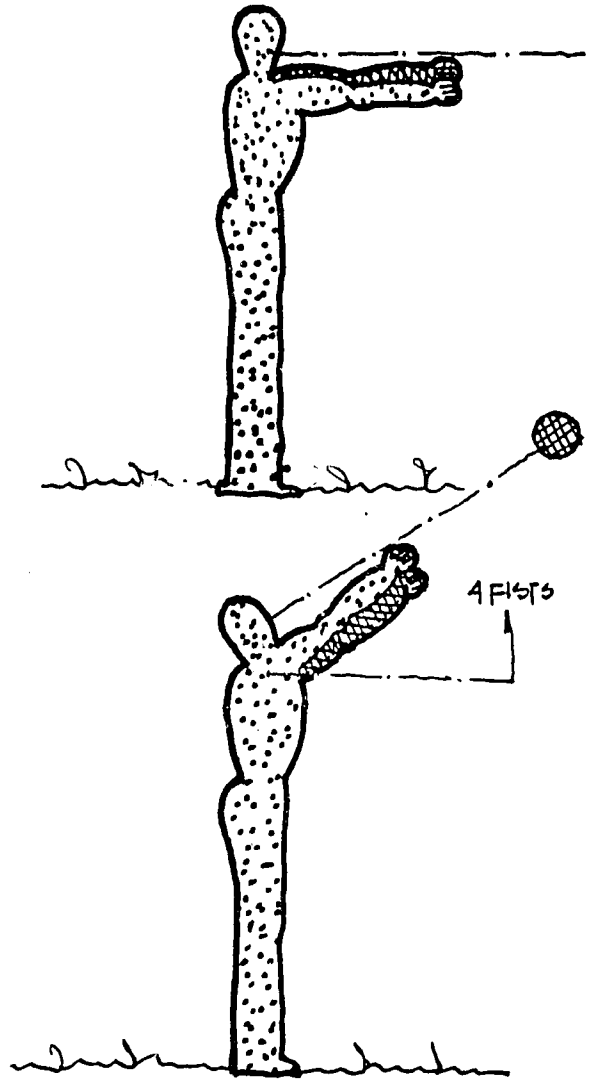


4. AFTERNOON

DETERMINING SOLAR EXTREMES BY HAND

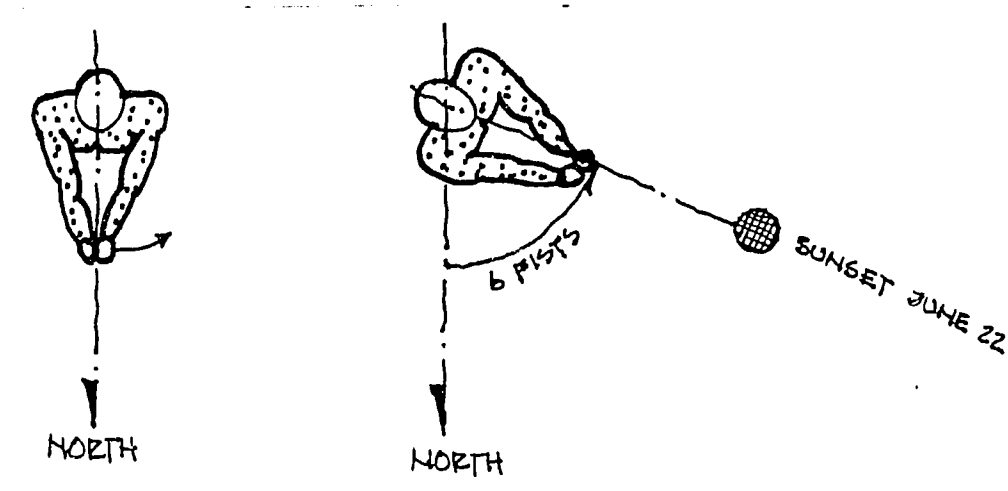
The annual solar extremes occur once in winter when the sun is at its lowest on or about June 21st, and once in summer when the sun is at its highest on or about December 21st. Because the sun's path will remain within these extremes for the balance of the year, plotting them on the site permits one to anticipate the level of solar exposure the building will endure annually.

Though typically determined with the help of a compass and sight level or protractor on a string, the following "fist" method, which relies on the geometry of the body, is accurate enough to preview the solar extrmes without technical devices. In Botswana, it is accurate enough primarily because obstacles to solar access are minimal. If the site presents substantial obstacles such as tall trees or multi-storey buildings close by, employ the more detailed approach to solar access analysis outlined on page 5-6.



SITING THE WINTER SOLSTICE SOLAR ALTITUDE

Start by determining true, i.e. solar north, using either a compass or the method sited on page 5-3. Once solar north has been located,



SITING THE WINTER SOLSTICE SUNSET

straddle the north axis with your weight comfortably distributed on both legs (See figure 1a). Now extend your arms in front of you without straining to stretch them. Stay comfortable and relaxed. Sight along your right arm to the horizon. If the horizon is not visible, line your arm up so that the inside top of your loosely clenched fist is level with your eye. Hold your head erect. You are now in the starting position.

The first extreme position to determine is the lowest noontime altitude reached by the sun on the winter solstice. Measure in degrees the altitude is 43. Measured in "fists", it is four plus some. Place your left fist atop the "horizon" fist followed by the right fist and so on until you have stacked up four fists. Sight along the top fist and locate the sun at noon on the winter solstice.

The fist method can also be used to locate the winter solstice sunrise and sunset positions. These are horizon positions so the motion will now be to the left and right and the fists staggered horizontally rather than vertically (See figure 2a and 2b).

The winter solstice sunrize azimuth (degrees of true north) is 63 degrees east. Count six fists to the east and locate the sunrise position. Because sunrise and sunset are symetrical about solar north, count six fists to the west to locate the setting position.

Combine the two azimuth locations with the altitude location and describe a low curve from northeast to northwest. This is the path of the sun at the winter solstice.

Using the fist method, describe a similar curve for the summer solstice azimuth and altitude extremes. The noon altitude is 89 degrees or 9 fists while the sunrise azimuths are 112 degrees or 11 fists.

These two curves describe both the lowest and the highest trajectories of the sun throughout the year. All other daily trajectories are bounded by these. If you wish to plot the trajectory at some other time of the year, determine from the solar chart on page 11.13 noon altitude and sunrise and set azimuths, translate the degrees into fists and go to it.

MORE DETAILED APPROACH TO SOLAR ACCESS ANALYSIS

If an initial site appraisal indicates that there may be signficant winter obstruction of the sun, a more detailed solar site survey and analysis is probably warranted. A simple technique which will aid such analysis is plotting the horizon on a chart similar to that presented on the next page. To plot the horizon on this chart, proceed as follows:

1. Stand as close as possible to the proposed location of the solar aperture.

2. Using either the "sundial " method described earlier, or a compass, determine true north.

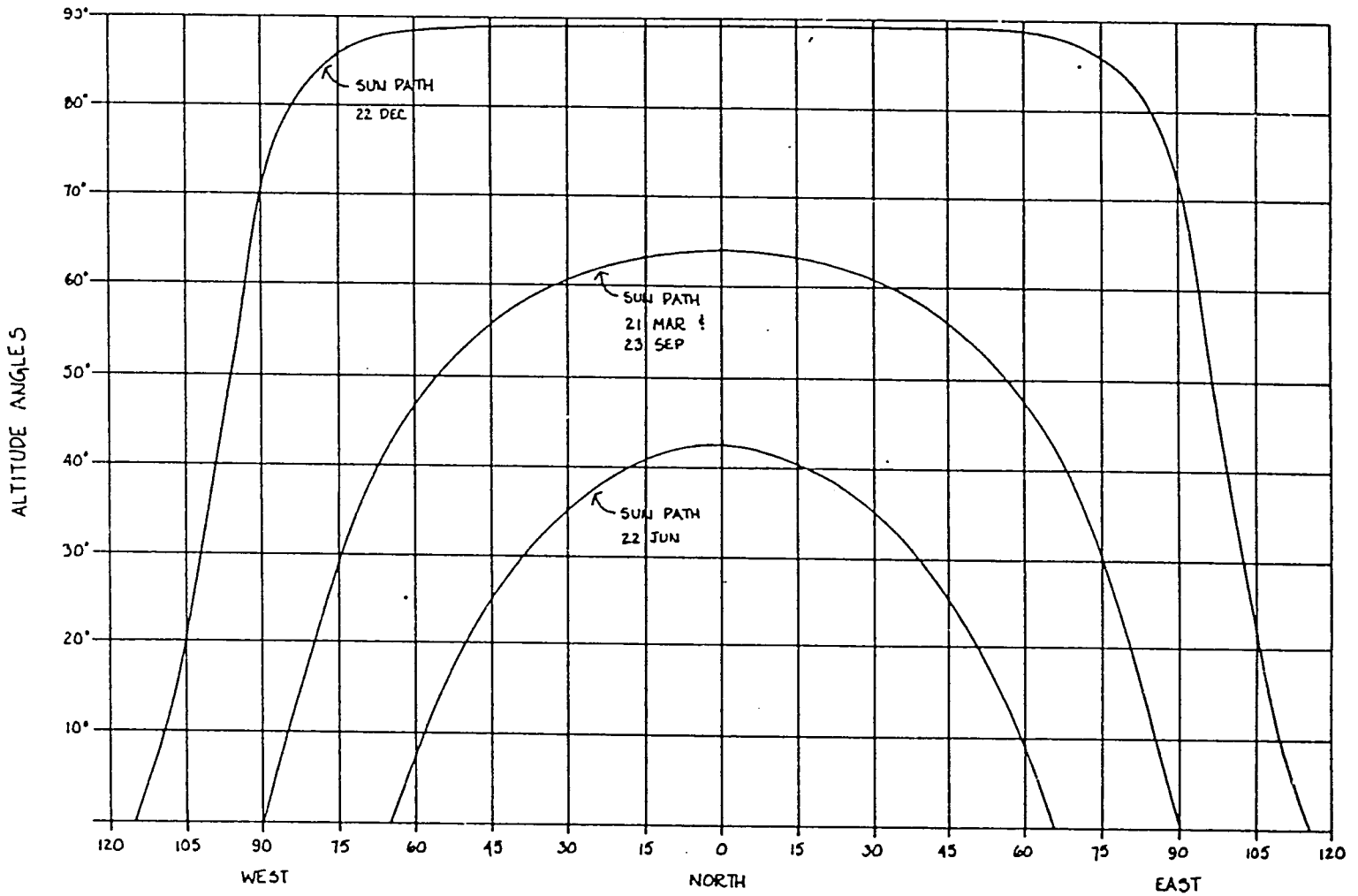
3. Depending on the degree of precision desired, use fists (previously described), a protractor, a transit or other angular measurment device to determine the elevation of the horizon at due north. When choosing where you will sight, use either the distant horizon or closer opaque objects, such as trees or buildings, whichever appears to be higher. Remember that if you are sighting only for solar heating when it is cold to account for trees which lose their leaves in winter. Note the elevation of the horizon as an altitude angle above horizontal (0°).

4. Take the altitude of the horizon at due north and note it on the horizon profile chart.

5. Face 30° west of south and take another horizon sighting. Note this on the chart and sketch in the horizon profile between 0° and 30° west. If necessary, take an additional sighting at 15° west.

6. Repeat this procedure up to 120° west and 120° east of north until you have a complete horizon profile plotted on the chart.

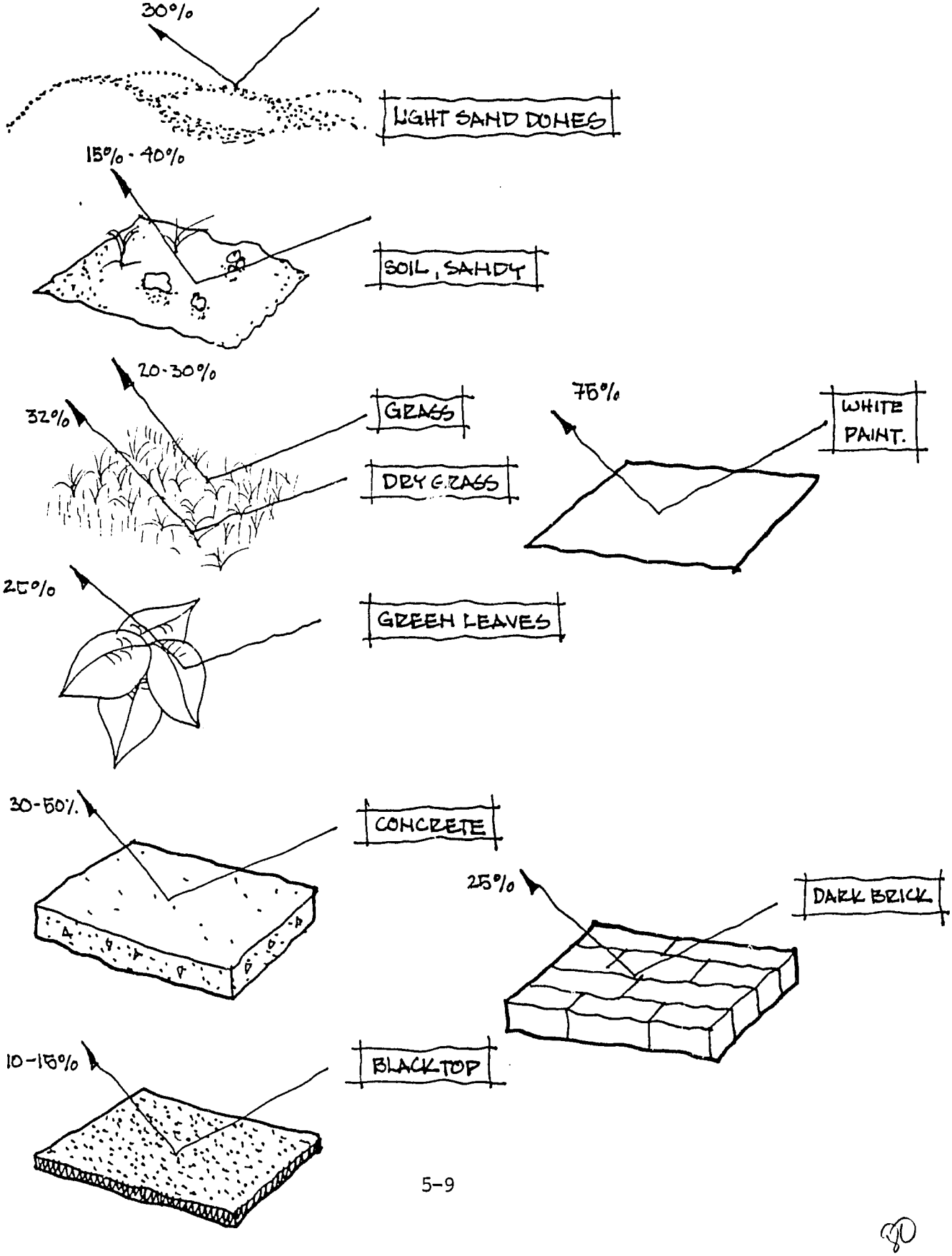
7. Examination of the sunpath lines on the chart with respect to the horizon profile can yield a preliminary analysis of shading for each season. A more detailed analysis can be performed by weighting each block in the chart grid by the relative seasonal magnitude of solar radiation received when the sun is in that position in the sky.



BLANK CHART FOR RECORDING HORIZON PROFILE AT 24° SOUTH LATITUDE

REFLECTIVE SURFACES

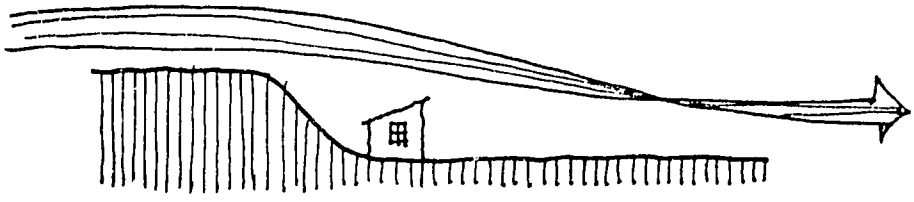
VIRTUALLY ALL SURFACES REFLECT RADIATION. EVALUATE THE SITE & NEIGHBORING SURFACES TO AVOID UNWANTED REFLECTED GAINS.



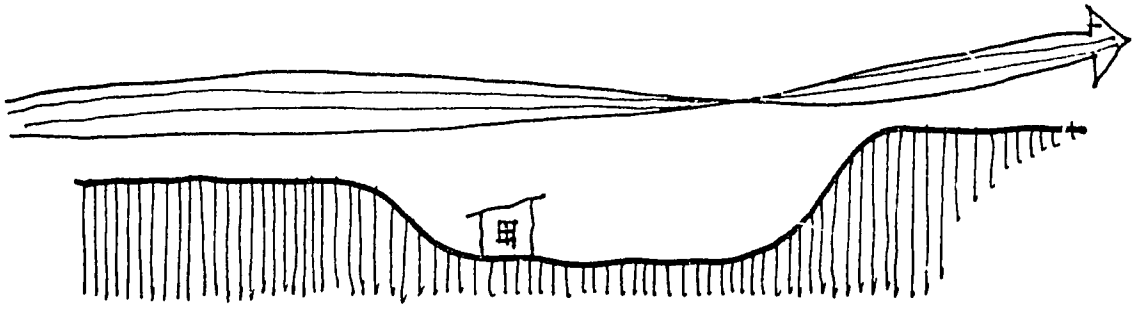
WIND

1. DETERMINE THE ORIENTATION OF PREVAILING WINDS
   a) PRIMARILY EAST THROUGHOUT MOST OF BOTSWANA.

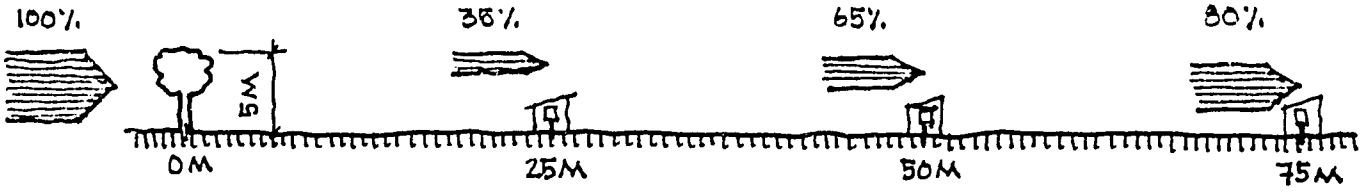
2. LOCATE SITE FEATURES WHICH INFLUENCE THE FLOW OF WIND.
   a) OBSTRUCTIONS



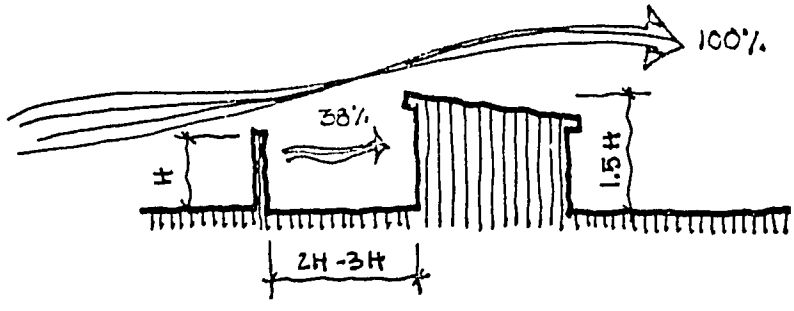
A RIDGE WILL FORCE AIR FLOW OVER THE BUILDING



A DEPRESSION WILL DROP THE BUILDING OUT OF THE AIR FLOW

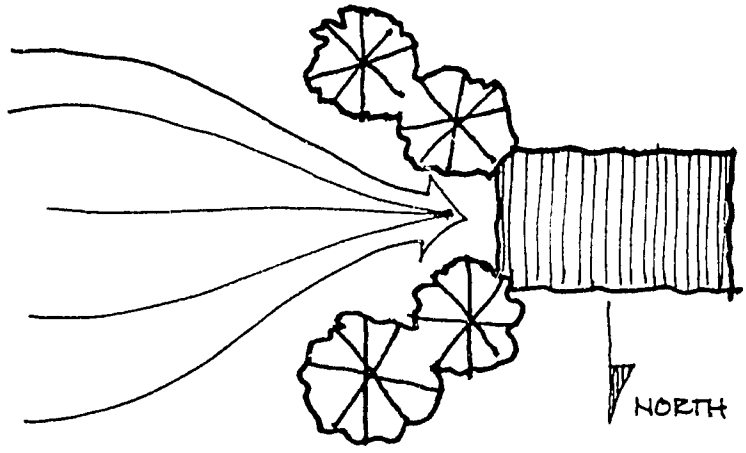


WINDBREAKS OF TREES REDUCE WIND VELOCITY OVER LONG DISTANCES

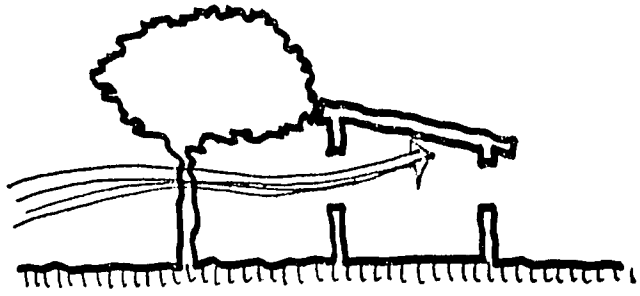


WALLS AND FENCES CUT SEVERELY THE VELOCITY OF AIR TO THE FACADE

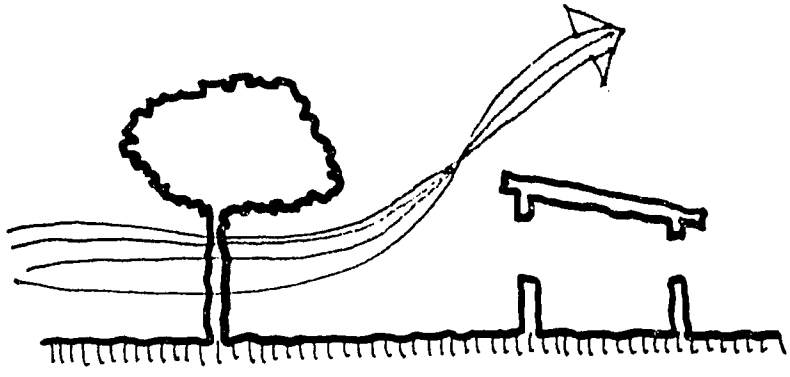
b) FUNNELS



TOPOGRAPHY, OTHER BUILDINGS AND VEGETATION CAN BE USED TO INCREASE THE VELOCITY OF THE WIND



A TREE CLOSE BY A HOUSE FORCES THE FLOW DOWN AND INTO THE BUILDING.



A TREE A DISTANCE OF 3 TO 6M. WILL "WARP" THE AIR FLOW UP AND THEREBY MISS THE HOUSE ALTOGETHER.

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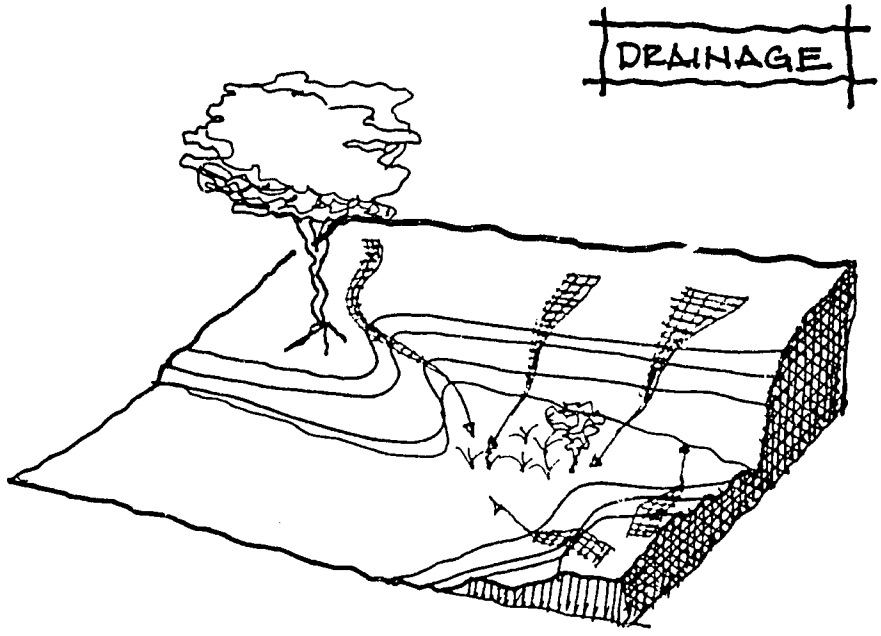
Table 2. Beaufort Scale of Wind Force
(Compiled by U.S. Weather Bureau, 1955)

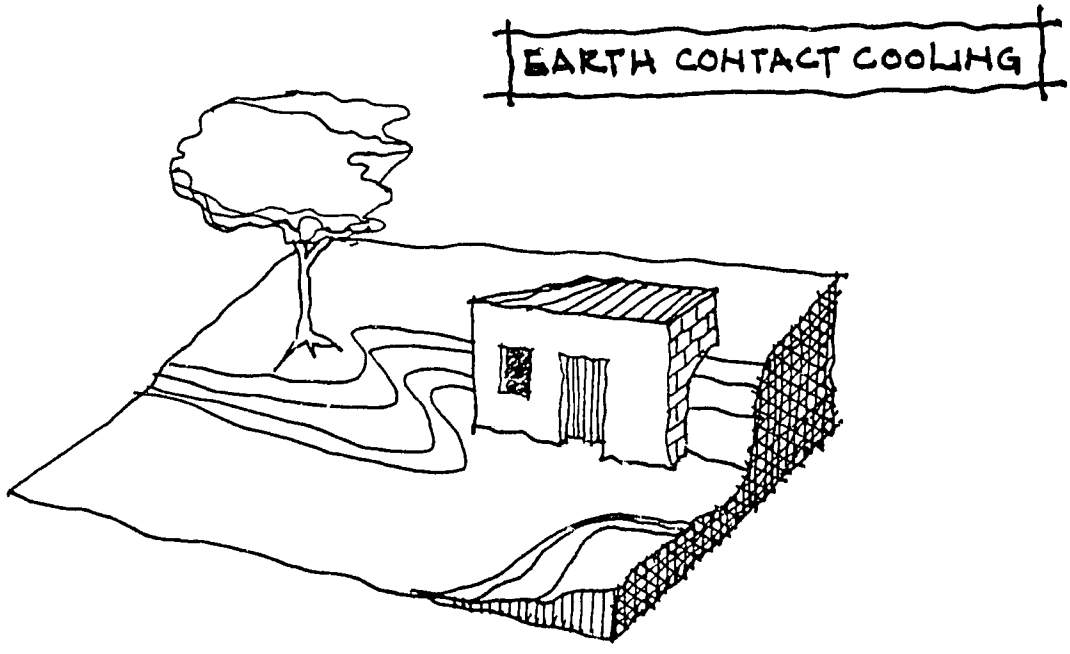
Beaufort number	Miles per hour	Knots	Wind effects observed on land	Terms used in USWB forecasts
0	Less than 1	Less than 1	Calm; smoke rises vertically	Light
1	1–3	1–3	Direction of wind shown by smoke drift; but not by wind vanes	
2	4–7	4–6	Wind felt on face; leaves rustle; ordinary vane moved by wind	
3	8–12	7–10	Leaves and small twigs in constant motion; wind extends light flag	Gentle
4	13–18	11–16	Raises dust, loose paper; small branches are moved	Moderate
5	19–24	17–21	Small trees in leaf begin to sway; crested wavelets form on inland waters	Fresh
6	25–31	22–27	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	Strong
7	32–38	28–33	Whole trees in motion; inconvenience felt walking against wind	
8	39–46	34–40	Breaks twigs off trees; generally impedes progress	Gale
9	47–54	41–47	Slight structural damage occurs; (chimney pots, slates removed)	
10	55–63	48–55	Seldom experienced inland; trees uprooted; considerable structural damage occurs	Whole gale
11	64–72	56–63	Very rarely experienced; accompanied by widespread damage	
12 or more	73 or more	64 or more	Very rarely experienced; accompanied by widespread damage	Hurricane

Source: Marks' Standard Handbook for Mechanical Engineers, Eight Edition, McGraw-Hill.

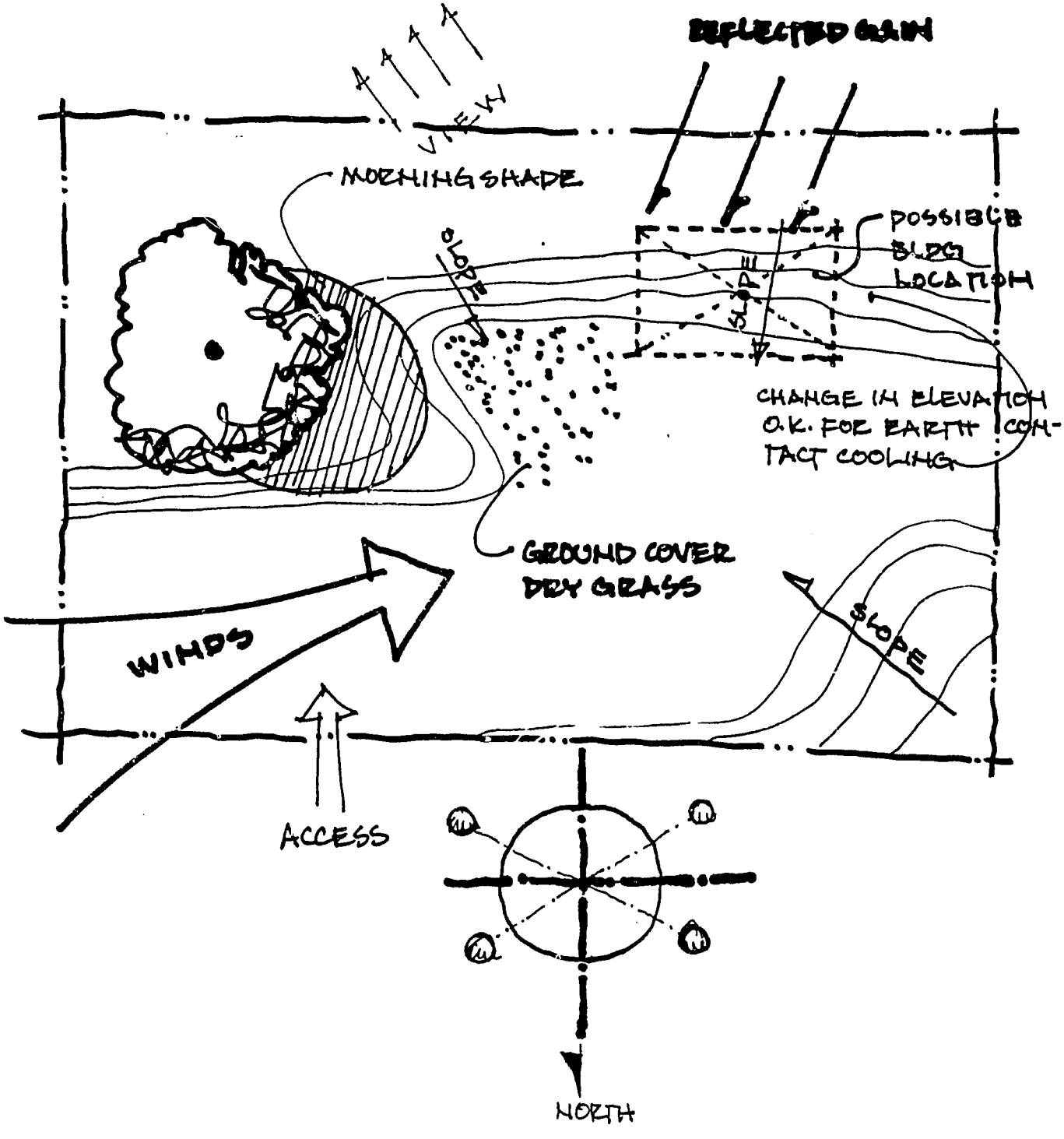
SLOPE



- THE SLOPE OF THE SITE DETERMINES HOW IT DRAINS. IF THE SLOPE OR SLOPES FORM A NATURAL CATCHMENT THIS WOULD BE A NATURAL LOCATION FOR SHADE TREES OR PLANTINGS AND THEREFORE A BUILDING WHICH COULD BENEFIT FROM THEM.



- THE SLOPE MAY PRESENT THE POTENTIAL TO PUT PART OF THE BUILDING UNDERGROUND WHERE IT WILL BE IN CONTACT WITH SOIL WHICH IS WARMER IN WINTER AND COOLER IN SUMMER THAN THE AIR TEMPERATURE.



SITE ANALYSIS: ENERGY RESOURCES

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6. BUILDING FORM AND ORIENTATION

BUILDING FORM AND ORIENTATION

While there are many other factors which must also be considered in determining building form and orientation, i.e., view, topography, function requirements, etc., this section will deal only with climatic considerations. These determinants can be organized according to the six elements of climate discussed in Section 3.

1. Solar Radiation. Both building form and orientation will affect how much solar radiation is received on different building surfaces at different times of the day and year. Absorbed solar radiation will then result in heat gain to the building, affecting thermal comfort and/or the heating and cooling loads on the building. The relative heat gains from different surfaces for a hypothetical "typical" residential building, along with the resultant heat balance for the building, are shown on the following pages.

2. Temperature Difference. Diurnal temperature difference helps to heat or cool a building largely through the controlled exchange of indoor and outdoor air. Thus, the primary concern here with respect to building form and orientation is to achieve optimum levels of controllable ventilation.

3. Wind. Wind is the major potential driving force in providing natural cooling of buildings in Botswana. Accordingly it should be a major determinant of building form and orientation. A whole section of design for natural ventilation follows later in this workbook.

4. Ground Temperature. To maximize the usefulness of ground temperatures, a building form should have as high a surface area in contact with the ground as possible.

5. Night Sky Radiation. To maximize the usefulness of night sky radiation, a building should have a horizontal or near horizontal roof with the largest surface area possible.

6. Rain. To make the best use of rainfall in water catchment designs, building form should maximize the roof area and provide it with a tilt to the collection system.

Tables of Solar Heat Gain Factors

After the illustrations of solar heat fluxes mentioned above, the remainder of this section presents tables of "Solar Heat Gain Factors" for various locations in and near Botswana. These are values for the solar heat gain through a single sheet of glass facing in each of the cardinal directions for each hour of the day, as calculated by van Deventer of NBRI ("Climatic and Other Design Data for Evaluating Heating and Cooling Requirements of Buildings," CSIR Research Report 300, Pretoria, 1971). Again, as for the design weather data in section 3, the data is presented by probability of occurance at the 0.05%, 2.5%, 5% and 10% levels. Using data from the 0.05% tables means that these values for solar heat gain will hardly ever be exceeded. Recognizing that it is not usually economical to design for the absolute worst case, most designers will use the 2.5% or 5% tables, accepting that sometimes there will be excessive heat gain for a short period of time.

ASSUMPTIONS FOR "TYPICAL HOUSE" USED IN ILLUSTRATIONS BELOW

Floor Area: 49 m^2

Dimensions: 4.9 m X 9.9 m

Ceiling Height: 2.5 m

Outside Ground Reflectance: 25%

Roof: Galvanized Steel with Ceiling Below

Walls: 230 mm hollow-core concrete block, absorb. = 50%

Floor: 100 mm concrete slab

Windows: one on each wall - 1.22 m^2 each

Internal Gains: 8 kWh/day

Windows opened for cooling when temperature in house rises above 25° in winter or 22° in summer.

Heat provided when temperature falls below 15° during day or 12° at night.

DISTRIBUTION OF SOLAR HEAT GAINS IN A TYPICAL HOUSE

	WINTER		SUMMER	
	MJ	%	MJ	%
ROOF	80	43%	119	58%
NORTH WALL	33	18%	6	3%
EAST WALL	9	5%	11	5%
WEST WALL	9	5%	11	5%
SOUTH WALL	6	3%	14	7%
NORTH WINDOW	20	11%	4	2%
EAST WINDOW	11	6%	15	7%
WEST WINDOW	13	7%	15	7%
SOUTH WINDOW	4	2%	8	4%
TOTAL	186	100%	205	100%

TYPICAL HOUSE ENERGY BALANCE

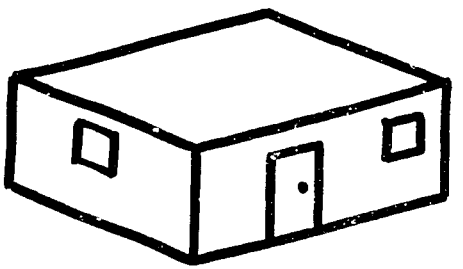
SUMMER

LOSSES

INFILTRATION • 22 MJ

CONDUCTION • 81 MJ

VENTILATION • 156 MJ



GAINS

CONDUCTION FROM OUTSIDE AIR • 25 MJ

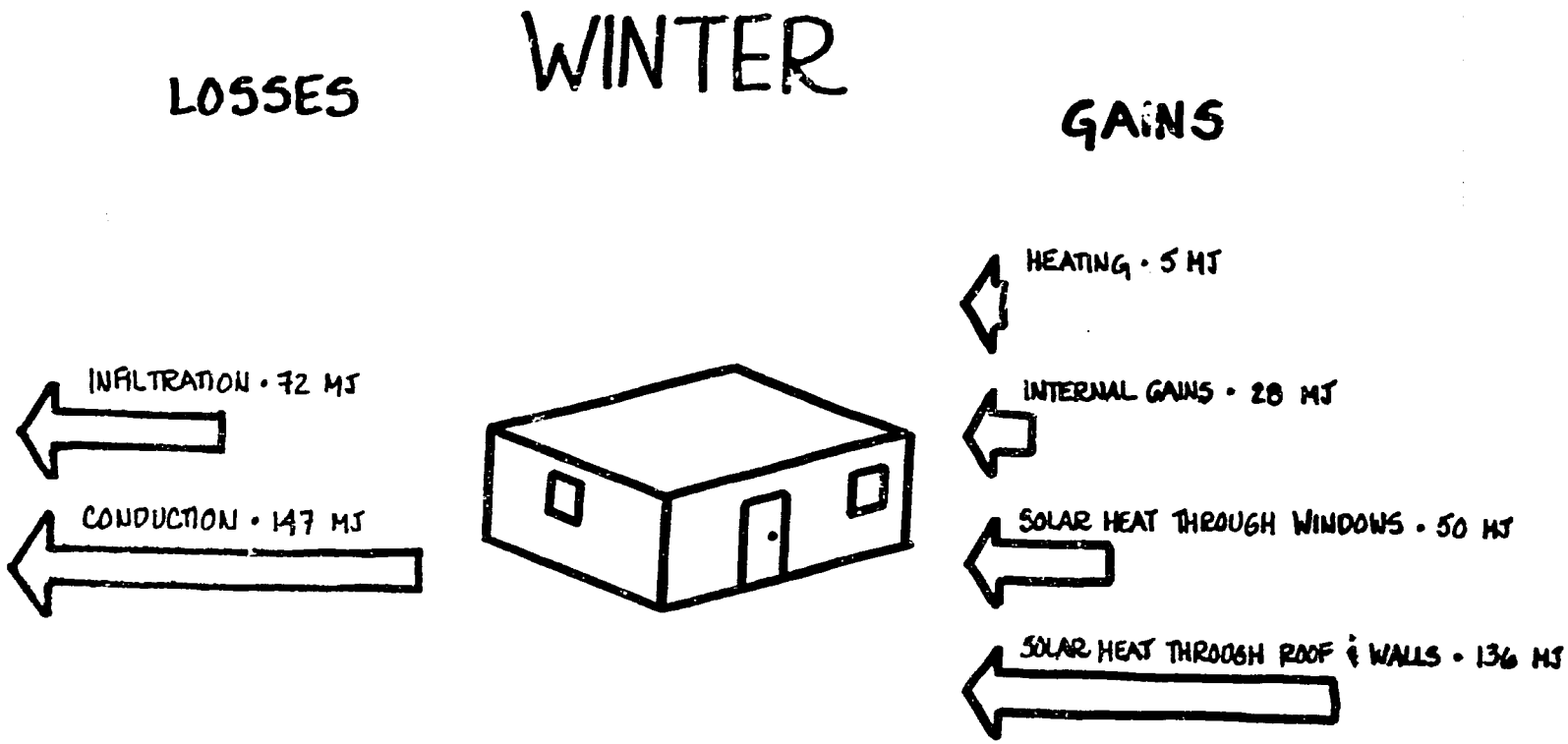
INTERNAL GAINS • 29 MJ

SOLAR GAIN THROUGH WINDOWS • 45 MJ

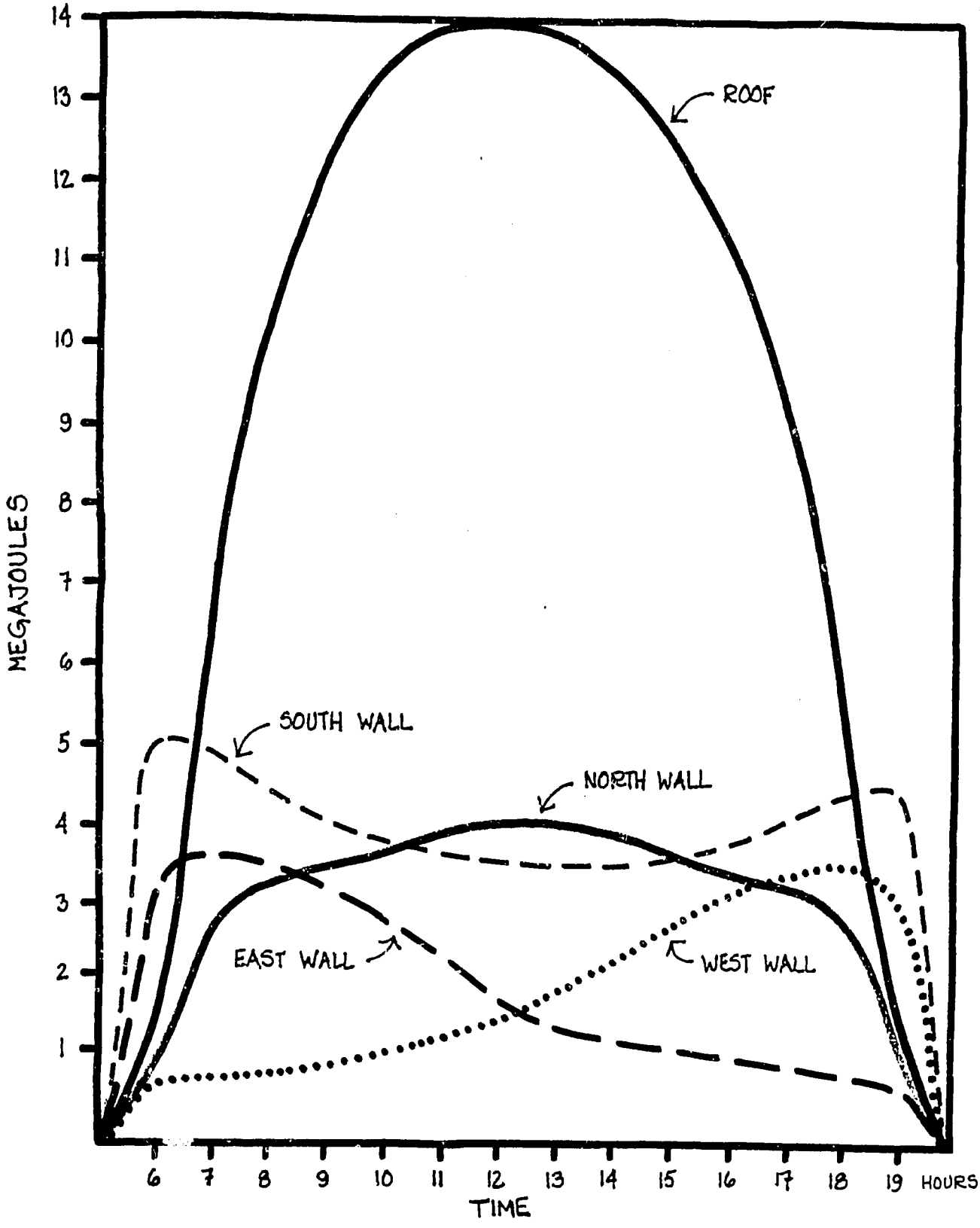
SOLAR GAIN THROUGH ROOF & WALLS • 160 MJ

TYPICAL HOUSE ENERGY BALANCE

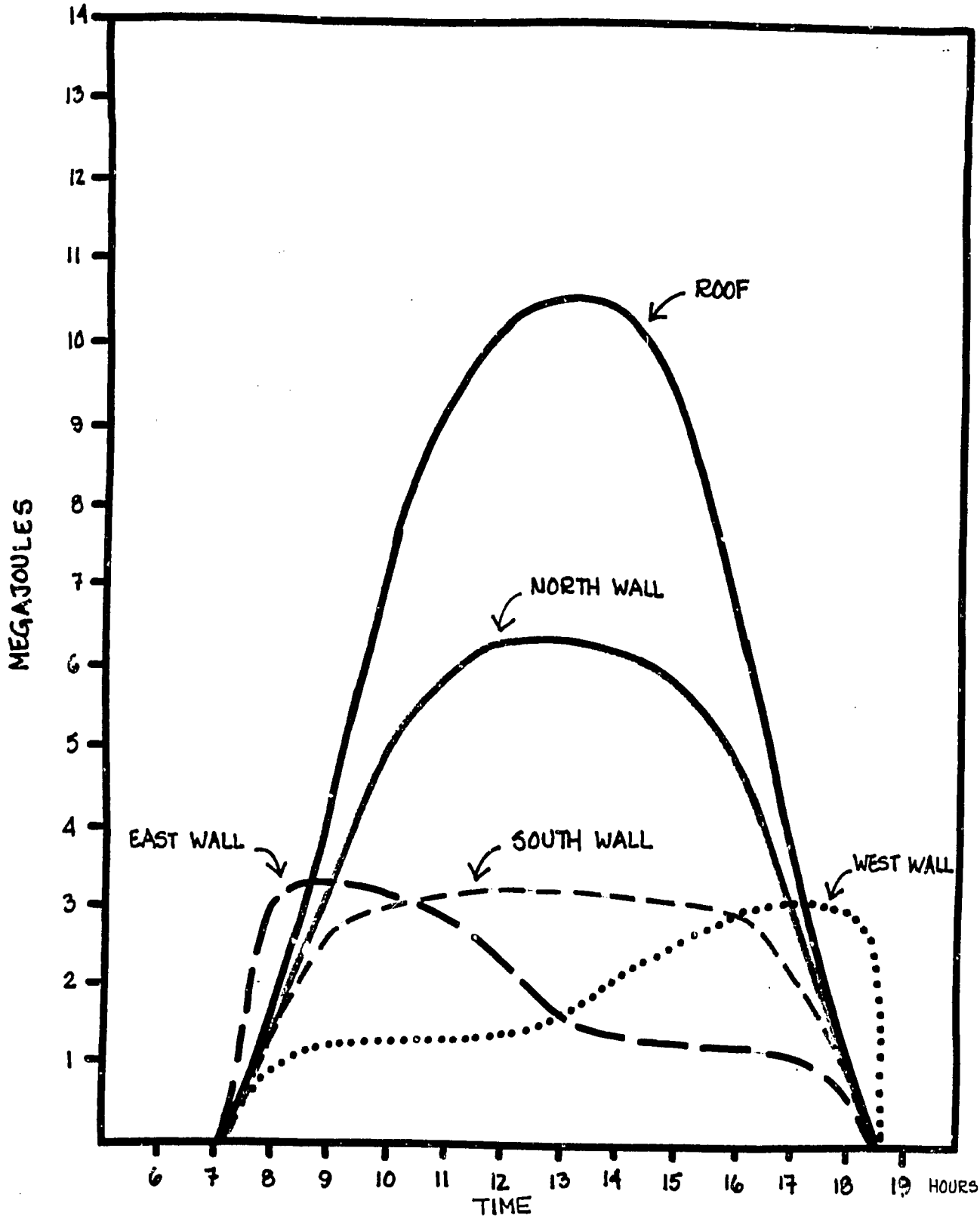
WINTER



TYPICAL HOUSE SOLAR GAIN ON A SUMMER DAY



TYPICAL HOUSE SOLAR GAIN ON A WINTER DAY



SOLAR HEAT GAIN FACTORS

Solar heat gain factors for ordinary clear glass by direct transmission and retradiation from the glass for the winter design days

10 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maun	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0.271	0.502	0.640	0.675	0.604	0.428	0.184	0.035	0.033	0.034	0.034	0.035	0.034	0.034	0.033	0.063
	9	0.386	0.605	0.718	0.719	0.603	0.381	0.130	0.053	0.053	0.054	0.055	0.055	0.054	0.053	0.053	0.131
	10	0.506	0.681	0.744	0.688	0.518	0.268	0.079	0.072	0.073	0.074	0.075	0.074	0.073	0.072	0.079	0.255
	11	0.581	0.696	0.699	0.588	0.379	0.146	0.080	0.078	0.079	0.080	0.080	0.079	0.078	0.079	0.140	0.370
	12	0.669	0.737	0.689	0.528	0.291	0.107	0.104	0.105	0.106	0.107	0.106	0.105	0.101	0.110	0.250	0.492
	13	0.659	0.482	0.242	0.110	0.106	0.107	0.108	0.108	0.108	0.107	0.106	0.108	0.296	0.529	0.685	0.729
	14	0.605	0.383	0.144	0.095	0.094	0.096	0.096	0.096	0.095	0.094	0.096	0.165	0.410	0.624	0.735	0.728
	15	0.501	0.260	0.084	0.079	0.080	0.081	0.081	0.081	0.080	0.079	0.084	0.258	0.501	0.667	0.723	0.666
	16	0.390	0.138	0.053	0.053	0.054	0.055	0.055	0.054	0.053	0.052	0.116	0.358	0.578	0.697	0.703	0.599
	17	0.211	0.057	0.027	0.028	0.028	0.029	0.029	0.028	0.027	0.029	0.141	0.349	0.502	0.568	0.545	0.434
	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	1.816	4.541	4.040	3.562	2.757	1.698	0.945	0.710	0.708	0.710	0.893	1.586	2.631	3.433	3.946	4.169

5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maun	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0.293	0.515	0.644	0.670	0.591	0.408	0.164	0.035	0.034	0.035	0.035	0.035	0.035	0.034	0.033	0.069
	9	0.427	0.650	0.761	0.753	0.623	0.384	0.126	0.059	0.060	0.061	0.062	0.062	0.061	0.060	0.061	0.155
	10	0.575	0.767	0.832	0.766	0.572	0.291	0.092	0.084	0.087	0.088	0.088	0.088	0.087	0.084	0.093	0.299
	11	0.664	0.788	0.788	0.661	0.423	0.162	0.093	0.091	0.093	0.093	0.093	0.093	0.091	0.093	0.162	0.425
	12	0.699	0.773	0.724	0.554	0.304	0.106	0.100	0.102	0.103	0.104	0.104	0.103	0.101	0.108	0.255	0.511
	13	0.728	0.531	0.270	0.113	0.104	0.106	0.108	0.108	0.108	0.106	0.104	0.111	0.310	0.570	0.748	0.801
	14	0.695	0.446	0.171	0.099	0.098	0.099	0.100	0.100	0.099	0.098	0.099	0.173	0.447	0.696	0.830	0.829
	15	0.600	0.314	0.091	0.081	0.083	0.084	0.084	0.084	0.083	0.081	0.087	0.286	0.577	0.782	0.855	0.793
	16	0.451	0.171	0.064	0.063	0.064	0.065	0.065	0.065	0.063	0.062	0.122	0.378	0.625	0.763	0.778	0.672
	17	0.312	0.083	0.033	0.034	0.035	0.035	0.035	0.035	0.034	0.035	0.157	0.410	0.603	0.689	0.667	0.538
	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	5.441	5.041	4.379	3.793	2.897	1.742	0.968	0.763	0.763	0.763	0.954	1.739	2.937	3.879	4.482	5.090

SOLAR HEAT GAIN FACTORS - MAUN (WINTER)

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Solar heat gain factors for ordinary clear glass by direct transmission and retradiation from the glass for the winter design days

2.5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maun	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0.307	0.560	0.713	0.750	0.670	0.473	0.202	0.040	0.036	0.037	0.038	0.038	0.038	0.037	0.035	0.076
	9	0.441	0.652	0.749	0.730	0.592	0.349	0.107	0.049	0.050	0.051	0.051	0.051	0.051	0.050	0.051	0.170
	10	0.585	0.767	0.822	0.746	0.545	0.262	0.079	0.074	0.075	0.076	0.076	0.076	0.075	0.073	0.084	0.310
	11	0.568	0.688	0.697	0.593	0.391	0.148	0.085	0.083	0.084	0.085	0.085	0.084	0.083	0.081	0.141	0.355
	12	0.624	0.696	0.656	0.508	0.284	0.096	0.088	0.090	0.091	0.091	0.091	0.090	0.089	0.094	0.217	0.419
	13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	14	0.523	0.347	0.145	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.146	0.346	0.524	0.617	0.616
	15	0.490	0.263	0.083	0.080	0.080	0.081	0.081	0.081	0.080	0.080	0.082	0.231	0.464	0.625	0.684	0.638
	16	0.471	0.146	0.068	0.067	0.068	0.069	0.069	0.068	0.068	0.067	0.111	0.320	0.517	0.626	0.636	0.550
	17	0.200	0.063	0.041	0.041	0.042	0.042	0.042	0.042	0.041	0.042	0.105	0.254	0.366	0.416	0.404	0.331
	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	4.108	4.182	3.975	3.625	2.780	1.629	0.861	0.635	0.634	0.637	0.748	1.291	2.028	2.528	2.869	3.496

0.05 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maun	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0.219	0.369	0.452	0.465	0.403	0.271	0.102	0.029	0.028	0.029	0.029	0.030	0.029	0.028	0.027	0.064
	9	0.450	0.661	0.763	0.744	0.603	0.356	0.111	0.053	0.055	0.056	0.056	0.056	0.056	0.054	0.056	0.175
	10	0.538	0.705	0.755	0.686	0.503	0.245	0.081	0.075	0.077	0.078	0.078	0.078	0.077	0.075	0.084	0.288
	11	0.652	0.772	0.768	0.640	0.405	0.156	0.091	0.090	0.091	0.092	0.092	0.091	0.090	0.092	0.160	0.424
	12	0.685	0.749	0.694	0.523	0.279	0.103	0.097	0.098	0.100	0.100	0.100	0.099	0.097	0.105	0.264	0.509
	13	0.696	0.517	0.268	0.106	0.098	0.100	0.101	0.101	0.101	0.100	0.098	0.105	0.283	0.531	0.705	0.761
	14	0.651	0.424	0.162	0.095	0.093	0.095	0.096	0.096	0.095	0.093	0.095	0.158	0.406	0.639	0.767	0.771
	15	0.538	0.288	0.084	0.075	0.077	0.078	0.078	0.078	0.077	0.075	0.081	0.245	0.503	0.686	0.755	0.705
	16	0.328	0.137	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.095	0.264	0.431	0.524	0.537	0.472
	17	0.266	0.076	0.029	0.030	0.031	0.032	0.032	0.031	0.030	0.031	0.122	0.330	0.491	0.566	0.551	0.449
	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	5.024	4.700	4.040	3.428	2.556	1.501	0.854	0.716	0.718	0.719	0.847	1.455	2.461	3.300	3.905	4.617

SOLAR HEAT GAIN FACTORS - MAUN (WINTER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the summer design days

50 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maun	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.034	0.055	0.180	0.299	0.366	0.376	0.330	0.228	0.695	0.035	0.035	0.035	0.036	0.035	0.035	0.035
	8	0.077	0.139	0.338	0.510	0.598	0.596	0.502	0.324	0.128	0.078	0.077	0.078	0.079	0.079	0.078	0.078
	9	0.109	0.219	0.414	0.560	0.618	0.579	0.449	0.256	0.116	0.095	0.095	0.096	0.096	0.096	0.095	0.095
	10	0.141	0.272	0.446	0.562	0.590	0.524	0.377	0.201	0.118	0.108	0.108	0.108	0.108	0.108	0.107	0.108
	11	0.151	0.319	0.492	0.599	0.614	0.531	0.371	0.208	0.132	0.135	0.136	0.136	0.136	0.136	0.135	0.136
	12	0.131	0.305	0.428	0.493	0.482	0.399	0.268	0.164	0.135	0.133	0.133	0.134	0.134	0.133	0.133	0.137
	13	0.202	0.148	0.141	0.140	0.141	0.141	0.141	0.140	0.142	0.163	0.266	0.397	0.484	0.498	0.437	0.316
	14	0.171	0.150	0.150	0.150	0.151	0.151	0.150	0.150	0.142	0.224	0.373	0.502	0.559	0.530	0.423	0.265
	15	0.139	0.125	0.125	0.125	0.126	0.125	0.125	0.125	0.133	0.241	0.401	0.521	0.559	0.512	0.387	0.219
	16	0.115	0.112	0.112	0.112	0.112	0.112	0.112	0.112	0.119	0.265	0.418	0.510	0.526	0.465	0.333	0.168
	17	0.078	0.075	0.075	0.076	0.076	0.075	0.075	0.075	0.109	0.263	0.408	0.487	0.493	0.426	0.290	0.130
	18	0.032	0.032	0.032	0.033	0.033	0.032	0.032	0.032	0.075	0.182	0.268	0.310	0.305	0.253	0.159	0.055
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	1,471	1,952	2,933	3,660	3,906	3,642	2,931	2,015	1,443	1,922	2,722	3,315	3,515	3,272	2,614	1,743

5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maun	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.027	0.049	0.129	0.199	0.235	0.236	0.201	0.133	0.052	0.027	0.027	0.027	0.028	0.028	0.027	0.027
	8	0.061	0.133	0.292	0.415	0.470	0.455	0.369	0.222	0.078	0.060	0.060	0.060	0.061	0.061	0.060	0.060
	9	0.078	0.160	0.323	0.419	0.504	0.482	0.383	0.227	0.099	0.080	0.080	0.081	0.081	0.081	0.081	0.080
	10	0.117	0.188	0.352	0.477	0.528	0.499	0.392	0.235	0.124	0.111	0.111	0.112	0.112	0.112	0.111	0.111
	11	0.135	0.209	0.378	0.504	0.551	0.519	0.405	0.244	0.132	0.139	0.139	0.140	0.140	0.140	0.139	0.139
	12	0.139	0.217	0.325	0.394	0.407	0.358	0.258	0.147	0.134	0.130	0.130	0.131	0.131	0.131	0.130	0.132
	13	0.153	0.137	0.139	0.140	0.140	0.140	0.140	0.139	0.141	0.152	0.255	0.357	0.411	0.404	0.340	0.233
	14	0.111	0.110	0.139	0.140	0.140	0.140	0.140	0.139	0.123	0.182	0.287	0.374	0.410	0.388	0.311	0.197
	15	0.098	0.102	0.102	0.102	0.102	0.102	0.102	0.102	0.099	0.157	0.252	0.317	0.337	0.309	0.238	0.139
	16	0.081	0.083	0.083	0.083	0.083	0.083	0.083	0.083	0.094	0.197	0.301	0.359	0.365	0.317	0.223	0.108
	17	0.079	0.076	0.077	0.077	0.078	0.077	0.077	0.077	0.115	0.258	0.389	0.459	0.460	0.394	0.264	0.120
	18	0.029	0.029	0.029	0.030	0.030	0.029	0.029	0.030	0.074	0.160	0.221	0.247	0.236	0.189	0.110	0.032
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	1,111	1,522	2,308	3,009	3,271	2,120	2,579	1,779	1,265	1,653	2,253	2,664	2,771	2,552	2,033	1,379

SOLAR HEAT GAIN FACTORS - MAUN (SUMMER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the summer design days

2.5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maun	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.034	0.043	0.113	0.175	0.207	0.210	0.184	0.128	0.055	0.034	0.034	0.034	0.034	0.034	0.034	0.034
	8	0.048	0.088	0.228	0.350	0.414	0.414	0.350	0.226	0.087	0.048	0.048	0.049	0.049	0.049	0.048	0.048
	9	0.104	0.157	0.294	0.396	0.438	0.416	0.337	0.207	0.091	0.103	0.103	0.103	0.104	0.103	0.103	0.102
	10	0.113	0.204	0.368	0.487	0.531	0.494	0.380	0.217	0.127	0.114	0.114	0.115	0.115	0.115	0.114	0.113
	11	0.121	0.235	0.401	0.515	0.548	0.492	0.361	0.197	0.112	0.111	0.111	0.112	0.112	0.111	0.111	0.112
	12	0.132	0.218	0.316	0.372	0.372	0.315	0.213	0.118	0.107	0.104	0.105	0.106	0.106	0.105	0.105	0.108
	13	0.151	0.152	0.149	0.150	0.150	0.150	0.150	0.149	0.153	0.171	0.272	0.373	0.422	0.410	0.340	0.230
	14	0.118	0.127	0.127	0.127	0.127	0.127	0.127	0.127	0.124	0.154	0.260	0.342	0.377	0.359	0.285	0.184
	15	0.101	0.107	0.107	0.107	0.107	0.107	0.107	0.107	0.103	0.141	0.210	0.253	0.263	0.241	0.187	0.114
	16	0.095	0.097	0.098	0.098	0.098	0.098	0.098	0.097	0.087	0.183	0.287	0.351	0.366	0.330	0.246	0.132
	17	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.097	0.210	0.303	0.349	0.348	0.301	0.208	0.100
	18	0.036	0.037	0.037	0.037	0.037	0.037	0.036	0.037	0.063	0.196	0.284	0.324	0.317	0.262	0.162	0.051
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	1.112	1.548	2.321	2.897	3.114	2.945	2.425	1.692	1.225	1.568	2.131	2.511	2.613	2.420	1.946	1.328

0.05 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Maun	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.032	0.085	0.299	0.504	0.618	0.634	0.549	0.367	0.135	0.034	0.033	0.034	0.035	0.035	0.035	0.034
	8	0.060	0.142	0.417	0.646	0.764	0.760	0.633	0.397	0.128	0.060	0.060	0.061	0.062	0.062	0.061	0.060
	9	0.088	0.200	0.471	0.686	0.786	0.759	0.607	0.357	0.136	0.084	0.086	0.087	0.087	0.087	0.086	0.085
	10	0.112	0.241	0.484	0.667	0.741	0.694	0.532	0.297	0.113	0.105	0.107	0.108	0.108	0.108	0.107	0.105
	11	0.124	0.267	0.482	0.635	0.686	0.623	0.461	0.241	0.126	0.118	0.120	0.120	0.121	0.120	0.119	0.118
	12	0.116	0.302	0.472	0.580	0.596	0.514	0.352	0.193	0.130	0.125	0.126	0.127	0.127	0.126	0.125	0.129
	13	0.131	0.152	0.147	0.148	0.149	0.149	0.148	0.146	0.155	0.215	0.377	0.545	0.631	0.614	0.502	0.325
	14	0.151	0.141	0.144	0.146	0.146	0.146	0.144	0.142	0.156	0.262	0.487	0.654	0.718	0.666	0.509	0.288
	15	0.115	0.107	0.109	0.110	0.110	0.110	0.108	0.106	0.114	0.281	0.498	0.649	0.692	0.624	0.454	0.228
	16	0.091	0.087	0.089	0.090	0.090	0.089	0.088	0.086	0.137	0.352	0.596	0.744	0.770	0.673	0.463	0.198
	17	0.063	0.062	0.064	0.065	0.065	0.064	0.062	0.0062	0.126	0.383	0.610	0.732	0.736	0.622	0.402	0.139
	18	0.044	0.047	0.049	0.049	0.049	0.048	0.046	0.048	0.141	0.369	0.549	0.634	0.618	0.505	0.303	0.094
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0*
	Daily total	1.129	1.833	3.226	4.327	4.801	4.589	3.731	2.443	1.597	2.387	3.648	4.494	4.705	4.242	3.167	1.804

SOLAR HEAT GAIN FACTORS - MAUN (SUMMER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the winter design days

10 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Pretoria	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,295	0,407	0,503	0,519	0,453	0,307	0,116	0,024	0,022	0,023	0,024	0,024	0,023	0,023	0,022	0,063
	9	0,396	0,573	0,651	0,631	0,508	0,295	0,091	0,047	0,049	0,050	0,050	0,050	0,049	0,048	0,050	0,161
	10	0,530	0,686	0,730	0,660	0,480	0,229	0,076	0,072	0,073	0,074	0,074	0,074	0,073	0,071	0,076	0,285
	11	0,590	0,692	0,686	0,571	0,363	0,151	0,094	0,094	0,095	0,096	0,096	0,095	0,094	0,095	0,165	0,393
	12	0,673	0,726	0,664	0,493	0,253	0,104	0,097	0,098	0,099	0,099	0,099	0,098	0,096	0,099	0,279	0,513
	13	0,691	0,530	0,290	0,098	0,094	0,096	0,097	0,097	0,097	0,096	0,094	0,099	0,247	0,594	0,673	0,740
	14	0,622	0,416	0,171	0,090	0,088	0,089	0,090	0,090	0,089	0,088	0,088	0,146	0,367	0,590	0,715	0,726
	15	0,528	0,291	0,075	0,071	0,072	0,073	0,073	0,073	0,072	0,071	0,074	0,221	0,470	0,649	0,719	0,678
	16	0,361	0,1[illegible]	0,053	0,052	0,053	0,053	0,053	0,053	0,052	0,051	0,056	0,287	0,481	0,590	0,604	0,528
	17	0,180	0,051	0,025	0,026	0,027	0,027	0,027	0,026	0,026	0,026	0,056	0,239	0,346	0,[illegible]	0,381	0,308
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	4,808	4,518	3,848	3,211	2,390	1,424	0,815	0,674	0,675	0,675	0,790	1,333	2,246	3,052	3,454	4,400

5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Pretoria	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,307	0,524	0,645	0,662	0,576	0,386	0,140	0,026	0,025	0,026	0,027	0,027	0,027	0,026	0,025	0,081
	9	0,435	0,632	0,719	0,697	0,562	0,327	0,101	0,052	0,053	0,054	0,055	0,055	0,054	0,053	0,054	0,177
	10	0,580	0,746	0,790	0,712	0,513	0,238	0,076	0,073	0,074	0,074	0,075	0,074	0,073	0,072	0,079	0,318
	11	0,607	0,705	0,691	0,567	0,350	0,136	0,086	0,087	0,088	0,088	0,088	0,087	0,086	0,088	0,168	0,409
	12	0,703	0,742	0,665	0,480	0,231	0,109	0,105	0,106	0,107	0,107	0,107	0,106	0,104	0,102	0,318	0,554
	13	0,70[illegible]	0,553	0,315	0,102	0,102	0,103	0,104	0,105	0,104	0,104	0,102	0,107	0,233	0,485	0,669	0,745
	14	0,654	0,155	0,193	0,085	0,081	0,083	0,084	0,085	0,084	0,082	0,080	0,130	0,346	0,585	0,728	0,753
	15	0,597	0,331	0,078	0,069	0,071	0,073	0,073	0,073	0,072	0,070	0,074	0,226	0,505	0,712	0,799	0,760
	16	0,426	0,172	0,053	0,052	0,053	0,054	0,054	0,053	0,052	0,051	0,101	0,325	0,555	0,687	0,708	0,621
	17	0,250	0,069	0,026	0,027	0,027	0,028	0,028	0,027	0,027	0,027	0,116	0,313	0,404	0,531	0,519	0,434
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	5,269	4,930	4,175	3,453	2,566	1,537	0,851	0,687	0,656	0,685	0,825	1,449	2,447	3,342	4,008	4,842

SOLAR HEAT GAIN FACTORS - PRETORIA (WINTER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the winter design days

2.5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Pretoria	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,311	0,575	0,703	0,720	0,623	0,414	0,146	0,028	0,027	0,028	0,028	0,029	0,028	0,027	0,026	0,091
	9	0,373	0,515	0,622	0,607	0,494	0,296	0,096	0,055	0,056	0,057	0,057	0,057	0,057	0,056	0,057	0,150
	10	0,588	0,761	0,809	0,731	0,529	0,249	0,075	0,072	0,073	0,073	0,074	0,073	0,072	0,071	0,079	0,318
	11	0,677	0,785	0,767	0,624	0,378	0,136	0,077	0,077	0,079	0,079	0,079	0,078	0,077	0,079	0,180	0,455
	12	0,687	0,730	0,659	0,479	0,233	0,094	0,092	0,093	0,093	0,093	0,093	0,092	0,092	0,096	0,296	0,533
	13	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	14	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	15	0,404	0,194	0,065	0,065	0,065	0,065	0,065	0,065	0,065	0,065	0,069	0,244	0,447	0,577	0,613	0,554
	16	0,278	0,089	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,107	0,305	0,464	0,542	0,535	0,446
	17	0,425	0,113	0,031	0,032	0,033	0,034	0,031	0,033	0,032	0,033	0,171	0,501	0,760	0,883	0,865	0,711
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	3,773	3,792	3,700	3,300	2,397	1,331	0,629	0,467	0,469	0,472	0,679	1,379	1,997	2,331	2,652	3,258

0,05 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Pretoria	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,386	0,647	0,786	0,802	0,691	0,454	0,154	0,027	0,026	0,027	0,028	0,028	0,027	0,027	0,025	0,102
	9	0,473	0,680	0,768	0,739	0,588	0,332	0,094	0,044	0,046	0,047	0,047	0,047	0,046	0,045	0,047	0,195
	10	0,628	0,797	0,836	0,744	0,524	0,228	0,069	0,066	0,067	0,068	0,068	0,068	0,067	0,065	0,076	0,352
	11	0,716	0,820	0,793	0,676	0,373	0,135	0,080	0,081	0,083	0,083	0,083	0,082	0,081	0,084	0,206	0,492
	12	0,695	0,732	0,653	0,465	0,218	0,097	0,091	0,093	0,094	0,095	0,094	0,092	0,090	0,094	0,312	0,546
	13	0,597	0,476	0,281	0,094	0,106	0,106	0,106	0,106	0,106	0,106	0,106	0,106	0,200	0,409	0,563	0,627
	14	0,630	0,434	0,186	0,085	0,081	0,083	0,084	0,081	0,084	0,082	0,080	0,127	0,332	0,560	0,697	0,721
	15	0,530	0,301	0,070	0,066	0,068	0,069	0,070	0,070	0,068	0,066	0,071	0,198	0,443	0,627	0,705	0,673
	16	0,383	0,163	0,051	0,048	0,049	0,051	0,051	0,050	0,049	0,047	0,085	0,271	0,474	0,596	0,619	0,548
	17	0,153	0,049	0,022	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,068	0,177	0,261	0,299	0,294	0,245
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	5,191	5,099	4,453	3,706	2,726	1,584	0,827	0,651	0,652	0,650	0,729	1,196	2,921	2,806	3,545	4,500

SOLAR HEAT GAIN FACTORS - PRETORIA (WINTER)

Solar heat gain factors for ordinary clear glass by direct transmission and reradiation from the glass for the summer design days

10 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Pretoria	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,036	0,050	0,232	0,363	0,430	0,433	0,365	0,239	0,087	0,036	0,036	0,037	0,037	0,037	0,037	0,036
	8	0,076	0,176	0,382	0,538	0,607	0,584	0,469	0,277	0,097	0,073	0,073	0,074	0,074	0,074	0,073	0,073
	9	0,114	0,256	0,476	0,629	0,682	0,629	0,476	0,257	0,112	0,102	0,103	0,103	0,104	0,103	0,103	0,102
	10	0,144	0,313	0,523	0,659	0,690	0,611	0,434	0,221	0,120	0,116	0,117	0,118	0,118	0,118	0,117	0,117
	11	0,159	0,366	0,537	0,631	0,626	0,522	0,344	0,178	0,143	0,140	0,141	0,142	0,142	0,141	0,140	0,142
	12	0,229	0,384	0,529	0,591	0,560	0,441	0,271	0,156	0,144	0,142	0,143	0,143	0,143	0,142	0,143	0,151
	13	0,235	0,154	0,148	0,147	0,148	0,149	0,148	0,147	0,148	0,153	0,256	0,427	0,551	0,579	0,535	0,404
	14	0,178	0,145	0,145	0,145	0,146	0,146	0,145	0,145	0,147	0,177	0,340	0,501	0,594	0,592	0,499	0,336
	15	0,151	0,132	0,132	0,133	0,133	0,133	0,133	0,132	0,132	0,198	0,390	0,530	0,624	0,603	0,489	0,306
	16	0,111	0,109	0,110	0,111	0,111	0,111	0,110	0,110	0,113	0,245	0,440	0,573	0,616	0,567	0,430	0,232
	17	0,076	0,075	0,075	0,076	0,076	0,075	0,075	0,075	0,092	0,256	0,420	0,512	0,526	0,462	0,324	0,144
	18	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,070	0,185	0,263	0,333	0,334	0,253	0,188	0,071
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	1,517	2,237	3,428	4,063	4,249	3,873	3,014	1,975	1,405	1,826	2,744	3,514	3,861	3,714	3,077	2,114

5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Pretoria	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,060	0,084	0,234	0,359	0,422	0,422	0,358	0,232	0,084	0,04	0,040	0,041	0,041	0,041	0,040	0,040
	8	0,075	0,169	0,390	0,564	0,644	0,627	0,500	0,308	0,107	0,071	0,072	0,072	0,073	0,072	0,072	0,071
	9	0,104	0,218	0,448	0,620	0,692	0,656	0,514	0,294	0,115	0,097	0,098	0,099	0,099	0,099	0,098	0,098
	10	0,150	0,309	0,512	0,642	0,671	0,594	0,425	0,220	0,124	0,123	0,124	0,124	0,125	0,124	0,123	0,123
	11	0,172	0,344	0,521	0,626	0,631	0,535	0,361	0,180	0,135	0,131	0,133	0,133	0,133	0,133	0,132	0,134
	12	0,211	0,377	0,514	0,579	0,553	0,440	0,271	0,160	0,145	0,143	0,144	0,145	0,144	0,144	0,144	0,150
	13	0,234	0,157	0,150	0,149	0,150	0,150	0,150	0,149	0,150	0,159	0,257	0,423	0,542	0,574	0,524	0,395
	14	0,165	0,145	0,143	0,144	0,144	0,144	0,144	0,143	0,146	0,176	0,346	0,501	0,586	0,579	0,482	0,319
	15	0,134	0,130	0,130	0,130	0,131	0,130	0,130	0,130	0,130	0,197	0,372	0,508	0,567	0,540	0,432	0,264
	16	0,110	0,109	0,109	0,109	0,109	0,109	0,109	0,109	0,109	0,224	0,401	0,521	0,561	0,515	0,396	0,219
	17	0,065	0,064	0,064	0,065	0,065	0,064	0,064	0,064	0,080	0,220	0,353	0,428	0,438	0,384	0,268	0,117
	18	0,037	0,036	0,037	0,037	0,037	0,037	0,037	0,036	0,064	0,172	0,266	0,315	0,317	0,272	0,181	0,070
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	1,495	2,140	3,251	4,024	4,250	3,913	3,072	2,024	1,389	1,754	2,605	3,311	3,625	3,485	2,893	2,000

SOLAR HEAT GAIN FACTORS - PRETORIA (SUMMER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the summer design days

2,5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Pretoria	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,037	0,067	0,240	0,402	0,492	0,566	0,441	0,309	0,116	0,036	0,037	0,038	0,038	0,038	0,038	0,037
	8	0,076	0,137	0,347	0,523	0,611	0,606	0,508	0,325	0,120	0,076	0,076	0,077	0,077	0,077	0,076	0,076
	9	0,112	0,220	0,430	0,583	0,644	0,607	0,476	0,274	0,114	0,110	0,111	0,112	0,112	0,112	0,111	0,110
	10	0,153	0,290	0,484	0,613	0,647	0,581	0,426	0,231	0,134	0,135	0,136	0,136	0,137	0,136	0,136	0,136
	11	0,169	0,324	0,496	0,600	0,611	0,527	0,368	0,190	0,152	0,149	0,150	0,150	0,150	0,150	0,149	0,150
	12	0,223	0,386	0,519	0,580	0,551	0,438	0,274	0,168	0,158	0,156	0,157	0,158	0,157	0,157	0,157	0,167
	13	0,214	0,166	0,157	0,157	0,156	0,158	0,156	0,157	0,159	0,170	0,265	0,420	0,523	0,547	0,489	0,363
	14	0,159	0,157	0,152	0,153	0,153	0,154	0,153	0,152	0,154	0,173	0,332	0,491	0,556	0,591	0,505	0,348
	15	0,137	0,130	0,132	0,132	0,133	0,133	0,132	0,131	0,131	0,193	0,360	0,493	0,551	0,527	0,424	0,263
	16	0,107	0,108	0,109	0,109	0,109	0,109	0,109	0,108	0,108	0,213	0,372	0,477	0,511	0,470	0,359	0,198
	17	0,076	0,074	0,073	0,074	0,074	0,074	0,073	0,073	0,088	0,226	0,365	0,444	0,456	0,402	0,284	0,130
	18	0,039	0,038	0,039	0,039	0,039	0,039	0,038	0,038	0,064	0,165	0,249	0,291	0,291	0,249	0,164	0,064
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	1,532	2,097	3,178	3,963	4,221	3,931	3,156	2,149	1,500	1,805	2,909	3,257	3,589	3,455	2,891	2,042

0,05 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Pretoria	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,036	0,079	0,280	0,492	0,617	0,642	0,567	0,392	0,159	0,035	0,036	0,037	0,038	0,038	0,038	0,037
	8	0,063	0,133	0,407	0,642	0,766	0,767	0,645	0,411	0,135	0,064	0,065	0,064	0,065	0,065	0,064	0,063
	9	0,091	0,203	0,472	0,685	0,783	0,764	0,602	0,353	0,084	0,086	0,088	0,089	0,089	0,089	0,088	0,087
	10	0,114	0,258	0,497	0,673	0,738	0,682	0,514	0,277	0,112	0,106	0,108	0,109	0,109	0,109	0,108	0,106
	11	0,125	0,298	0,510	0,652	0,689	0,611	0,437	0,213	0,126	0,120	0,121	0,122	0,122	0,121	0,120	0,121
	12	0,190	0,338	0,504	0,600	0,590	0,501	0,328	0,184	0,130	0,126	0,127	0,128	0,128	0,127	0,126	0,131
	13	0,198	0,140	0,134	0,135	0,136	0,136	0,135	0,134	0,139	0,192	0,335	0,510	0,610	0,610	0,513	0,346
	14	0,144	0,168	0,168	0,168	0,168	0,168	0,168	0,168	0,168	0,201	0,368	0,492	0,547	0,521	0,420	0,266
	15	0,167	0,167	0,167	0,167	0,167	0,167	0,167	0,167	0,158	0,264	0,446	0,571	0,611	0,564	0,434	0,249
	16	0,115	0,115	0,115	0,115	0,115	0,115	0,115	0,115	0,079	0,250	0,396	0,452	0,495	0,413	0,321	0,158
	17	0,090	0,090	0,090	0,090	0,090	0,099	0,090	0,090	0,121	0,321	0,483	0,566	0,564	0,481	0,318	0,120
	18	0,058	0,058	0,058	0,058	0,058	0,058	0,058	0,058	0,152	0,349	0,492	0,552	0,532	0,432	0,255	0,086
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	1,391	2,048	3,432	4,477	4,926	4,692	3,626	2,563	1,565	2,118	3,063	3,722	3,914	3,601	2,806	1,770

SOLAR HEAT GAIN FACTORS - PRETORIA (SUMMER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the winter design days

10 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Upirgton	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,152	0,270	0,340	0,355	0,315	0,219	0,091	0,022	0,020	0,021	0,022	0,022	0,022	0,021	0,020	0,039
	9	0,369	0,545	0,625	0,610	0,494	0,292	0,081	0,042	0,043	0,044	0,045	0,045	0,044	0,043	0,044	0,146
	10	0,526	0,682	0,726	0,657	0,475	0,223	0,066	0,062	0,063	0,064	0,064	0,064	0,063	0,061	0,075	0,284
	11	0,639	0,739	0,721	0,585	0,351	0,119	0,073	0,074	0,075	0,076	0,076	0,075	0,074	0,076	0,175	0,432
	12	0,693	0,741	0,671	0,487	0,237	0,086	0,082	0,083	0,084	0,084	0,084	0,083	0,081	0,091	0,290	0,532
	13	0,702	0,546	0,303	0,085	0,079	0,081	0,082	0,082	0,082	0,081	0,080	0,084	0,224	0,477	0,667	0,714
	14	0,644	0,412	0,183	0,074	0,072	0,073	0,074	0,074	0,073	0,072	0,071	0,105	0,338	0,575	0,715	0,739
	15	0,533	0,297	0,079	0,058	0,060	0,061	0,061	0,061	0,060	0,059	0,062	0,201	0,452	0,638	0,715	0,680
	16	0,373	0,150	0,043	0,041	0,043	0,043	0,044	0,043	0,042	0,041	0,072	0,279	0,482	0,599	0,619	0,543
	17	0,175	0,039	0,019	0,020	0,021	0,021	0,021	0,021	0,020	0,021	0,084	0,211	0,306	0,349	0,336	0,269
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	4,788	4,452	3,712	2,974	2,147	1,219	0,676	0,564	0,563	0,564	0,661	1,168	2,086	2,930	3,655	4,407

5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Upington	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,212	0,359	0,440	0,453	0,396	0,269	0,102	0,025	0,024	0,025	0,025	0,025	0,025	0,024	0,024	0,057
	9	0,373	0,546	0,623	0,606	0,491	0,239	0,081	0,044	0,045	0,046	0,046	0,046	0,045	0,045	0,046	0,148
	10	0,426	0,559	0,600	0,550	0,409	0,204	0,063	0,062	0,063	0,063	0,063	0,063	0,063	0,062	0,065	0,225
	11	0,627	0,724	0,706	0,572	0,342	0,115	0,072	0,073	0,074	0,074	0,074	0,074	0,072	0,075	0,172	0,424
	12	0,678	0,719	0,646	0,463	0,218	0,082	0,078	0,079	0,080	0,080	0,080	0,079	0,077	0,083	0,293	0,527
	13	0,684	0,531	0,294	0,085	0,079	0,081	0,082	0,082	0,082	0,081	0,080	0,082	0,222	0,469	0,652	0,726
	14	0,605	0,407	0,163	0,075	0,073	0,074	0,075	0,075	0,074	0,073	0,072	0,125	0,338	0,558	0,685	0,701
	15	0,471	0,252	0,067	0,063	0,064	0,064	0,064	0,064	0,064	0,063	0,064	0,212	0,438	0,597	0,655	0,613
	16	0,335	0,130	0,046	0,044	0,045	0,046	0,046	0,046	0,045	0,044	0,085	0,280	0,463	0,565	0,576	0,499
	17	0,202	0,056	0,021	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,101	0,266	0,387	0,441	0,427	0,346
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	4,613	4,282	3,609	2,936	2,142	1,248	0,687	0,575	0,575	0,574	0,694	1,251	2,131	2,918	3,595	4,266

SOLAR HEAT GAIN FACTORS - UPINGTON (WINTER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the winter design days

2.5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Upington	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0.147	0.262	0.330	0.345	0.308	0.218	0.094	0.024	0.023	0.024	0.024	0.024	0.024	0.023	0.023	0.036
	9	0.685	0.978	1.100	1.054	0.833	0.463	0.079	0.058	0.060	0.061	0.061	0.061	0.060	0.059	0.061	0.287
	10	0.530	0.678	0.715	0.640	0.456	0.206	0.063	0.059	0.061	0.062	0.062	0.061	0.060	0.059	0.069	0.293
	11	0.517	0.614	0.614	0.516	0.332	0.126	0.075	0.075	0.076	0.076	0.076	0.075	0.075	0.076	0.127	0.334
	12	0.770	0.812	0.725	0.515	0.236	0.089	0.085	0.086	0.087	0.087	0.087	0.085	0.084	0.089	0.338	0.602
	13	0.665	0.518	0.289	0.084	0.076	0.077	0.078	0.079	0.078	0.077	0.076	0.080	0.210	0.450	0.630	0.704
	14	0.597	0.406	0.166	0.071	0.069	0.070	0.071	0.071	0.070	0.069	0.068	0.117	0.321	0.539	0.668	0.687
	15	0.500	0.271	0.069	0.058	0.060	0.061	0.061	0.061	0.060	0.059	0.063	0.208	0.446	0.619	0.687	0.647
	16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	17	0.205	0.058	0.022	0.023	0.023	0.024	0.024	0.023	0.023	0.023	0.090	0.247	0.369	0.425	0.416	0.342
	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	4.615	4.598	4.029	3.306	2.393	1.333	0.629	0.536	0.537	0.537	0.606	0.960	1.649	2.339	3.018	3.931

0.05 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Upington	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0.141	0.233	0.284	0.289	0.249	0.165	0.059	0.017	0.017	0.018	0.018	0.018	0.018	0.017	0.016	0.041
	9	0.376	0.536	0.604	0.580	0.460	0.258	0.046	0.038	0.040	0.041	0.041	0.041	0.040	0.039	0.041	0.159
	10	0.539	0.678	0.707	0.626	0.437	0.186	0.059	0.057	0.058	0.059	0.059	0.059	0.057	0.056	0.061	0.308
	11	0.651	0.738	0.708	0.561	0.321	0.072	0.068	0.070	0.071	0.071	0.071	0.070	0.069	0.072	0.197	0.455
	12	0.712	0.742	0.653	0.452	0.195	0.078	0.075	0.077	0.077	0.078	0.077	0.076	0.074	0.076	0.329	0.567
	13	0.712	0.567	0.329	0.076	0.074	0.076	0.077	0.078	0.077	0.077	0.075	0.078	0.195	0.452	0.653	0.742
	14	0.651	0.455	0.197	0.072	0.069	0.070	0.071	0.071	0.071	0.070	0.068	0.072	0.321	0.561	0.708	0.738
	15	0.539	0.308	0.061	0.056	0.057	0.059	0.059	0.059	0.058	0.057	0.059	0.186	0.437	0.626	0.707	0.678
	16	0.376	0.159	0.041	0.039	0.040	0.041	0.041	0.041	0.040	0.038	0.046	0.258	0.460	0.580	0.604	0.536
	17	0.141	0.041	0.016	0.017	0.018	0.018	0.018	0.018	0.017	0.017	0.059	0.165	0.249	0.289	0.284	0.233
	18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	4.837	4.458	3.601	2.769	1.921	1.024	0.575	0.525	0.526	0.525	0.575	1.024	1.921	2.769	3.601	4.458

SOLAR HEAT GAIN FACTORS - UPINGTON (WINTER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the summer design days

10 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Upington	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.038	0.071	0.259	0.423	0.550	0.569	0.499	0.311	0.137	0.041	0.039	0.040	0.041	0.041	0.041	0.040
	8	0.067	0.152	0.409	0.621	0.728	0.720	0.594	0.367	0.120	0.065	0.066	0.067	0.068	0.068	0.067	0.065
	9	0.095	0.247	0.506	0.696	0.771	0.722	0.553	0.301	0.091	0.087	0.088	0.090	0.090	0.090	0.089	0.087
	10	0.137	0.336	0.565	0.710	0.739	0.648	0.450	0.215	0.110	0.105	0.107	0.108	0.108	0.107	0.106	0.106
	11	0.184	0.397	0.587	0.688	0.676	0.552	0.349	0.157	0.121	0.118	0.120	0.120	0.120	0.119	0.118	0.122
	12	0.239	0.422	0.568	0.625	0.586	0.449	0.257	0.127	0.127	0.126	0.127	0.127	0.127	0.126	0.126	0.134
	13	0.225	0.145	0.126	0.127	0.127	0.128	0.127	0.126	0.128	0.125	0.269	0.459	0.590	0.625	0.555	0.405
	14	0.165	0.123	0.119	0.120	0.121	0.121	0.120	0.119	0.123	0.169	0.375	0.571	0.682	0.651	0.568	0.371
	15	0.129	0.106	0.107	0.108	0.108	0.108	0.107	0.106	0.111	0.222	0.462	0.655	0.741	0.706	0.555	0.324
	16	0.095	0.087	0.089	0.090	0.090	0.090	0.088	0.087	0.090	0.299	0.552	0.721	0.771	0.697	0.507	0.249
	17	066	0.064	0.066	0.067	0.067	0.066	0.065	0.064	0.112	0.353	0.582	0.712	0.726	0.625	0.418	0.163
	18	0.038	0.039	0.040	0.041	0.041	0.040	0.039	0.040	0.130	0.330	0.485	0.557	0.540	0.438	0.259	0.073
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	1.481	2.179	3.440	4.339	4.605	4.212	3.249	2.050	1.399	2.040	3.271	4.226	4.604	4.323	3.411	2.141

5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Upington	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.040	0.072	0.248	0.420	0.518	0.535	0.469	0.322	0.129	0.042	0.040	0.041	0.042	0.042	0.042	0.041
	8	0.067	0.153	0.404	0.609	0.710	0.699	0.576	0.354	0.114	0.066	0.066	0.067	0.068	0.068	0.067	0.066
	9	0.093	0.228	0.489	0.687	0.771	0.730	0.570	0.321	0.092	0.087	0.089	0.090	0.091	0.091	0.090	0.088
	10	0.135	0.331	0.562	0.710	0.743	0.654	0.458	0.223	0.110	0.106	0.107	0.108	0.108	0.108	0.107	0.107
	11	0.149	0.346	0.547	0.669	0.682	0.582	0.394	0.186	0.123	0.119	0.120	0.121	0.121	0.120	0.119	0.122
	12	0.216	0.394	0.548	0.621	0.593	0.469	0.260	0.125	0.128	0.127	0.127	0.128	0.128	0.127	0.126	0.131
	13	0.229	0.134	0.127	0.127	0.128	0.128	0.128	0.127	0.128	0.127	0.269	0.460	0.592	0.625	0.561	0.411
	14	0.162	0.122	0.120	0.121	0.121	0.121	0.121	0.119	0.125	0.176	0.382	0.575	0.653	0.675	0.562	0.373
	15	0.132	0.106	0.107	0.108	0.108	0.108	0.107	0.106	0.110	0.216	0.457	0.653	0.742	0.709	0.560	0.330
	16	0.092	0.087	0.088	0.089	0.090	0.089	0.088	0.086	0.091	0.302	0.551	0.716	0.764	0.688	0.498	0.241
	17	0.067	0.066	0.067	0.068	0.068	0.067	0.066	0.066	0.121	0.360	0.583	0.706	0.715	0.641	.404	0.152
	18	0.041	0.041	0.042	0.042	0.042	0.042	0.041	0.042	0.127	0.319	0.467	0.534	0.519	0.423	0.252	0.071
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	1.422	2.084	3.347	4.272	4.574	4.225	3.295	2.076	1.397	2.046	3.256	4.200	4.572	4.293	3.386	2.123

SOLAR HEAT GAIN FACTORS - UPINGTON (SUMMER)

Solar heat gain factors for ordinary clear glass by direct transmission and reradiation from the glass for the summer design days

2.5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW m^{-2}															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Upington	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.042	0.065	0.243	0.415	0.514	0.532	0.469	0.326	0.134	0.043	0.043	0.043	0.044	0.044	0.043	0.043
	8	0.067	0.144	0.390	0.595	0.699	0.693	0.575	0.360	0.120	0.066	0.066	0.067	0.068	0.068	0.067	0.066
	9	0.093	0.223	0.482	0.678	0.763	0.724	0.566	0.320	0.089	0.087	0.089	0.090	0.090	0.090	0.089	0.087
	10	0.115	0.283	0.516	0.681	0.733	0.665	0.488	0.250	0.112	0.106	0.107	0.108	0.108	0.108	0.107	0.106
	11	0.140	0.315	0.546	0.669	0.683	0.583	0.395	0.186	0.124	0.119	0.120	0.121	0.121	0.121	0.119	0.122
	12	0.198	0.365	0.526	0.611	0.597	0.485	0.303	0.121	0.129	0.126	0.127	0.128	0.128	0.127	0.126	0.132
	13	0.211	0.131	0.126	0.127	0.128	0.128	0.127	0.126	0.129	0.123	0.288	0.474	0.594	0.617	0.540	0.383
	14	0.150	0.123	0.120	0.121	0.121	0.121	0.121	0.120	0.123	0.175	0.387	0.579	0.685	0.677	0.558	0.358
	15	0.128	0.107	0.107	0.109	0.109	0.109	0.108	0.107	0.112	0.232	0.472	0.663	0.746	0.706	0.551	0.318
	16	0.092	0.088	0.089	0.090	0.090	0.090	0.089	0.087	0.090	0.313	0.560	0.721	0.763	0.682	0.488	0.231
	17	0.067	0.066	0.067	0.068	0.068	0.067	0.066	0.066	0.116	0.350	0.566	0.686	0.695	0.595	0.394	0.149
	18	0.041	0.041	0.042	0.042	0.042	0.042	0.041	0.041	0.119	0.295	0.428	0.488	0.474	0.386	0.231	0.067
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	1,345	1,981	3,255	4,206	4,546	4,239	3,349	2,110	1,398	2,036	3,253	4,168	4,515	4,221	3,311	2,062

0.05 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW m^{-2}															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Upington	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	7	0.039	0.076	0.254	0.447	0.561	0.566	0.518	0.361	0.152	0.043	0.040	0.042	0.043	0.043	0.042	0.041
	8	0.067	0.132	0.393	0.615	0.732	0.732	0.614	0.391	0.131	0.067	0.067	0.068	0.069	0.069	0.068	0.067
	9	0.094	0.213	0.477	0.682	0.773	0.740	0.586	0.338	0.091	0.088	0.090	0.091	0.092	0.092	0.091	0.089
	10	0.113	0.280	0.519	0.689	0.746	0.681	0.503	0.261	0.115	0.107	0.109	0.110	0.110	0.110	0.109	0.107
	11	0.118	0.326	0.534	0.668	0.693	0.603	0.420	0.198	0.126	0.121	0.122	0.123	0.123	0.122	0.121	0.123
	12	0.200	0.367	0.530	0.617	0.604	0.492	0.309	0.122	0.131	0.128	0.129	0.129	0.129	0.128	0.127	0.133
	13	0.200	0.133	0.127	0.128	0.129	0.129	0.129	0.128	0.131	0.122	0.309	0.492	0.604	0.617	0.530	0.367
	14	0.118	0.123	0.121	0.122	0.123	0.123	0.122	0.121	0.126	0.198	0.426	0.603	0.693	0.668	0.534	0.326
	15	0.113	0.107	0.109	0.110	0.110	0.110	0.109	0.107	0.115	0.261	0.503	0.681	0.746	0.689	0.519	0.280
	16	0.094	0.089	0.091	0.092	0.092	0.091	0.090	0.088	0.091	0.338	0.586	0.740	0.773	0.682	0.477	0.213
	17	0.067	0.067	0.068	0.069	0.069	0.068	0.067	0.067	0.131	0.391	0.614	0.732	0.732	0.615	0.393	0.132
	18	0.039	0.041	0.042	0.043	0.043	0.042	0.040	0.043	0.152	0.361	0.518	0.586	0.561	0.447	0.254	0.076
	19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Daily total	1,263	1,954	3,266	4,283	4,676	4,397	3,507	2,226	1,491	2,226	3,507	4,397	4,676	4,283	3,266	1,954

SOLAR HEAT GAIN FACTORS - UPINGTON (SUMMER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the winter design days

10 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Windhoek	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,001	0,010	0,021	0,029	0,031	0,029	0,022	0,011	0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001
	8	0,309	0,559	0,708	0,743	0,661	0,462	0,192	0,034	0,031	0,032	0,032	0,032	0,032	0,031	0,030	0,075
	9	0,462	0,698	0,812	0,800	0,659	0,401	0,131	0,057	0,058	0,059	0,059	0,059	0,059	0,057	0,058	0,173
	10	0,570	0,773	0,848	0,788	0,596	0,310	0,092	0,076	0,077	0,078	0,078	0,078	0,077	0,076	0,083	0,283
	11	0,649	0,777	0,781	0,660	0,430	0,177	0,100	0,098	0,100	0,100	0,100	0,100	0,098	0,099	0,157	0,415
	12	0,681	0,754	0,708	0,546	0,304	0,118	0,105	0,106	0,106	0,107	0,107	0,106	0,105	0,108	0,255	0,498
	13	0,704	0,517	0,265	0,103	0,098	0,099	0,100	0,100	0,100	0,099	0,099	0,111	0,301	0,553	0,725	0,776
	14	0,650	0,417	0,159	0,095	0,094	0,095	0,096	0,096	0,095	0,094	0,095	0,172	0,423	0,655	0,778	0,776
	15	0,572	0,293	0,083	0,074	0,076	0,077	0,077	0,076	0,075	0,074	0,086	0,287	0,569	0,763	0,829	0,764
	16	0,437	0,161	0,054	0,053	0,054	0,055	0,055	0,054	0,053	0,053	0,117	0,375	0,618	0,732	0,765	0,659
	17	0,315	0,073	0,027	0,028	0,028	0,029	0,028	0,028	0,027	0,028	0,173	0,441	0,640	0,727	0,698	0,558
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	5,350	5,033	4,467	3,919	3,031	1,853	0,998	0,737	0,724	0,725	0,948	1,762	2,924	3,823	4,319	4,977

5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Windhoek	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,345	0,607	0,757	0,787	0,693	0,477	0,188	0,036	0,035	0,036	0,037	0,037	0,036	0,036	0,035	0,087
	9	0,452	0,681	0,792	0,781	0,644	0,395	0,132	0,061	0,062	0,063	0,063	0,063	0,063	0,062	0,062	0,169
	10	0,569	0,759	0,825	0,762	0,574	0,298	0,095	0,090	0,091	0,092	0,093	0,092	0,091	0,090	0,088	0,293
	11	0,681	0,803	0,797	0,663	0,418	0,163	0,095	0,094	0,095	0,096	0,096	0,095	0,094	0,095	0,168	0,445
	12	0,814	0,885	0,815	0,608	0,316	0,112	0,105	0,107	0,108	0,109	0,108	0,107	0,105	0,114	0,317	0,609
	13	0,831	0,618	0,319	0,114	0,107	0,108	0,110	0,110	0,110	0,108	0,107	0,113	0,328	0,627	0,836	0,905
	14	0,737	0,488	0,187	0,098	0,095	0,097	0,098	0,098	0,097	0,095	0,096	0,164	0,432	0,698	0,843	0,862
	15	0,499	0,271	0,098	0,091	0,092	0,092	0,093	0,093	0,092	0,091	0,089	0,241	0,474	0,636	0,695	0,649
	16	0,466	0,180	0,060	0,059	0,060	0,060	0,060	0,060	0,059	0,058	0,116	0,373	0,627	0,771	0,789	0,688
	17	0,349	0,091	0,030	0,031	0,032	0,032	0,032	0,031	0,031	0,031	0,171	0,456	0,673	0,770	0,745	0,603
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	5,742	5,382	4,680	3,993	3,030	1,836	1,007	0,780	0,780	0,779	0,974	1,742	2,922	3,898	4,594	5,310

SOLAR HEAT GAIN FACTORS - WINDHOEK (WINTER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the winter design days

2,5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Windhoek	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,329	0,571	0,708	0,733	0,641	0,136	0,165	0,030	0,029	0,030	0,030	0,030	0,030	0,029	0,028	0,063
	9	0,475	0,715	0,829	0,815	0,668	0,102	0,123	0,053	0,054	0,055	0,055	0,055	0,055	0,054	0,053	0,173
	10	0,603	0,787	0,810	0,761	0,553	0,261	0,073	0,069	0,071	0,071	0,072	0,071	0,070	0,069	0,080	0,320
	11	0,665	0,794	0,794	0,665	0,425	0,159	0,086	0,085	0,086	0,087	0,087	0,086	0,085	0,086	0,161	0,425
	12	0,727	0,786	0,720	0,533	0,271	0,095	0,090	0,091	0,092	0,093	0,092	0,091	0,090	0,097	0,288	0,548
	13	0,716	0,565	0,299	0,098	0,090	0,092	0,093	0,093	0,093	0,092	0,090	0,095	0,272	0,542	0,735	0,805
	14	0,692	0,455	0,172	0,086	0,084	0,085	0,086	0,086	0,085	0,084	0,085	0,152	0,409	0,660	0,802	0,812
	15	0,601	0,322	0,082	0,070	0,072	0,073	0,073	0,073	0,072	0,070	0,075	0,257	0,546	0,754	0,834	0,782
	16	0,447	0,172	0,050	0,048	0,050	0,050	0,050	0,050	0,049	0,048	0,106	0,351	0,597	0,738	0,757	0,660
	17	0,278	0,074	0,025	0,026	0,027	0,027	0,027	0,027	0,026	0,027	0,135	0,301	0,533	0,611	0,592	0,479
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	5,562	5,241	4,519	3,835	2,880	1,680	0,865	0,656	0,656	0,656	0,827	1,550	2,687	3,640	4,332	5,087

0,05 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Windhoek	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	8	0,420	0,711	0,869	0,890	0,769	0,509	0,175	0,026	0,026	0,027	0,027	0,027	0,027	0,026	0,025	0,108
	9	0,570	0,834	0,950	0,921	0,739	0,425	0,111	0,051	0,052	0,053	0,053	0,053	0,052	0,051	0,053	0,224
	10	0,647	0,836	0,887	0,797	0,572	0,262	0,072	0,069	0,070	0,071	0,071	0,071	0,070	0,069	0,083	0,350
	11	0,730	0,858	0,842	0,688	0,418	0,152	0,082	0,082	0,082	0,083	0,083	0,082	0,081	0,083	0,187	0,488
	12	0,779	0,836	0,761	0,556	0,274	0,095	0,090	0,091	0,092	0,092	0,092	0,091	0,090	0,099	0,316	0,592
	13	0,779	0,592	0,316	0,099	0,090	0,091	0,092	0,092	0,092	0,091	0,090	0,095	0,274	0,556	0,761	0,830
	14	0,722	0,480	0,185	0,086	0,084	0,085	0,086	0,086	0,085	0,084	0,084	0,152	0,412	0,675	0,826	0,842
	15	0,607	0,329	0,079	0,065	0,067	0,067	0,068	0,068	0,067	0,066	0,069	0,246	0,537	0,749	0,832	0,785
	16	0,420	0,168	0,047	0,045	0,046	0,047	0,047	0,047	0,046	0,044	0,094	0,314	0,543	0,676	0,697	0,612
	17	0,231	0,062	0,018	0,019	0,019	0,019	0,019	0,019	0,018	0,019	0,098	0,280	0,422	0,489	0,477	0,390
	18	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	5,911	5,707	4,952	4,165	3,078	1,751	0,851	0,630	0,630	0,629	0,760	1,410	2,508	3,472	4,257	5,228

SOLAR HEAT GAIN FACTORS - WINDHOEK (WINTER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the summer design days

10 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Windhoek	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,039	0,076	0,314	0,553	0,693	0,722	0,637	0,442	0,181	0,042	0,040	0,041	0,042	0,042	0,041	0,040
	8	0,070	0,147	0,420	0,672	0,809	0,817	0,694	0,453	0,164	0,072	0,071	0,072	0,073	0,073	0,072	0,071
	9	0,100	0,197	0,485	0,726	0,846	0,830	0,679	0,417	0,149	0,098	0,098	0,099	0,100	0,100	0,099	0,097
	10	0,130	0,238	0,495	0,694	0,781	0,743	0,583	0,341	0,126	0,125	0,126	0,127	0,127	0,127	0,126	0,125
	11	0,145	0,277	0,498	0,656	0,711	0,650	0,487	0,267	0,143	0,139	0,140	0,141	0,141	0,141	0,140	0,139
	12	0,171	0,315	0,491	0,603	0,624	0,544	0,382	0,207	0,159	0,153	0,154	0,155	0,155	0,154	0,153	0,156
	13	0,172	0,166	0,162	0,163	0,164	0,164	0,163	0,162	0,168	0,202	0,262	0,511	0,584	0,566	0,464	0,303
	14	0,169	0,165	0,165	0,166	0,166	0,166	0,165	0,165	0,161	0,259	0,452	0,594	0,648	0,602	0,465	0,271
	15	0,156	0,154	0,155	0,156	0,156	0,156	0,155	0,155	0,140	0,286	0,477	0,606	0,644	0,585	0,438	0,238
	16	0,121	0,119	0,120	0,121	0,121	0,120	0,119	0,119	0,131	0,324	0,522	0,641	0,660	0,580	0,408	0,192
	17	0,081	0,082	0,083	0,083	0,083	0,083	0,082	0,082	0,140	0,363	0,553	0,651	0,648	0,546	0,353	0,135
	18	0,041	0,042	0,043	0,043	0,043	0,042	0,041	0,043	0,153	0,367	0,525	0,593	0,570	0,456	0,262	0,066
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	1,395	1,977	3,430	4,635	5,196	5,036	4,189	2,852	1,815	2,428	3,519	4,230	4,391	3,971	3,021	1,832

5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Windhoek	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,043	0,058	0,255	0,459	0,582	0,612	0,547	0,390	0,171	0,045	0,043	0,044	0,044	0,044	0,044	0,043
	8	0,075	0,139	0,402	0,651	0,788	0,800	0,686	0,455	0,171	0,076	0,075	0,076	0,077	0,077	0,077	0,076
	9	0,099	0,191	0,486	0,731	0,854	0,839	0,687	0,423	0,155	0,097	0,097	0,098	0,099	0,099	0,098	0,096
	10	0,133	0,230	0,478	0,671	0,757	0,721	0,570	0,337	0,124	0,129	0,129	0,130	0,130	0,130	0,129	0,128
	11	0,147	0,263	0,488	0,654	0,717	0,663	0,505	0,283	0,144	0,139	0,140	0,141	0,141	0,141	0,140	0,139
	12	0,160	0,299	0,473	0,586	0,610	0,537	0,383	0,207	0,160	0,154	0,155	0,156	0,156	0,155	0,154	0,157
	13	0,165	0,164	0,162	0,162	0,163	0,163	0,162	0,161	0,167	0,211	0,385	0,531	0,602	0,576	0,464	0,293
	14	0,163	0,157	0,158	0,158	0,159	0,158	0,158	0,157	0,154	0,256	0,440	0,574	0,621	0,573	0,439	0,254
	15	0,115	0,141	0,142	0,143	0,143	0,143	0,142	0,141	0,123	0,296	0,492	0,622	0,656	0,589	0,431	0,222
	16	0,115	0,113	0,114	0,114	0,114	0,114	0,113	0,114	0,129	0,308	0,483	0,584	0,596	0,519	0,361	0,165
	17	0,081	0,082	0,083	0,083	0,083	0,083	0,082	0,082	0,145	0,340	0,579	0,682	0,639	0,571	0,367	0,139
	18	0,042	0,043	0,044	0,044	0,044	0,044	0,043	0,041	0,137	0,331	0,476	0,539	0,520	0,419	0,245	0,068
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	1,368	1,883	3,285	4,457	5,014	4,877	4,077	2,794	1,781	2,421	3,493	4,176	4,221	3,893	2,948	1,778

SOLAR HEAT GAIN FACTORS - WINDHOEK (SUMMER)

Solar heat gain factors for ordinary clear glass by direct transmission and re-radiation from the glass for the summer design days

2,5 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Windhoek	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,039	0,051	0,251	0,456	0,580	0,611	0,547	0,391	0,171	0,041	0,040	0,040	0,041	0,041	0,041	0,040
	8	0,072	0,131	0,381	0,621	0,754	0,768	0,661	0,441	0,168	0,073	0,072	0,073	0,074	0,074	0,074	0,073
	9	0,100	0,201	0,490	0,730	0,849	0,832	0,678	0,415	0,146	0,098	0,098	0,099	0,099	0,099	0,099	0,097
	10	0,120	0,241	0,507	0,714	0,804	0,763	0,596	0,344	0,122	0,115	0,116	0,117	0,117	0,117	0,116	0,115
	11	0,152	0,261	0,480	0,640	0,700	0,648	0,493	0,260	0,143	0,142	0,143	0,144	0,144	0,144	0,143	0,142
	12	0,149	0,289	0,467	0,586	0,616	0,546	0,391	0,212	0,153	0,145	0,146	0,147	0,147	0,147	0,146	0,148
	13	0,157	0,176	0,174	0,175	0,175	0,175	0,175	0,174	0,179	0,211	0,359	0,489	0,548	0,524	0,426	0,275
	14	0,167	0,166	0,166	0,167	0,167	0,167	0,166	0,166	0,157	0,257	0,433	0,569	0,603	0,556	0,426	0,245
	15	0,135	0,140	0,140	0,141	0,141	0,141	0,140	0,139	0,126	0,259	0,422	0,528	0,555	0,500	0,370	0,197
	16	0,089	0,089	0,089	0,090	0,090	0,089	0,089	0,089	0,115	0,257	0,396	0,473	0,477	0,410	0,279	0,121
	17	0,064	0,064	0,066	0,067	0,067	0,066	0,064	0,065	0,130	0,373	0,582	0,691	0,690	0,579	0,370	0,128
	18	0,040	0,042	0,042	0,043	0,043	0,042	0,041	0,043	0,148	0,354	0,507	0,572	0,549	0,440	0,252	0,063
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	1,286	1,850	3,255	4,429	4,986	4,846	4,041	2,757	1,758	2,325	3,312	3,933	4,046	3,630	2,740	1,645

0,05 PER CENT PROBABILITY LEVEL

Place	Time	Solar Heat Gain Factor kW/m²															
		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
Windhoek	6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	7	0,037	0,083	0,308	0,549	0,692	0,724	0,641	0,447	0,184	0,039	0,037	0,039	0,039	0,039	0,039	0,038
	8	0,066	0,141	0,431	0,696	0,841	0,851	0,724	0,472	0,166	0,067	0,066	0,068	0,068	0,068	0,068	0,067
	9	0,091	0,190	0,489	0,734	0,856	0,839	0,685	0,417	0,158	0,090	0,090	0,091	0,091	0,091	0,090	0,089
	10	0,119	0,239	0,503	0,708	0,798	0,757	0,591	0,340	0,119	0,113	0,114	0,115	0,116	0,116	0,115	0,113
	11	0,132	0,253	0,473	0,632	0,691	0,636	0,479	0,261	0,128	0,123	0,124	0,125	0,126	0,125	0,124	0,123
	12	0,154	0,276	0,402	0,481	0,497	0,444	0,331	0,214	0,206	0,206	0,206	0,206	0,206	0,206	0,206	0,206
	13	0,205	0,239	0,227	0,231	0,233	0,233	0,230	0,225	0,250	0,297	0,491	0,680	0,772	0,744	0,608	0,400
	14	0,222	0,222	0,222	0,222	0,222	0,222	0,222	0,222	0,212	0,284	0,464	0,588	0,631	0,586	0,459	0,277
	15	0,124	0,124	0,124	0,124	0,124	0,124	0,124	0,124	0,086	0,101	0,122	0,132	0,134	0,129	0,116	0,090
	16	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,103	0,117	0,135	0,142	0,142	0,137	0,123	0,092
	17	0,124	0,124	0,124	0,124	0,124	0,124	0,124	0,124	0,089	0,130	0,151	0,159	0,158	0,149	0,125	0,090
	18	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,051	0,075	0,088	0,093	0,091	0,082	0,063	0,048
	19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	Daily total	1,467	2,084	3,494	4,695	5,271	5,146	4,343	3,038	1,752	1,641	2,088	2,437	2,575	2,473	2,136	1,632

SOLAR HEAT GAIN FACTORS - WINDHOEK (SUMMER)

7. THERMAL DESIGN OF THE BUILDING ENVELOPE

THERMAL DESIGN OF THE BUILDING ENVELOPE

The notes in this section are meant to provide reference material to assist in the choice among various roof and wall constructions for buildings in Botswana based on the thermal performance of these elements. Any of several references listed in the bibliography of this workbook can be referred to for methods of calculating heat gain and loss of buildings using values from the charts presented in this section (see, in particular the references from ASHRAE, Givoni, Koenigsberger, Markus, van Straaten or Wentzel).

In general, the steady-state heat conduction through a given wall or roof section is defined by the expression:

$$Q = UA\ (\Delta T)$$

where Q = The rate of heat flow (W)

U = The overall average thermal conductance of the wall or roof element ($W/m^2 - °C$)

A = The area of the wall or roof element (m^2)

ΔT = The temperature difference between the inside and ouside air (°C)

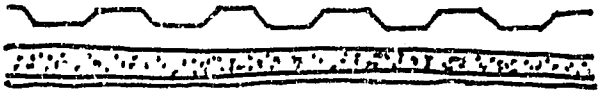
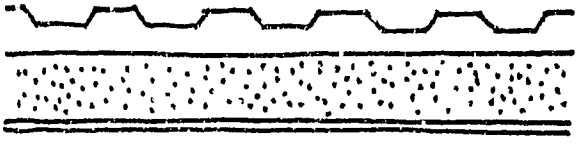
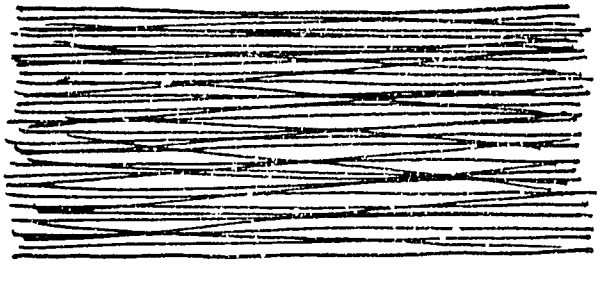
It is often easier to understand and work with the resistance (R-value) of building envelope elements than the conductance (U-value). These two quantities are the inverse of each other ($U = 1/R$ and $R = 1/U$). The following pages contain charts listing R and/or U values for various building envelope sections and materials likely to be found in Botswana.

Following the charts of R and U values is a brief discussion of the "CR" concept for examining building wall and roof sections.

This is followed by a chart developed by Higgs (NBRI) showing the relationship between north-facing glass area and predicted room air temperatures for one particular case. It suggests that using a north-facing glass area in excess of 20% of the floor area offers little additional benefit for winter heating in Pretoria. In Botswana, this value would probably be even less (i.e.: 15-18%). However, this is not to say that this is the best amount of glass to use. If there are substantial other heat gains, a lesser amount would probably be necessary to prevent overheating.

The last illustration contained in this section is a chart presenting typical values for internal heat gains which can be used in thermal calculations for buildings.

THERMAL RESISTANCE OF ROOFS

ROOF		THERMAL RESISTANCE (m^2-^oC / W)
	galvanized roof no ceiling	R= .19
	galvanized roof 10 mm ceiling	R= .53
	galvanized roof 50 mm fiberglass insulation 10 mm ceiling	R= 2.03
	galvanized roof 100 mm fiberglass insulation 10 mm ceiling	R= 3.42
	250 mm thatch	R= 4.5 (est)

ROOF CONSTRUCTIONS AND THEIR PERFORMANCE

T_{ex} under 4 degC is acceptable

Roof material	Ceiling material	Construction	U-value W/m²degC	Density of heat flow rate (q) and ceiling *temperature excess* (T_{ex}) above air temperature under assumed conditions ($T_{ex} = T_i = 30$°C and $I = 920$ W/m²) New: q W/m²	New: T_{ex} degC	Old: q W/m²	Old: T_{ex} degC
Corrugated asbestos cement	13 mm fibreboard	a/c* sheets on timber purlins, fibreboard nailed under rafters	1·7	29·3	4·3	62·4	9·4
Corrugated asbestos cement sandwiched with 25 mm fibreglass		sandwich sheets fixed on purlins and rafters	0·8	22·4	3·4	47·9	7·4
100 mm r/c slab 75 mm cement screed	13 mm fibreboard	*in situ* slab, fibreboard on battens	1·3	22·7	3·4	48·2	7·4
Corrugated asbestos cement	13 mm fibreboard	a/c sheets on purlins, fibreboard under horizontal ties	1·7	23·9	3·9	52·3	8·4
Corrugated iron sheets	13 mm fibreboard	iron sheets on purlins, fibreboard under horizontal ties	1·3	13·9	2·3	41·6	7·3
Corrugated iron sheets	13 mm timber board	iron sheets on purlins, timber board under horizontal ties	1·6	17·3	2·9	52·3	8·8
Corrugated iron sheets	5 mm a/c sheets	iron sheets on purlins, a/c sheets under horizontal ties	1·9	20·3	3·1	62·7	9·6
Corrugated asbestos cement	13 mm fibreboard + alum.† foil	a/c sheets on purlins, foil over fibreboard fixed under rafters	1·2	21·4	3·3	46·0	7·0
Corrugated asbestos cement	13 mm timber board + alum. foil	a/c sheets on purlins, foil over timber boards fixed under rafters	1·6	29·3	4·4	62·7	9·5
Corrugated asbestos cement	5 mm a/c sheets + alum. foil	a/c sheets on purlins, foil over a/c ceiling fixed under rafters	1·7	29·3	4·4	62·7	9·5
Corrugated iron sheets	13 mm fibreboard + alum. foil	iron sheets on purlins, foil over fibreboard fixed under rafters	1·0	16·0	2·5	47·9	7·4
Corrugated iron sheets	13 mm timber board + alum. foil	iron sheets on purlins, foil over timber boards fixed under rafters	1·3	20·2	3·0	60·5	9·2
Corrugated iron sheets	5 mm a/c sheets + alum foil	iron sheets on purlins, foil over a/c ceiling fixed under rafters	1·4	23·0	3·4	69·0	10·3
Red clay tiles	13 mm fibreboard 25 mm fibreglass + alum. foil	tiles on battens on rafters, foil on fibreglass on fibreboard under rafters	0·62	23·0	3·3	23·0	3·3
Red clay tiles	13 mm timber board, 25 mm fibreglass + alum. foil	tiles on battens on rafters, foil on fibreglass on boards under rafters	0·74	27·1	4·0	27·1	4·0
Red clay tiles	5 mm a/c sheets, 25 mm fibreglass + alum. foil	tiles on battens on rafters, foil on fibreglass on a/c under rafters	0·80	29·3	4·4	29·3	4·4
Corrugated asbestos cement	13 mm fibreboard, 25 mm fibreglass + alum. foil	a/c sheets on purlins, foil on fibreglass on fibreboard under under rafters	0·68	11·3	1·7	25·2	3·6

(Source: Koenigsberger)

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ROOF CONSTRUCTIONS AND THEIR PERFORMANCE (continued)

T_{ex} under 4 degC is acceptable

Roof material	Ceiling material	Construction	U-value W/m²degC	Density of heat flow rate (q) and ceiling temperature excess (T_{ex}) above air temperature under assumed conditions (T_o = T_i = 30°C and I = 920 W/m²) New: q W/m²	New: T_{ex} degC	Old: q W/m²	Old: T_{ex} degC
Corrugated asbestos cement	13 mm timber board, 25 mm fibreglass + alum. foil	a/c sheets on purlins, foil on fibreglass on boards under rafters	0·74	12·6	1·9	27·1	4·0
Corrugated asbestos cement	5 mm a/c sheets, 25 mm fibreglass + alum. foil	a/c sheets on purlins, foil on fibreglass on a/c ceiling under rafters	0·80	13·5	2·4	29·3	4·4
Corrugated alum. sheets	13 mm fibreboard	alum. on timber purlins, fibreboard under rafters	1·3	16·1	2·5	22·4	3·4
Corrugated alum. sheets	13 mm timber board	alum. on timber purlins, timber board under rafters	1·6	20·2	3·0	28·3	4·3
Corrugated alum. sheets	5 mm a/c sheets	alum. on timber purlins, a/c under rafters	1·9	22·1	3·3	31·2	4·6
Corrugated alum. sheets	100 mm reinforced concrete slab	alum. on timber purlins, reinforced concrete slab horizontal	1·6	20·2	3·0	28·3	4·3
Corrugated alum. sheets	13 mm resin bonded jute board	alum. sheets on timber purlins, board under rafters	1·4	16·7	2·5	23·6	3·6
Corrugated alum. sheets	50 mm strawboard	alum. on timber purlins, strawboard under rafters	1·08	11·0	1·8	15·4	2·5
Corrugated alum. sheets	25 mm wood wool slab	alum. on timber purlins, wood wool under rafters	1·42	14·5	2·2	20·5	3·1
Corrugated alum. sheets	10 mm plasterboard	alum. on timber purlins, plasterboard under rafters	1·88	19·2	2·9	27·4	3·5
Corrugated alum. sheets	25 mm cork slab	alum. on timber purlins, cork under rafters	1·27	13·2	2·0	18·6	2·7
Corrugated alum. sheets	100 mm reinforced concrete slab, 75 mm cement screed, 13 mm plastering	alum. on timber purlins, reinforced concrete slab horizontal underside plastered	1·23	17·3	2·4	24·6	3·4

Based on Koenigsberger and Lynn *Roofs in the warm-humid tropics.*
* a/c = asbestos cement
† alum. = aluminium

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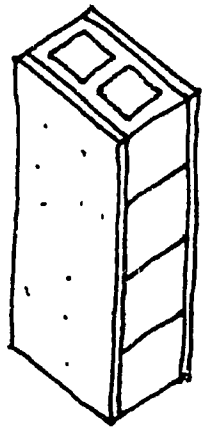
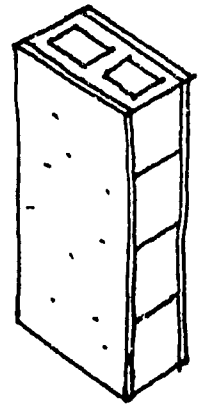
THERMAL RESISTANCE OF WALLS

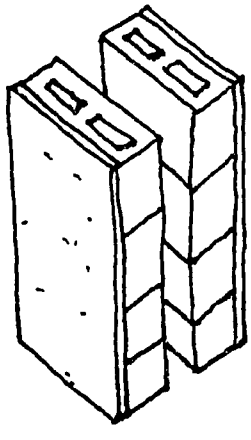
(m^2 - ^oC / W)



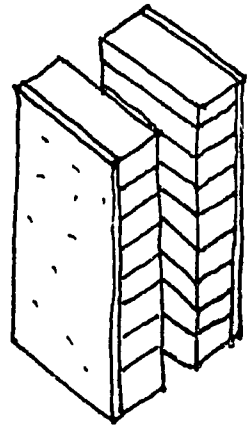
outside surface	.06
15 mm cement plaster	.01
230 mm hollow block	.31
15 mm cement plaster	.01
inside surface	.12
R Value =	.51



outside surface	.06
15 mm cement plaster	.01
150 mm hollow block	.21
15 mm cement plaster	.01
inside surface	.12
R Value =	.41

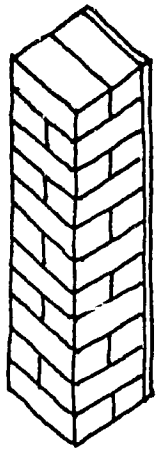


outside surface	.06
15 mm cement plaster	.01
115 mm hollow block	.13
115 mm air space	.16
115 mm hollow block	.13
15 mm cement plaster	.01
inside surface	.12
R Value	.62

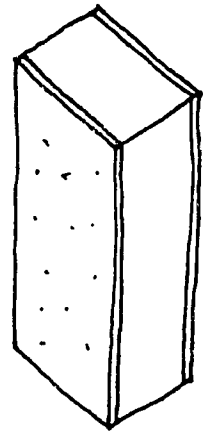


outside surface	.06
15 mm cement plaster	.01
115 mm brick	.11
115 mm air space	.16
115 mm brick	.11
15 mm cement plaster	.01
inside surface	.12
R Value =	.57

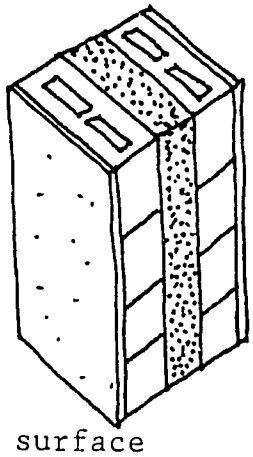
THERMAL RESISTANCE OF WALLS
(Continued)



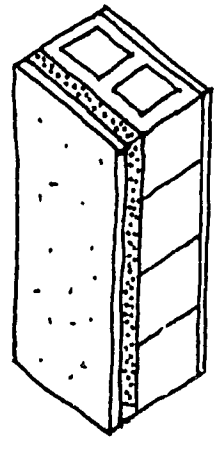
outside surface	.06
230 mm brick	.22
15 mm cement plaster	.01
inside surface	.12
R Value =	.41



outside surface	.06
15 cm cement plaster	.01
230 mm solid concrete blk.	.28
15 mm cement plaster	.01
inside surface	.12
R Value =	.48



outside surface	.06
15 mm cement plaster	.01
115 mm hollow block	.13
115 mm foam insulation styrene beads)	2.20
115 mm hollow block	.13
inside surface	.12
R Value =	2.36



outside surface	.06
20 mm cement plaster	.01
25 mm polystyrene insulation board	1.32
hollow concrete block	.13
15 mm cement plaster	.01
inside surface	.12
R Value =	1.84

TRANSMITTANCE (U-VALUE) OF SOME CONSTRUCTIONS

Type of construction	W/m² deg C
Walls	
Brick: solid, unplastered 114 mm	3·64
plastered both sides 114 mm	3·24
solid, unplastered 228 mm	2·67
plastered both sides 228 mm	2·44
Concrete, ordinary, dense: 152 mm	3·58
203 mm	3·18
Stone, medium, porous 305 mm	2·34
457 mm	2·27
Brick, 280 mm cavity, fletton outer skin, common inner, inside plastered	1·70
Brick with insulating boards, plastered:	
25 mm corkboard	0·85
13 mm fibreboard	1·19
50 mm wood wool slab	0·85
Brick but 16 mm vermiculite plaster on inside	1·47
Brick but rigid boards on battens on inside:	
13 mm asbestos board	1·19
13 mm fibreboard	0·95
50 mm strawboard, plastered	0·74
Brick but inner skin lightweight concrete blocks:	
100 mm aerated concrete blocks	1·13
100 mm clinker concrete blocks	1·30
Concrete block, cavity, 250 mm (100 +50 +100) outside rendered, inside plastered.	
aerated concrete blocks	1·19
clinker concrete blocks	1·08
Hollow concrete block, 228 mm single skin, outside rendered, inside plastered:	
aerated concrete blocks	1·70
clinker concrete blocks	1·59
Corrugated asbestos cement sheets on steel frame	6·53
+13 mm fibreboard	2·04
+50 mm straw or wood wool slab	1·19
+76 mm aerated concrete blocks	2·10
Roofs, pitched	
Corrugated asbestos cement sheets	7·95
+13 mm timber boarding	2·16
+50 mm straw or wood wool slab	1·25
+25 mm quilt on 13 mm boarding	0·85
Corrugated iron sheets or tiles on battens	8·52
+plaster ceiling	3·18
Tiles or slates on boarding and felt with plaster ceiling	1·70
Aluminium deck, 13 mm fibreboard with two layers bituminous felt	2·16
Aluminium deck, 50 mm straw or wood wool slab	1·25
Roofs, flat	
Reinforced concrete slab, 100 mm, screed 63+12 mm, 3 layers bituminous felt	3·35
As above – with insulation on the screed:	
25 mm cork	1·08
50 mm straw or wood wool slab	1·13
two 12 mm fibreboards	1·25
As above – but lightweight screed (in lieu of normal)	

(Continued)

(Source: Koenigsberger)

TRANSMITTANCE (U-VALUE) OF SOME CONSTRUCTIONS (continued)

Type of construction	W/m² deg C
127 mm to 76 mm aerated concrete	1·36
127 mm to 76 mm foamed slag concrete	1·47
Timber boarding, 25 mm on 178 mm joists with 3 layers bituminous felt, plaster ceiling	1·62
As above: with insulating slabs on boarding:	
25 mm cork	0·85
13 mm fibreboard	1·25
50 mm straw or wood wool slab	0·91
Floors	
Concrete on ground or hardcore fill	1·13
+ grano, terrazzo or tile finish	1·13
+ wood block finish	0·85
Timber board on joists, underfloor space ventilated on one side	1·70
+ parquet, lino or rubber finish	1·42
Timber board on joists, underfloor space ventilated on more sides	2·27
+ parquet, lino or rubber finish	1·98
+ 25 mm fibreboard under boarding	1·08
+ 25 mm corkboard under boarding	0·95
+ 25 mm corkboard under joists	0·79
+ 50 mm strawboard under joists	0·85
+ double sided aluminium foil, draped	1·42
Windows:	
Exposure South, sheltered: single glazing	3·97
double glazing, 6 mm space	2·67
double glazing 20 mm space	2·32
South normal, West, Southwest, Southeast sheltered:	
single glazing	4·48
double glazing, 6 mm space	2·90
double glazing, 20 mm space	2·50
South severe, West, Southwest, Southeast, normal or Northwest, North, Northeast East sheltered:	
single glazing	5·00
double glazing, 6 mm space	3·06
double glazing 20 mm space	2·67
West, Southwest, Southeast severe, Northwest, North, Northeast, East normal:	
single glazing	5·67
double glazing, 6 mm space	3·29
double glazing, 20 mm space	2·84
Exposure Northwest severe: single glazing	6·47
double glazing, 6 mm space	3·58
double glazing, 20 mm space	3·00
Exposure North severe: single glazing	7·38
double glazing, 6 mm space	3·80
double glazing, 20 mm space	3·18

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CONDUCTIVITY AND RESISTIVITY OF SOME MATERIALS

	conductivity k W/m degC	resistivity $1/k$ m degC/W
Asbestos: loose	0·034	29·40
sprayed	0·046	21·75
Asbestos cement sheet: light	0·216	4·63
average	0·360	2·78
dense	0·576	1·74
Asphalt	0·576	1·74
Brickwork commons: light	0·806	1·24
average	1·210	0·83
dense	1·470	0·68
in lightweight bricks	0·374	2·68
in engineering bricks	1·150	0·87
Concrete: ordinary, dense	1·440	0·69
clinker aggregate	0·403	2·48
expanded clay aggregate	0·345	2·90
foamed slag aggregate	0·245	4·08
Cork slab: natural	0·043	23·20
regranulated, baked	0·039	25·60
Eel grass blanket	0·043	23·20
Glass-wool: quilt	0·034	29·40
blanket	0·042	23·80
Mineral wool: felt	0·037	27·00
rigid slab	0·049	20·40
Onozote (expanded ebonite)	0·029	34·50
Plasterboard, gypsum	0·159	6·33
Plastering: gypsum	0·461	2·17
vermiculite	0·201	4·98
Plywood	0·138	7·25
Polystyrene foam slab	0·033	30·30
Rendering, sand-cement	0·532	1·88
Stone: granite	2·920	0·34
limestone	1·530	0·65
sandstone	1·295	0·77
Strawboard	0·093	10·75
Timber: softwood	0·138	7·25
hardwood	0·160	6·25
Wood chipboard	0·108	9·26
Wood fibre softboard	0·065	15·38
Wood wool slab: light	0·082	12·20
dense	0·115	8·70
Metals: lead	34	0·0294
cast-iron	50	0·0200
steel	58	0·0172
bronze	64	0·0156
zinc	110	0·0091
aluminium	220	0·0045
copper	350	0·0029
silver	407	0·0024
Air	0·026	38·45
Water	0·580	1·72

(Source: Koenigsberger)

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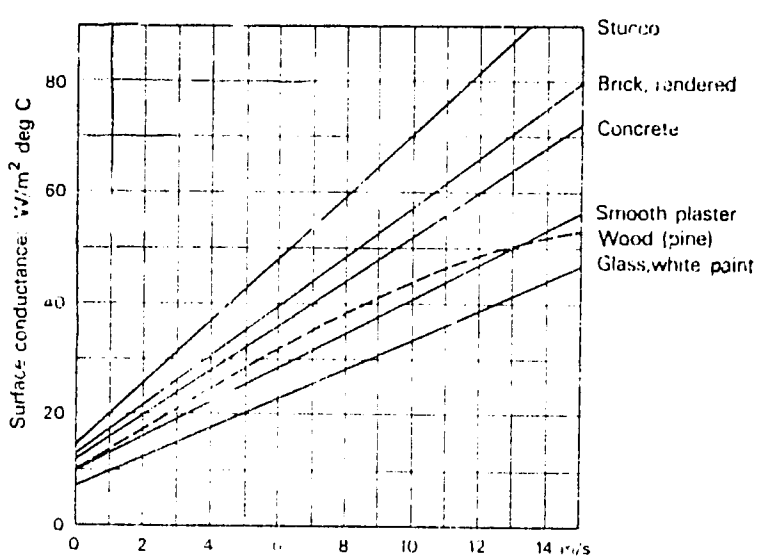
SURFACE CONDUCTANCES AND RESISTANCES

surface		conductance f W/m²degC	resistance $1/f$ m²degC/W
Internal surfaces (f_i):			
Walls		8·12	0·123
Floor, ceiling, heat flow up		9·48	0·105
Floor, ceiling, heat flow down		6·70	0·149
Underside of roof		9·48	0·105
External surfaces (f_o):			
Walls, South facing	sheltered	7·78	0·128
	normal	10·00	0·100
	severe exposure	13·18	0·076
Walls, West, Southwest, Southeast facing	sheltered	10·00	0·100
	normal	13·18	0·076
	severe exposure	18·90	0·053
Walls, Northwest facing:	sheltered	13·18	0·076
	normal	18·90	0·053
	severe exposure	31·50	0·032
Walls, North, Northeast, East facing:	sheltered	13·18	0·076
	normal	18·90	0·053
	severe exposure	81·20	0·012
Roofs:	sheltered	14·20	0·070
	normal	22·70	0·044
	severe exposure	56·70	0·018

(Source: Koenigsberger)

SURFACE CONDUCTANCE AS A FUNCTION OF WIND SPEED



(Source: Koenigsberger)

THERMAL PROPERTIES OF MATERIALS

Type of material	Density (kg/m³)	Thermal conductivity (W/m °C)	Specific heat (kJ/kg °C)
Asbestos cement sheet: pressed	2 100	0,62	0,83
unpressed	1 830	0,48	0,84
Asphalt	2 243	1,23	1,67
Ashcrete	753	0,33	1,2
	1 346	0,61	
Bitumen	1 050	0,16	
	1 450	0,35	0,84
	2 400	0,85	
Brickwork	1 826	0,82	0,80
Firebrick	2 083	1,08	0,84
Concrete			
Dense, vibrated	2 323	1,5	0,88
Poured	1 986	1,5	0,88
No fines	1 360	0,5	0,96
Cellular	961	0,26	0,88
Felt			
Undercarpet	120	0,045	
Asbestos	144	0,078	
Roofing	960	0,19	
Bitumen sacking	1 100	0,20	
Fireboard	240	0,053	1,46
	300	0,057	
	400	0,065	
Glass			
Window	2 483	0,75	0,67
Heat resistant	2 250	1,10	
Flint	3 500	0,70	
Glass wool	25	0,040	
	50	0,033	
Gypsum			
Powder	320	0,065	
Plaster board	993	0,17	1,05
Plastering	1 100	0,38	
Hardboard	1 121	0,20	1,36
Metals			
Aluminium	2 690	211	0,88
Brass	8 090	108	0,36
Cast Iron	7 400	48	0,51
Mild Steel	7 850	53	0,5
Mineral wool	12 - 144	0,033 - 0,042	0,88
Felted	50	0,039	
	70	0,039	0,84
	180	0,042	
Rigid slab	155	0,05	
Plaster	1 442 - 1 570	0,48 - 0,53	0,88 - 0,84

(Continued)

(Source: Wentzel et al, NBRI)

THERMAL PROPERTIES OF MATERIALS (continued)

Type of material	Density (kg/m³)	Thermal conductivity (W/m °C)	Specific heat (kJ/kg °C)
Polystyrene, expanded board	15	0,037	
	25	0,033	1,40
	30	0,030	
Polyurethane, gas filled rigid board foam	24 - 48	0,025	1,90
	30	0,026	
P.V.C. floor covering		0,40	
Refractory brick			
Alumina insulating grade	720	0,30	
Diatomaceous brick	480	0,13	
	560	0,15	
	720	0,20	
Firebrick	2 082	1,08	0,84
Vermiculite insulating brick	700	0,26	
Sand for building	1 500	0,30	0,84
Slate	2 500	1,4	
	2 723	1,88	0,75
Soil	1 500	0,85	1,5
Stone			
Artificial	1 762	1,33	0,92
Granite	2 643	2,93	0,92
Limestone	2 180	1,54	0,88
Marble	2 500	2,0	
Sandstone	2 000	1,3	
Tiles			
Asphalt	2 243	1,23	1,46
Burnt clay	1 922	0,84	0,92
Cork	136 - 176	0,042 - 0,046	1,80
	530	0,085	
PVC - Asbestos	2 000	0,85	
Rubber	1 800	0,5	
Timber			
Balsa	150	0,055	1,4
Mahogany	700	0,155	1,4
Pine	660	0,140	1,4
Plywood	530	0,14	1,4
Teak	700	0,17	1,4
Vermiculite			
Loose granules	100	0,065	
	128	0,072	0,88
Plastering	480	0,144	
	800	0,260	
	960	0,303	

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OPTIMUM COMBINATION OF THERMAL MASS (HEAT CAPACITY) AND THERMAL RESISTANCE (R VALUE) FOR OUTSIDE WALLS

The most important wall characteristics which affect indoor temperature are wall thermal resistance (R-value) , heat capacity (C) and outside wall solar absorptivity. If the outside color of the building is highly reflective, R and C are the remaining values to be determined. These two qualities are somewhat interchangeable and thus their combined effect can be expressed by the product CR.

Givoni has proposed interim formulae for the optimum values of CR in various climates, based on maximum temperature, temperature amplitude and absorbed solar radiation. Assuming an outside surface of high solar reflectivity and the summer climate of Botswana, optimum CR = 93,

where C= heat capacity ($kJ/m^2\ ^oC$)
R= R-value ($m^{2o}C/W$)

This can be compared to typical constructions previously discussed:

230mm hollow block wall:	CR= 149
150mm hollow block wall:	CR= 84
115mm hollow block cavity wall:	CR= 184
230mm solid brick wall:	CR= 156
230mm solid concrete wall:	CR= 186

This shows the 150mm hollow block wall would not meet the criteria. It also suggests that the additional mass of a solid wall is more effective than the better thermal resistance of a hollow block wall, although all the walls with CR values above 93 are acceptable.

A method to manually calculate the hottest and coldest likely indoor conditions in a house based on a whole-house CR value has been developed by NBRI and may be useful for building design in Botswana (see Wentzel et. al. in bibliography).

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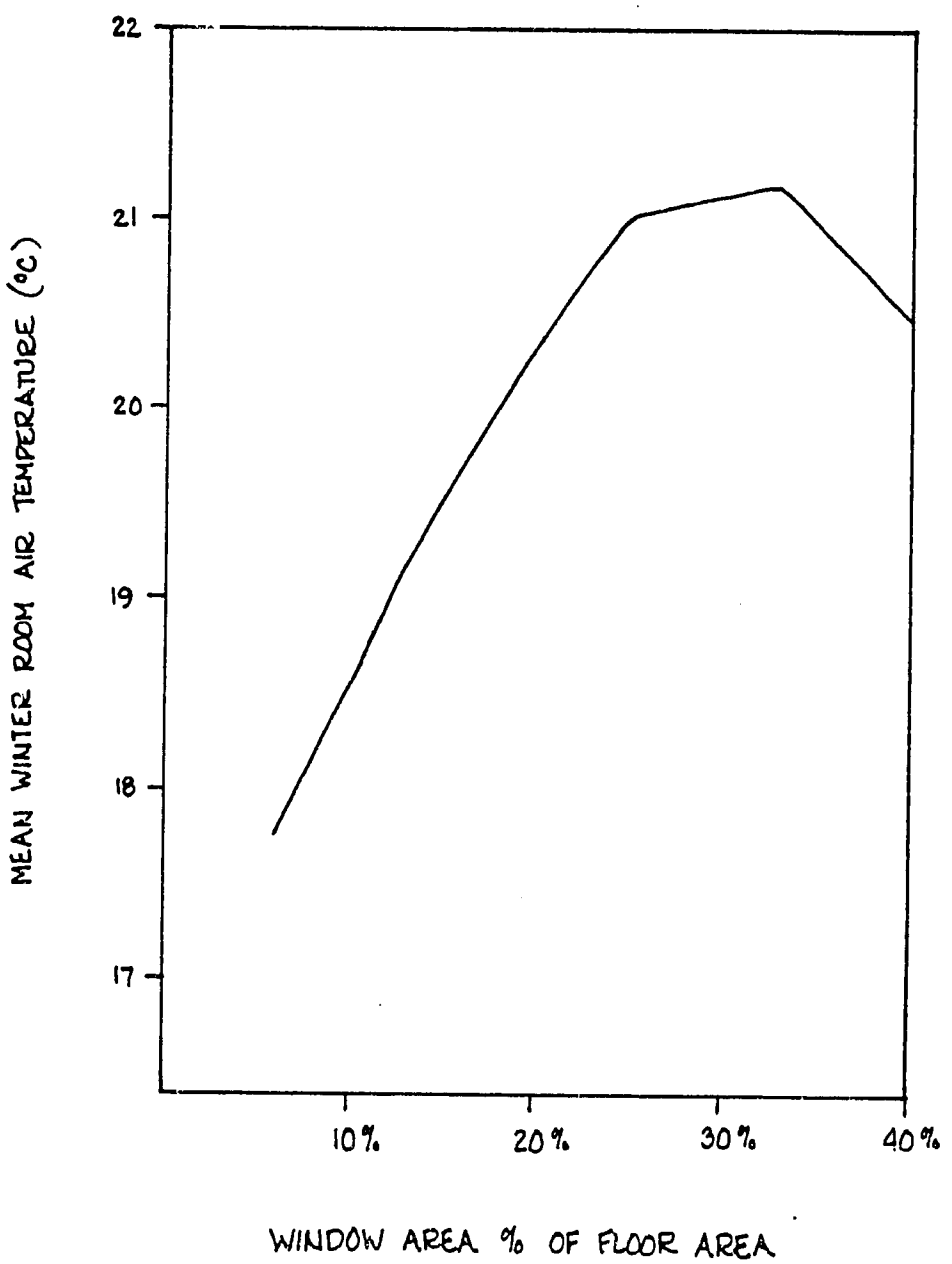
MODEL-PREDICTED MEAN WINTER ROOM AIR TEMPERATURES AS A FUNCTION OF NORTH-FACING GLASS AREA (FOR PRETORIA)



(Source: Higgs)

INTERNAL GAINS

Activity	Rate Of Heat Gain Per Person
Seated, at rest	100 W
Seated, very light work (writing)	120 W
Seated, eating	170 W
Seated light work (typing)	150 W
Standing, light work	185 W
Light bench work (factory)	230 W
Walking 1.3 m/s	305 W
Dancing	375 W
Heavy Work	420 W
Athletics	525 W

Appliance	Average Wattage	Estimated Annual kWh Usage
Air Conditioner	860	
Fan (attic)	370	
Fan (circulating)	88	
Fan (roll-away)	171	
Heater (portable)	1000	
Iron (hand)	1100	60
Washing Machine (automatic)	512	103
Washing Machine (non-automatic)	266	76
Water Heater	2475	4219
Water Heater (quick recovery)	4474	4811
Vacuum Cleaner	630	46
Sewing Machine	75	11
Radio	71	86
Radio/Record Player	109	109
Television (solid state)	60	160
Freezer (manual defrost)		1320
Refrigerator/Freezer		700
Coffee Maker	894	106
Deep fryer	1448	83
Dishwasher	1201	363
Hot Plate	1200	90
Range (with oven)	12200	1205
Hair Dryer	381	14
Shaver	15	0.5

Sources: ASHRAE; Wolfe and Klegg, Home Energy for the Eighties, Garden Way, 1979.

8. VENTILATION DESIGN FOR PASSIVE SOLAR COOLING

VENTILATION

Proper design for ventilation cooling in buildings can have a major impact on the comfort conditions which can be achieved in the summer. In this section, a number of illustrations which were used in the workshop presentation have been reproduced for reference use.

The "Summary of Ventilation Functions and Requirements" on the next page organizes ventilation methods and requirements by the three primary functions of ventilation:

1. ventilation for adequate indoor air quality
2. ventilation for structural cooling
3. ventilation for cooling the body

Below this is shown the typical air flow pattern and velocities which can be achieved with one of the most effective strategies for cooling the body by ventilation: a ceiling fan.

The following pages provide additional reference material on effects of various ventilation rates, illustrate the wind flow patterns determined by different site planning variables and provide quantitative information on determination of "wind shadows". This is followed by illustrations of wind patterns through buildings as determined by location of openings and the use of "wing walls". Then, a method developed by the Florida Solar Energy Center is presented which can be used to determine the required size of openings for wind-driven ventilation of buildings. The chart on "Ventilation Rate Sensitivity" illustrates that increasing the ventilation rate beyond a certain point results in very little improvement in energy performance.

A method for calculating the ventilation which is achieved by the "stack effect" is also included, both in equation and graphical form. Finally, results generated in a study by Kammerud are presented which show that, in a typical situation, increasing storage partition wall thickness beyond about 100mm has very little incremental energy benefit. This implies that only the first 50mm of mass thickness below a ventilated surface is very useful when a night ventilation strategy is used to "pre-cool" a building for the coming day.

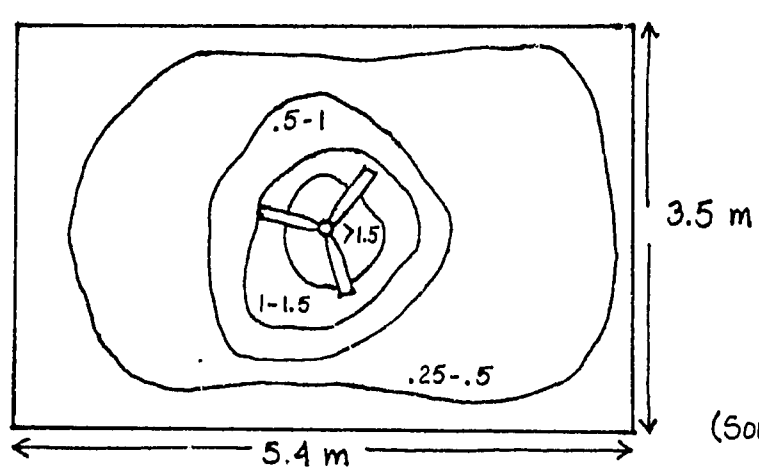
SUMMARY OF VENTILATION FUNCTIONS & REQUIREMENTS

Function	1 Minimum ventilation for odour removal etc.	2 Ventilation for structural cooling	3 Air movement for cooling the body
Required	In all occupied buildings	Mainly in hot dry conditions	Mainly in warm humid conditions
Conditions	All conditions of external temperature	Outside air cooler than inside air by more than 2 deg C	Outside air the same or cooler than inside air
Suitable building	All buildings	High internal heat capacity building	Single banked building
Methods Stack effect	Adequate for ventilation under most conditions	Adequate for cooling	Not adequate
—Openings	No special requirement	High outlet and low inlet, each 5% of floor area	—
Wind pressure	Adequate for ventilation	Adequate, but may not be available at night	Good if available
—Openings	No special requirement	Follow the requirements for stack effect	Large inlet and outlet on opposite sides of building, each 20% of wall area minimum
Mechanical	Not usually necessary, but extract fans may be used in kitchens. Internal WCs also require extract fans	Not necessary as stack effect will work automatically if outside air is cooler than inside air	May be desirable; fans are needed to move the air in the room not to provide air change
Typical requirement	1 air change per hour	10 air changes per hour	·1–1.5 m/sec air speed (equivalent to 100 air changes per hour or more)

(Source: Commonwealth Science Council)

APPROXIMATE AIRFLOW PATTERN FROM A CEILING FAN IN A ROOM WITH NO FURNITURE

AIR FLOWS AT APPROXIMATELY 1 M ABOVE FLOOR CREATED BY A 1.2 M FAN HUNG 25 CM BELOW THE CEILING



(Source: Florida Solar Energy Center)

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INDOOR WINDSPEEDS

Speed (m/sec)	Mechanical Effect	Effect on Humans	Cooling Effect (°C) Dry Skin Ambient air temperature 15°C	20°C	25°C	30°C	Moist skin 30°C
0.1	Minimum likely in domestic situations	May feel stuffy	0	0	0	0	0
0.25	Smoke (from cigarette) indicates movement	Movement not noticeable except at low air temperatures	2	1.3	0.8	0.5	0.7
0.5	Flame from a candle flickers	Feels fresh at comfortable temperatures, but draughty at cool temperatures	4	2.7	1.7	1.0	1.2
1.0	Loose papers may be moved, equivalent to walking speed	Generally pleasant when comfortable or warm, but causing constant awareness of motion, maximum limit for night comfort	6.7	4.5	2.8	1.7	2.2
1.5	Too fast for desk work with loose papers	Draughty at comfortable temperatures, maximum limit for indoor activities	8.5	5.7	3.5	2.0	3.3
2.0	Equivalent to a fast walking speed	Acceptable only in very hot and humid conditions when no other relief is available	10	6.7	4.0	2.3	4.2

Note: Effect on man relates to domestic situations. In factories and other buildings higher windspeeds may be desirable, and comfortable

MINIMUM VENTILATION REQUIREMENTS

Space and activity	Ventilation rate: Litres/second Good	Fair	m³ per hour Good	Fair	Air changes/h
Odour removal (per person):					
Occupation density 5m³/person	8	5	29	18	1.2-2.0
10m³/person	5	3	18	11	0.4-0.7
15m³/person	3	1.5	11	5.5	0.1-0.25
Removal of tobacco smoke (per average smoker):	7		25		
Wc (4.5m³)	6*		22*		3
Wc and bathroom (12m³)	12*		44*		1.5
Kitchen (10m³) to prevent condensation:					
Gas cooking, non absorbent surfaces	108		390		13
Electric cooking, ditto	75		270		9
Gas cooking, absorbent surfaces	46		166		5.5
Electric cooking, ditto	22		72		2.7
Control of cooking odours only	33		120		4
Minimum for whole dwelling:†					
Minimum					1
To avoid odours and stuffiness					2
To avoid condensation (but at the expense of increasing heat loss)					4

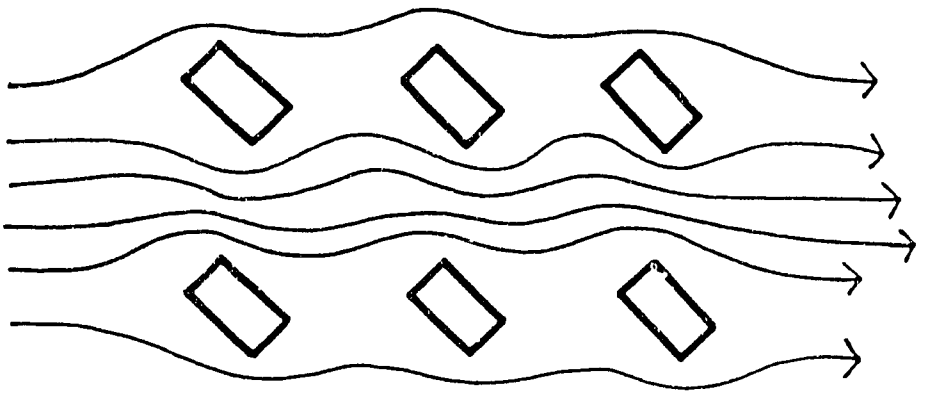
Notes:
*Intermittent artificial ventilation only.
†Dependant on dwelling size and density of occupation. Proportionally higher rates may be required in smaller and more densely occupied dwellings.

CONVERSION FACTORS

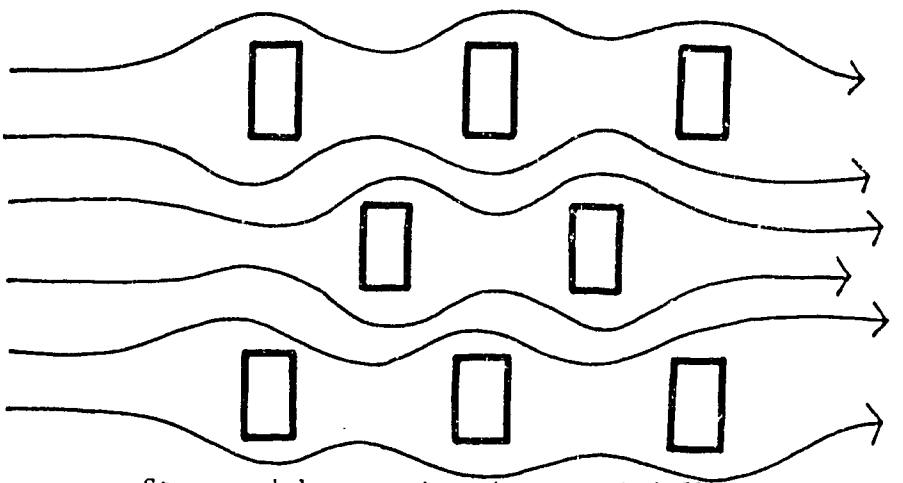
Metres/second	1	0.515	0.447	0.305	0.278
Knots	1.943	1	0.868	0.592	0.540
Miles/hour	2.237	1.152	1	0.682	0.621
Feet/second	3.281	1.689	1.467	1	0.911
Kilometres/hour	3.600	1.853	1.609	1.097	1

(Source: Commonwealth Science Council)

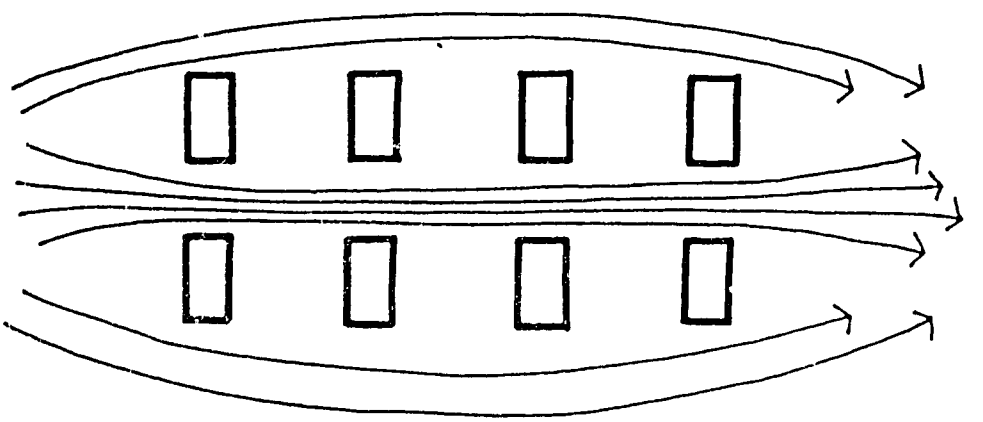
WIND PATTERNS IN SETTLEMENTS



Building orientation diagonal to wind can create more airflow and turbulance around house.



Staggered layout gives better wind flow around houses and a smaller "wind shadow" behind each.

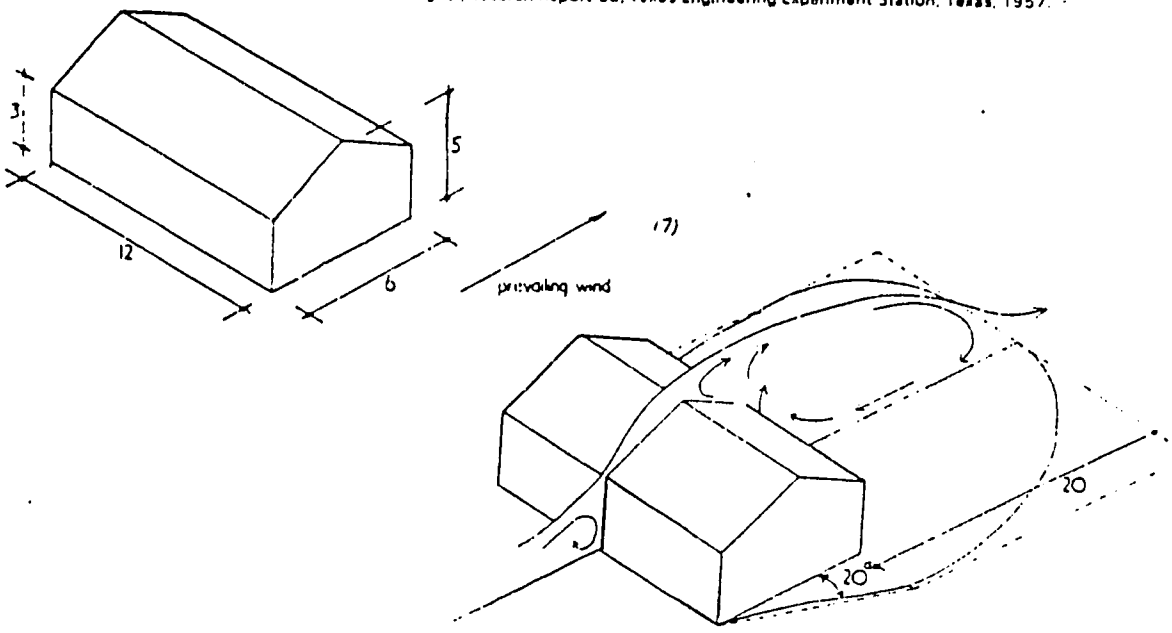


This layout results in buildings crating a large "wind shadow" that reduces wind around downwind houses.

TABLE 7.1 LENGTH OF THE WIND SHADOW OF A BUILDING, IN TERMS OF THE HEIGHT, LENGTH AND WIDTH OF THE BUILDING FORM

Building form Width (W)	Height (H)	Roof pitch	Wind shadow length (xH) Length of the building (L) 2A	4A	8A	16A	24A	Wind direction
A	A	0°	2½	3¾	5½	8	8¾	
2A	A	0°	2	2¾	3¾	6	7	
3A	A	0°	2¼	3¼	4½	5¾	5½	
A	2A	0°	5½	8¼	11¾	16½	18	
A	3A	0°	6¾	11½	16½	18¾	20¾	
2A	2A	45°	2¾	5½	9½	13½	15	
2A	1.6A	30°	3	4	6¾	10	13	
2A	1.5A	15°	3	5½	8½	11½	14½	
2A	1.5A	15°	2½	4½	6½	11	13¾	

Source: R. H. Evans, 'Natural Air Flow around Buildings', Research Report 59, Texas Engineering Experiment Station, Texas, 1957.



Example of the application of Table 7.1

(1) As wind blows against the face of a building a high pressure zone develops.

(2) As the wind escapes upwards a low pressure zone is created over the roof

(3) This low pressure zone extends behind the building and draws the wind stream back towards the ground

(4) A similar flow and pressure distribution is found in plan

(5) Air movement within a building occurs when air moves from an opening in a high pressure zone to an opening in a low pressure zone

(6) Similar movement occurs in plan

(7) The dimensions of a proposed building can be used to find a shape of similar proportions in table 7.1. In this case A = 5, width = 2A, H = 1.6A, roof pitch = 30° and length of building = 4A.

(8) From table 7.1 the length of the wind shadow is found to be four times the height of the building, 4 × 5 = 20m. The shaded area indicates the approximate shape of the area in which air movement will be poor, and the dotted line shows the limit within which other buildings requiring cross ventilation are not recommended.

(Source: Commonwealth Science Council)

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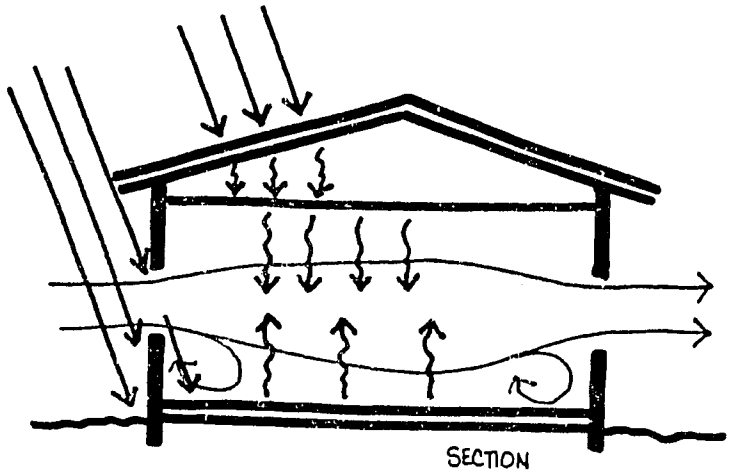
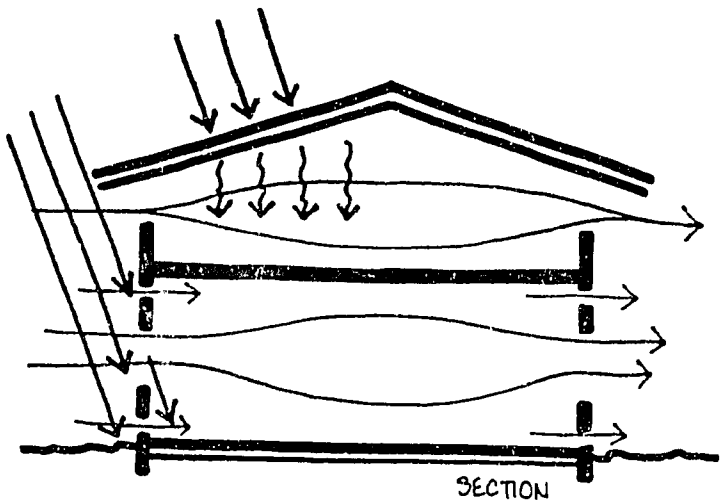
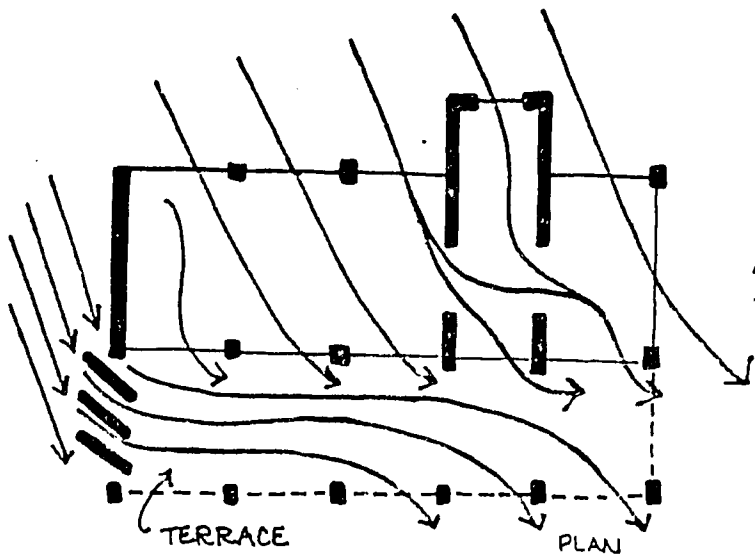


CROSS-VENTILATION THROUGH WINDOWS ONLY MAKES HOT CEILING AND FLOOR



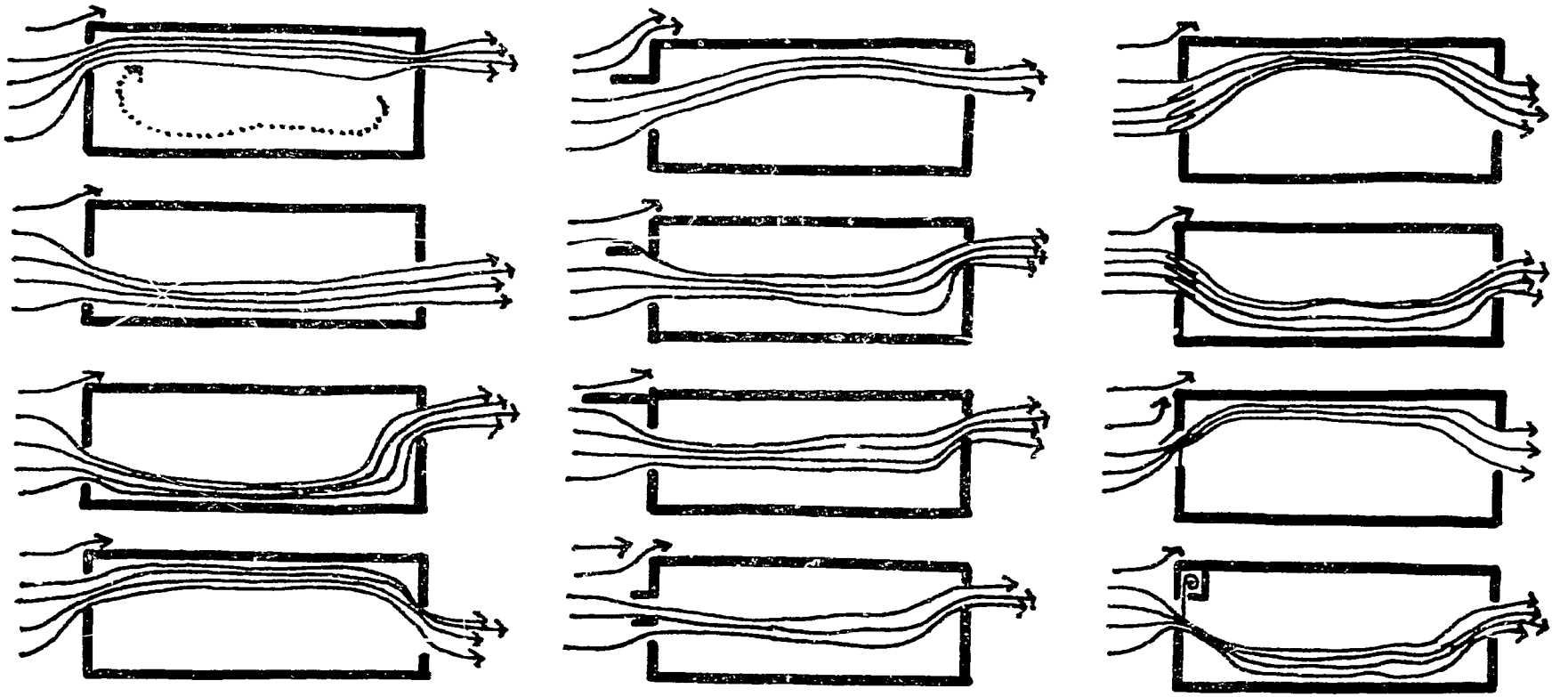
FREE FLOW FOR WIND COOLS TOP OF CEILING

VENT OPENINGS AT TOP AND BOTTOM OF WALL GIVE BETTER COOLING OF CEILING AND FLOOR



ADJUSTABLE LOUVERS DIRECT WIND ONTO TERRACE

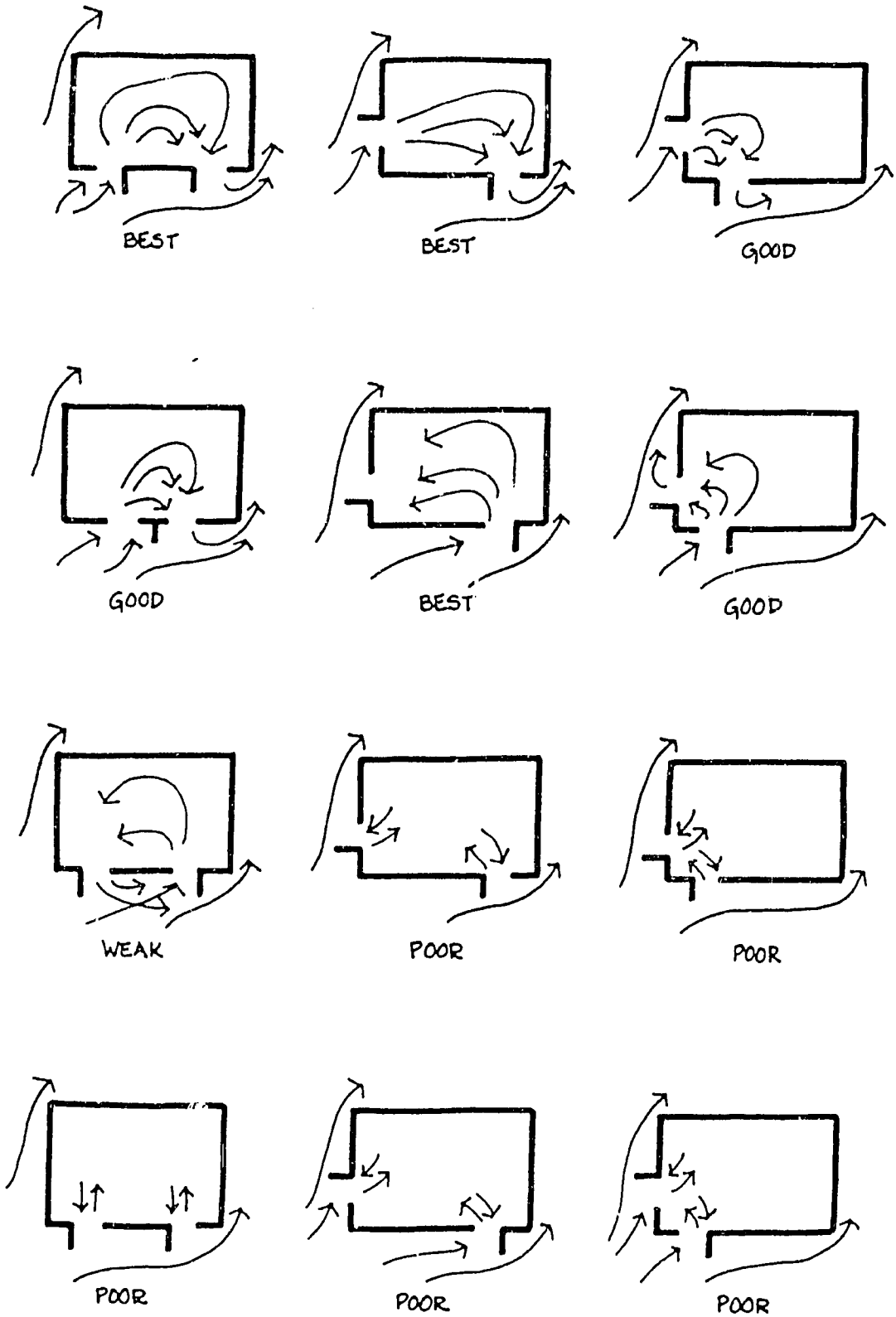
(Source: Kuhn [in Golany])



AIRFLOW PATTERNS WITH DIFFERENT TYPES AND LOCATIONS OF OPENINGS

(Source: Commonwealth Science Council)

USE OF WING WALLS



(Source: Florida Solar Energy Center)

WORKSHEET
BUILDING CROSS-VENTILATION DRIVEN BY WIND

1. House Volume (floor area x celing height) V = _____ m^3
2. Required Airchange Rate in airchanges/hour AH = _____
   (recommended value is 30)
3. Required Ventilation Rate (V x AH) VR = _____ m^3/hr
4. Design Wind Velocity for summer conditions W = _____ m/s
5. Prevailing Wind Direction for summer WD = _____
6. Incidence Angle on windward face of house = _____ °
7. From Table 1, determine:

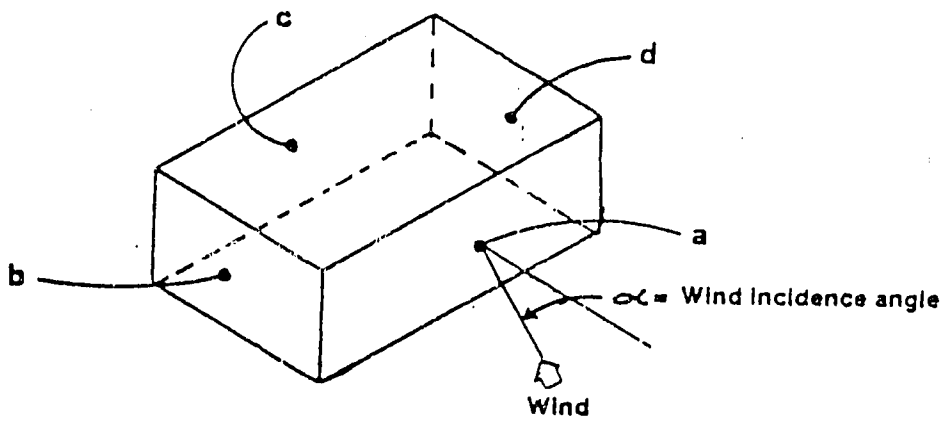
   7a. Windward Pressure Coefficient (normally .4) WPC = _____
   7b. Leeward Pressure Coefficient (normally -.25) LPC = _____
8. Coefficient Differential (WPC - LPC) CD = _____
9. From Table 2, determine PCCF PCCF = _____
10. Revised Pressure Differential (CD x PCCF) PD = _____
11. Compute Required Open Area of inlet & outlet:

$$ROA = \text{inlet area} = \text{outlet area} = \frac{VR}{2288\ W\ \sqrt{PD}} = _____\ m^2$$

12. Identify Inlet Porosity Factor from Table 3 IPF = _____
13. Inlet Opening Size = ROA ÷ IPF = _____ m^2
14. Identify Outlet Prosity Factor from Table 3 OPF = _____
15. Outlet Opening Size = ROA ÷ OPF = _____ m^2

(Source: Florida Solar Energy Center)

TABLE 1 Typical Surface Average Pressure Coefficients on the Walls of a Residential Scale Building



Wind angle	Building Wall Surface Pressure Coefficients, PC at Surfaces			
α	a	b	c	d
0	+0.40	-0.40	-0.25	-0.40
22.5	+0.40	-0.06	-0.40	-0.60
45	+0.25	+0.25	-0.45	-0.45
67.5	-0.06	+0.30	-0.55	-0.40
90	-0.40	+0.40	-0.40	-0.25

Source - Colorado State University wind tunnel tests on a 1:25 scale model of the Florida Solar Energy Center Passive Cooling Laboratory

Notes: Recommended Pressure Coefficient, PC values for other apertures are
1. Inlet with wingwall assist, PC = +0.40
2. Outlet with wingwall assist, PC = -0.25
3. Roof outlets (e.g. venturi type), PC = -0.30

Table 2. Pressure Coefficient Correction Factor

Height of typical upwind buildings = _____ m

Distance between buildings = _____ m

Ratio of $\frac{\text{distance between buildings}}{\text{height of upwind buildings}}$ _____

Ratio	PCCF
0	0.00
1	0.17
2	0.40
3	0.59
4	0.73
5	0.87
6 or greater	1.00

Table 3. Porosity Factors (PF)

a) Insect screening porosity factor, SPF

	Screen type	Typical SPF
i.	No screen	1.00
ii.	Bronze, 14 wires/inch	0.80
iii.	Fiberglass, 18 wires/inch	0.60

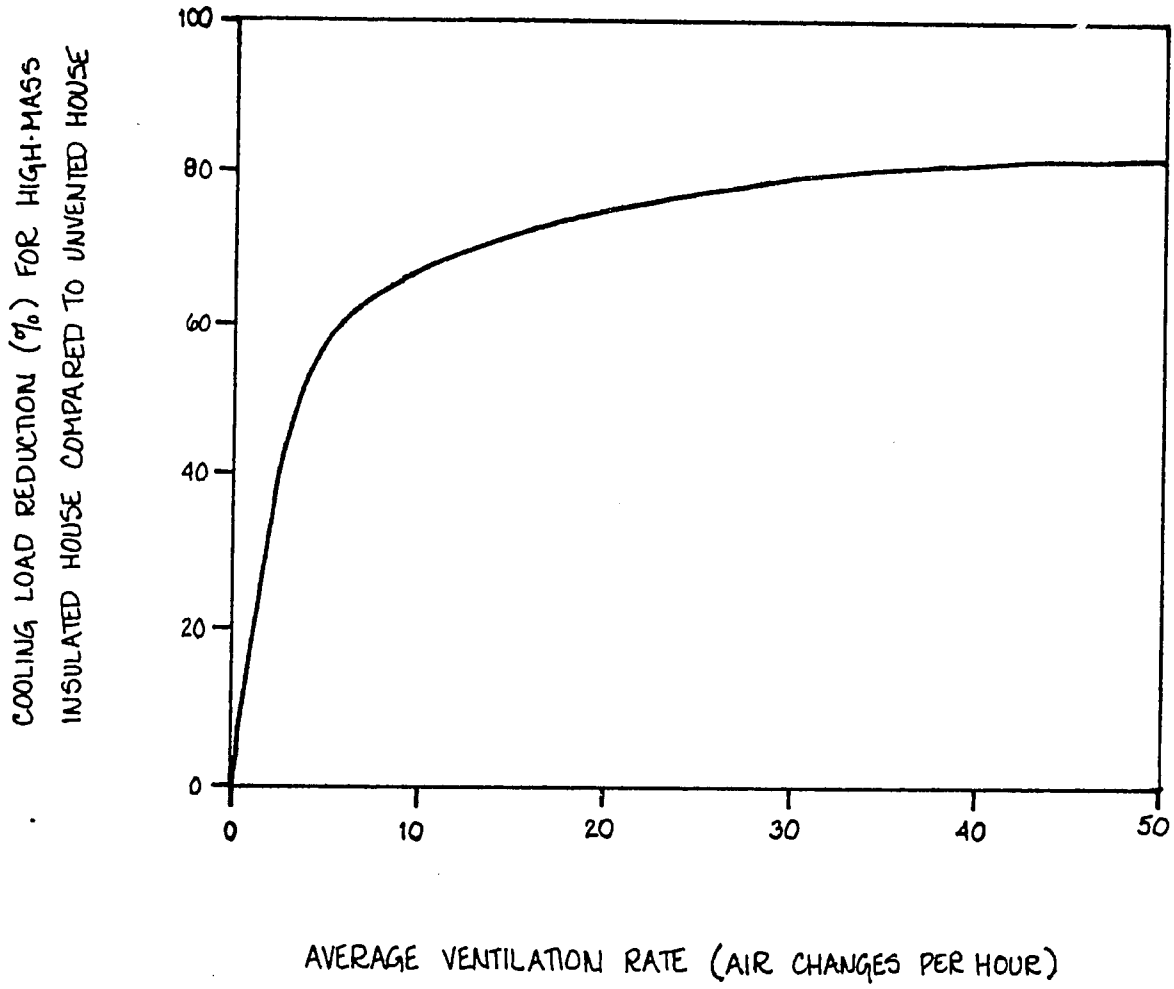
b) Window porosity factor, WPF

	Window Type	Typical WPF
i.	Single or double hung	0.40
ii.	Awning, Hopper, Jalousie or Projection which swivel open on a horizontal pilot	0.60
iii.	Casement.	.70-.90 depending on fixed sash amount. Need to measure porosity

Porosity Factor, PF = SPF x WPF = _____

Note: Above SPF's assume that interior drapes or shades will not be blocking any wind.

VENTILATION RATE SENSITIVITY



(Source: Kammerud)

VENTILATION COOLING BY STACK EFFECT

The following equation can be used to calculate the approximate ventilation flow rate resulting from inside - outside temperature difference (see illustration on following page):

$$V_S = K \cdot A \cdot \sqrt{h\ \Delta T}$$

V_S = the stack-effect ventilation rate (m^3/sec)

A = the area of the smaller ventilation opening, either high or low, assuming both are about the same area (m^2)

K = a constant. assume K = .12 if there is no obstruction to the free flow of air and K = .09 if there are significant obstructions

h = the vertical height between the centers of the two openings (m)

ΔT = the temperature difference between indoor and outdoor air (°K)

To calculate the heat removed by this flow:

$$Q_V = 1200 \cdot V_S \cdot \Delta T$$

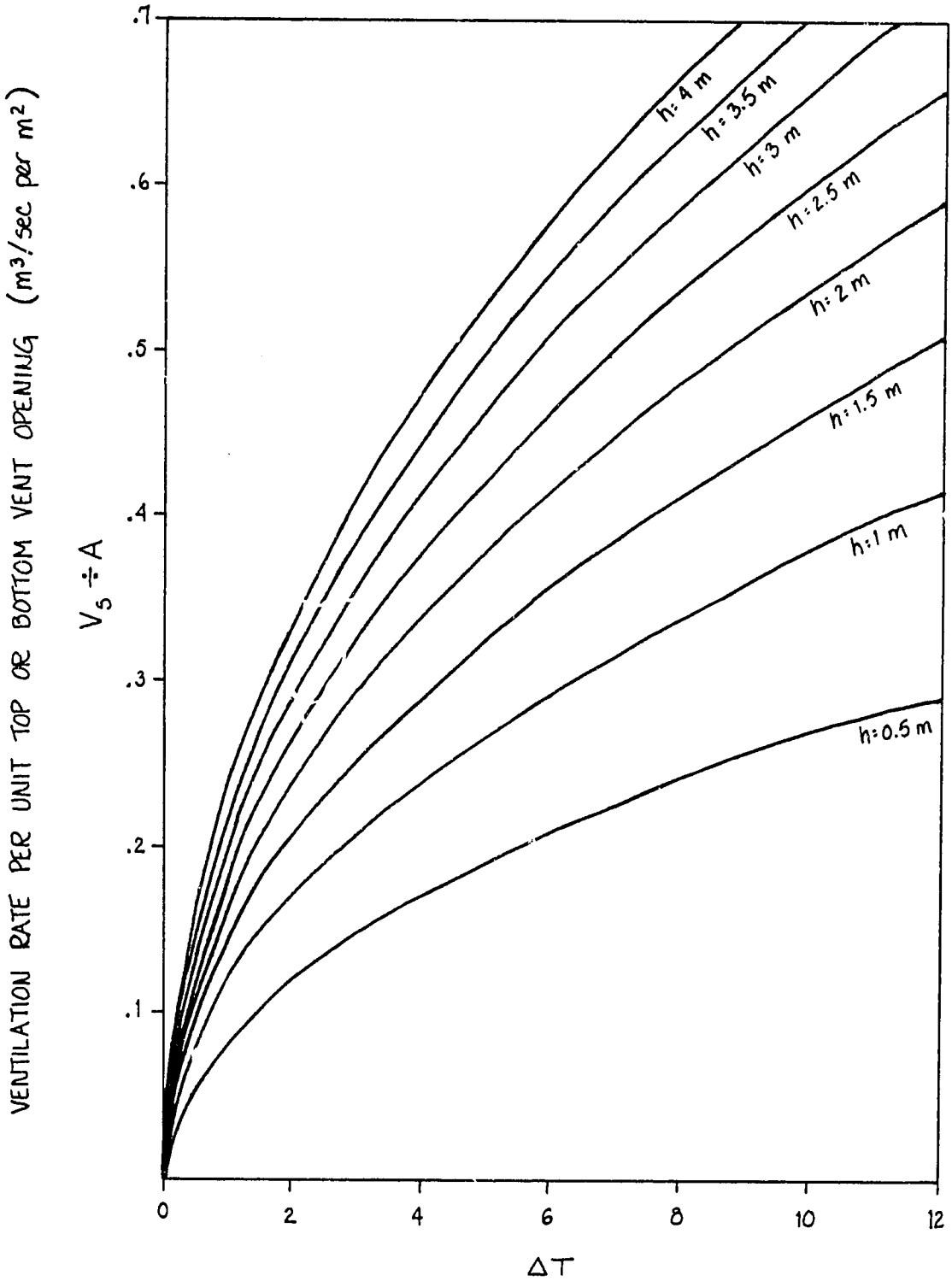
Q_V = the rate of heat removal (W)

1200 = the typical volumetric specific heat of air (J/m^3°K)

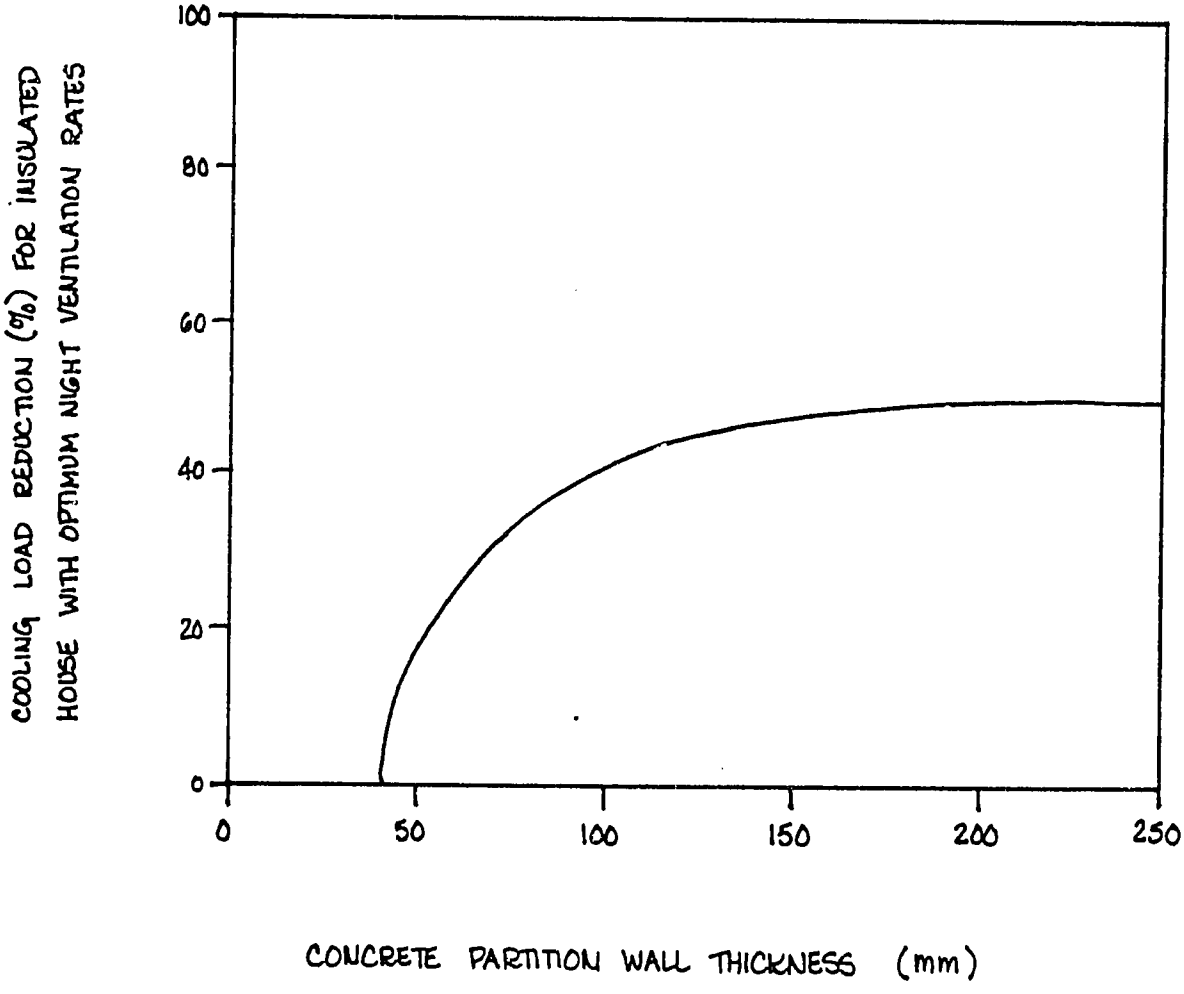
V_S = the stack-effect ventilation rate determined above (m^3/sec)

ΔT = the temperature difference between indoor and outdoor air (°K)

STACK-DRIVEN VENTILATION



THERMAL STORAGE THICKNESS SENSITIVITY
FOR NIGHT VENTILATION COOLING



(Source: Kammerud)

9. SELECTION OF BUILDING ENERGY STRATEGIES

SELECTION OF BUILDING ENERGY STRATEGIES

The examples presented in this section illustrate the process of selecting among the many possible energy conservation and passive solar strategies which are available for a particular building. In this case, the base case house is a small low to middle income home in Gaborone. A description of this base case house in found in the table at the top of the next page. The energy performance of the house and various design options for it were modelled with the computer simulation model CALPAS3, which simulates dynamic building thermal behavior for each hour of a typical year.

The table at the bottom of page 9-2 presents the annual heating and cooling energy loads of various designs, based on winter heating set-point temperature of 20° during the day and 13° at night, and a summer cooling set-point of 25°. While few homes in Botswana have mechanical cooling and heating systems, these "loads" are useful in ranking the relative impact of different design options. This is followed by several pages with graphs of hourly indoor temperatures predicted for various design options on average winter and summer days. These graphs assume no mechanical cooling, a winter heating set-point of 15° during the day and 12° at night, and that windows or other vents will be opened when the temperature rises above 25°.

DESIGN OPTIONS CONSIDERED IN COMPUTER SIMULATIONS

- move all windows to north and south sides of building
- paint the roof white (or start with a white roof material)
- reduce the infiltration level by 50%
- add 25mm of insulation to ceiling
- add 50mm of insulation to ceiling
- add $2.5m^2$ low and $2.5m^2$ high vent openings on walls
- paint walls white
- paint all walls white except north, to be painted dark
- relocate 75% of windows to north side of building
- add a .5 m overhang on all sides of the building

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BASE CASE BUILDING

LOCATION : Gabarone

FLOOR AREA : 49 m^2

DIMENSIONS : 4.95 m x 9.9 m

WALL : 220 mm concrete block w/ 10 mm plaster

FLOOR : 100 mm concrete slab

ROOF : flat galvanized sheet w/ rhinoboard 100 mm below

OUTSIDE WALL AREA: 61.5 m^2

WINDOWS : four - 1.22 m^2 each

PREDICTED HEATING AND COOLING LOADS FOR VARIOUS BUILDING ENERGY OPTIONS

		ANNUAL LOAD HEATING (MJ)	ANNUAL LOAD COOLING (MJ)
# 1	"base case" building - equal windows on all sides	6772	41857
# 2	move windows - 50% on north, 50% on south + .5 m overhang all sides	--	---
# 3	#2 + roof painted white	9540	19156
# 4	#3 + infiltration reduced	6428	18056
# 5	#3 + 50 mm roof insulation	7354	11375
# 6	#3 + larger vents	9446	17119
# 7	#3 + reduced infiltration + 50 mm roof insulation + larger vents	4135	8188
# 8	#3 + 25 mm roof insulation	7590	12371
# 9	#8 + larger vents	7640	10410
#10	#8 + infiltration reduced	4425	11241
#11	#8 + larger vents + reduced infil	4300	9202
#12	#11 + dark north wall, others light	--	---
#13	#11 + 75% of windows on north	3786	8713
#14	#11 + all light walls	5131	7750

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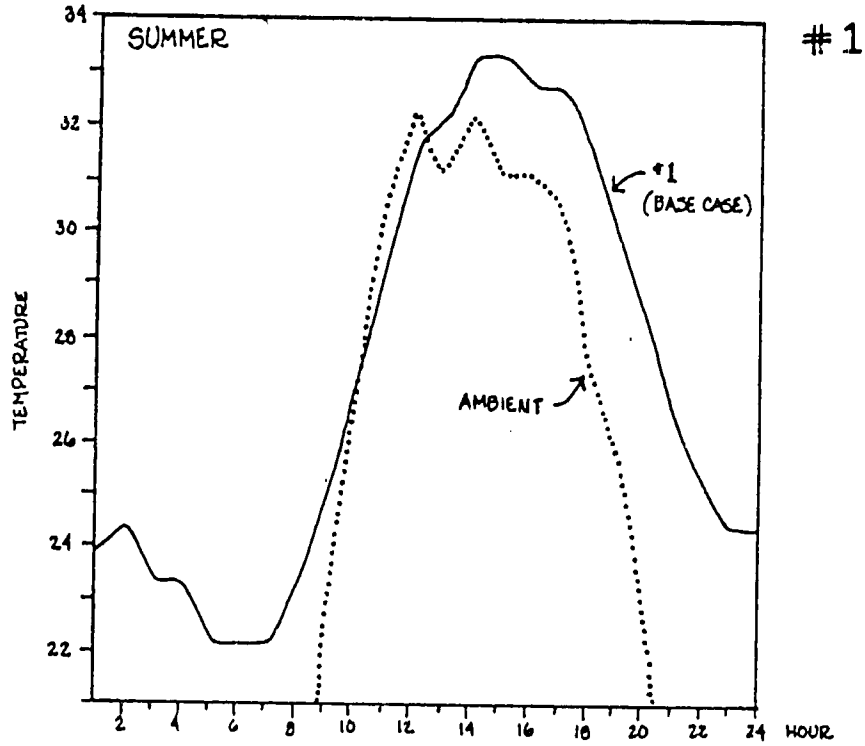
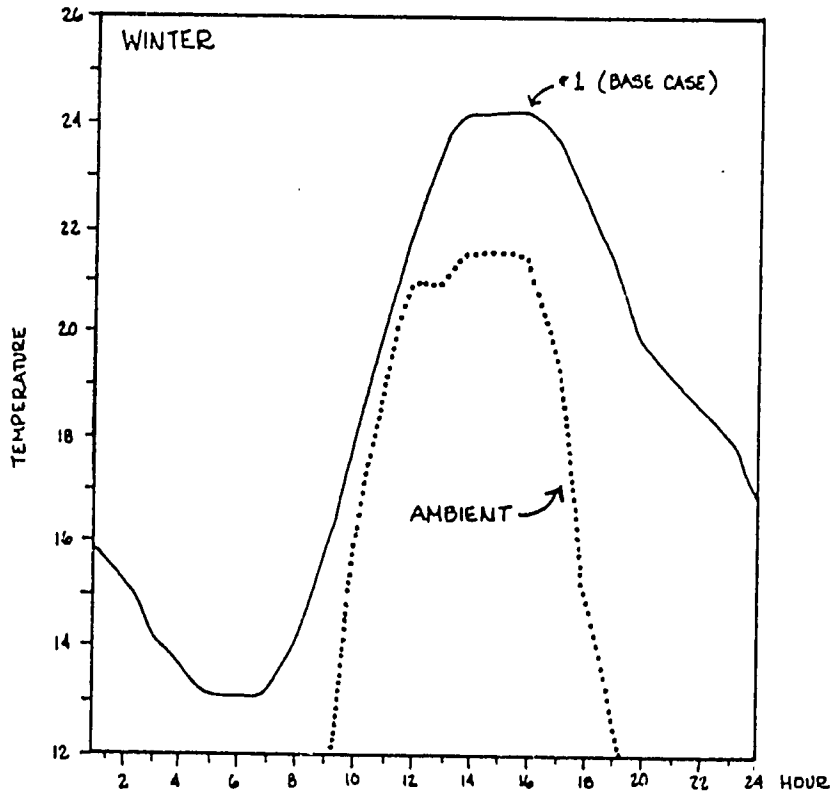
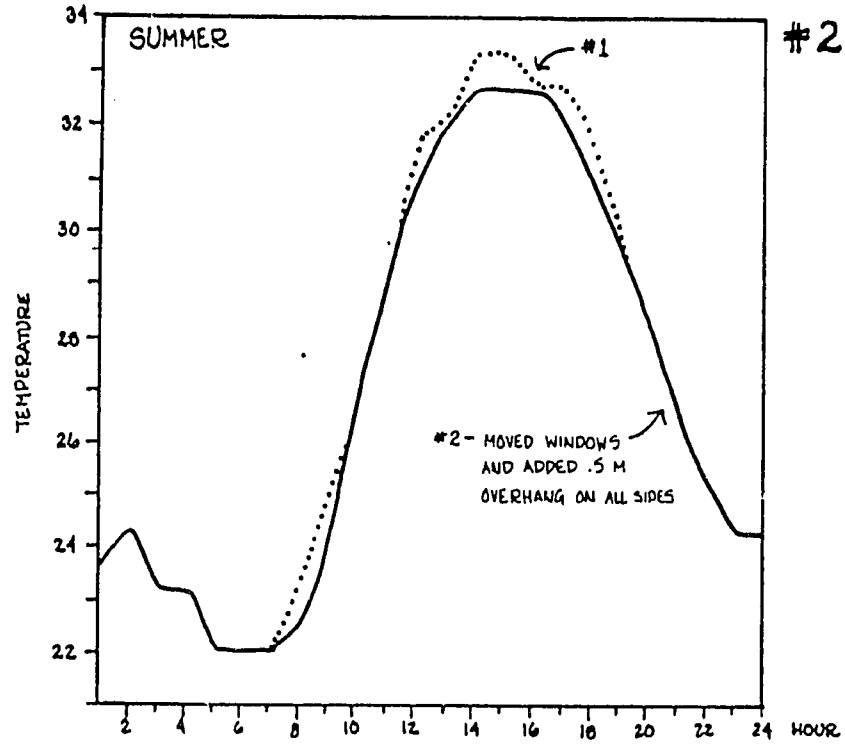
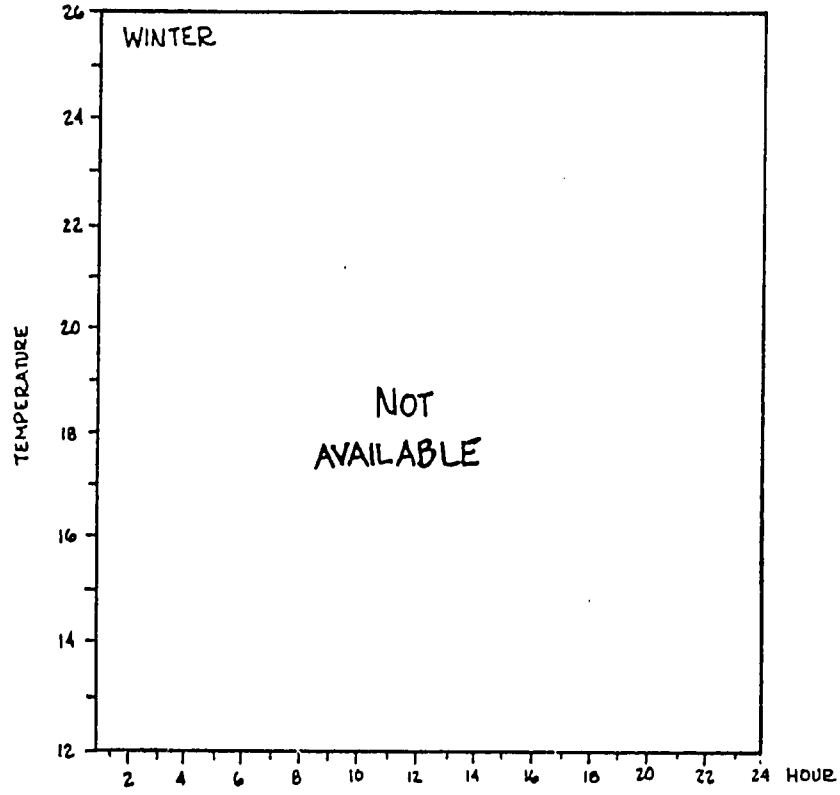

SUMMER
#1
#1
(BASE CASE)
AMBIENT
TEMPERATURE
34
32
30
28
26
24
22
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

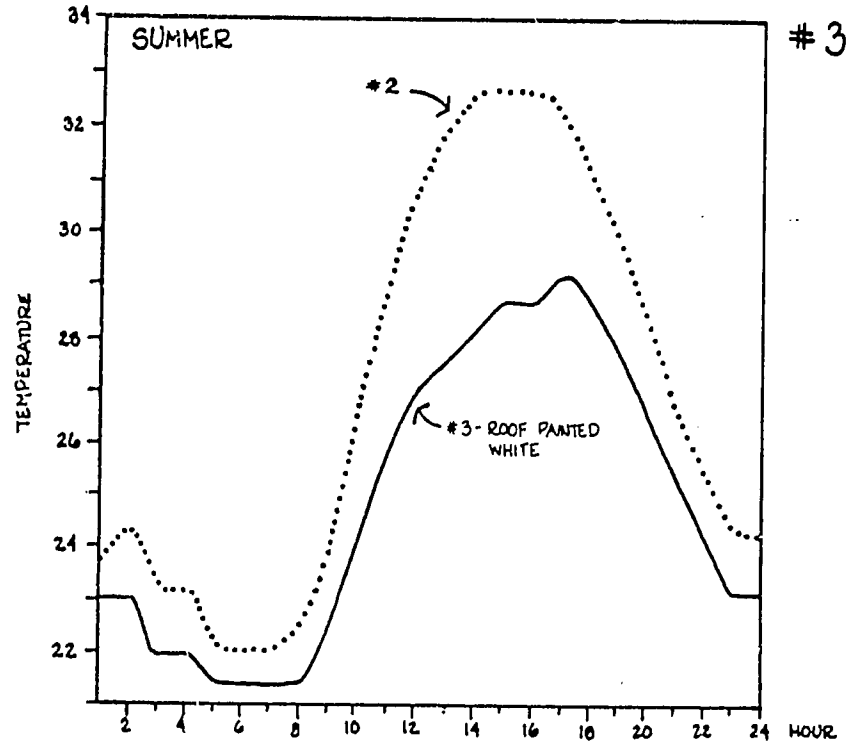

WINTER
#1 (BASE CASE)
AMBIENT
TEMPERATURE
26
24
22
20
18
16
14
12
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

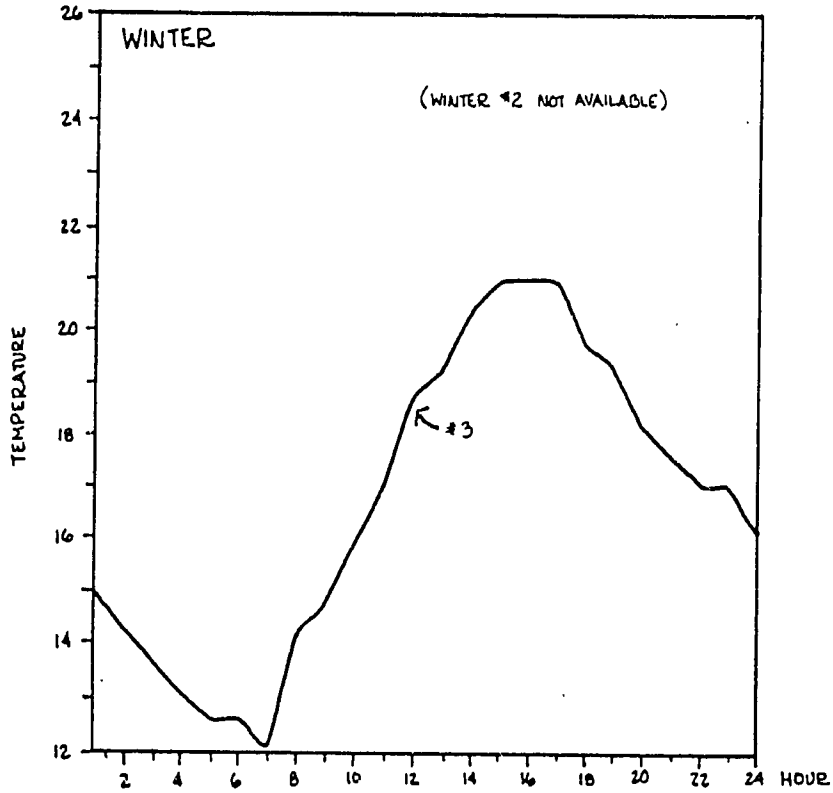
148


SUMMER
#2
#1
#2 - MOVED WINDOWS AND ADDED .5 M OVERHANG ON ALL SIDES
TEMPERATURE
34
32
30
28
26
24
22
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

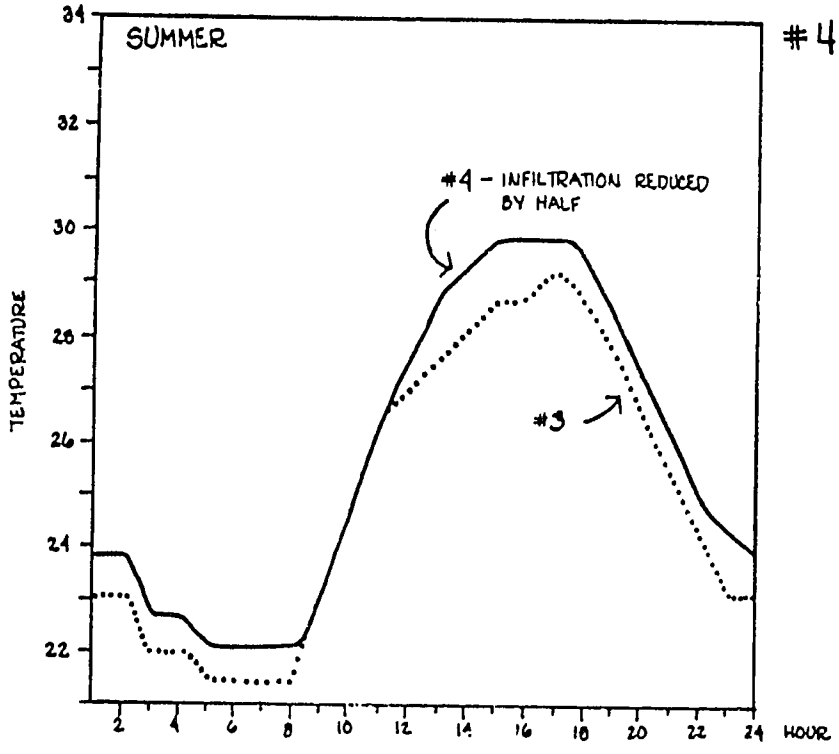

WINTER
NOT AVAILABLE
TEMPERATURE
26
24
22
20
18
16
14
12
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

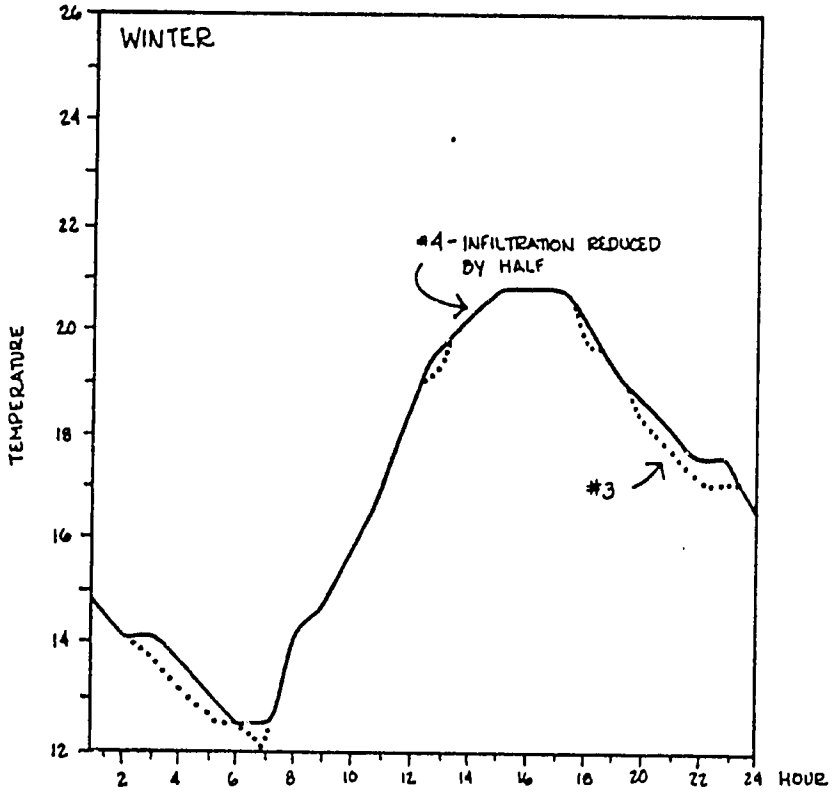
141


SUMMER
#3
#2
#3 - ROOF PAINTED WHITE
TEMPERATURE
34
32
30
28
26
24
22
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

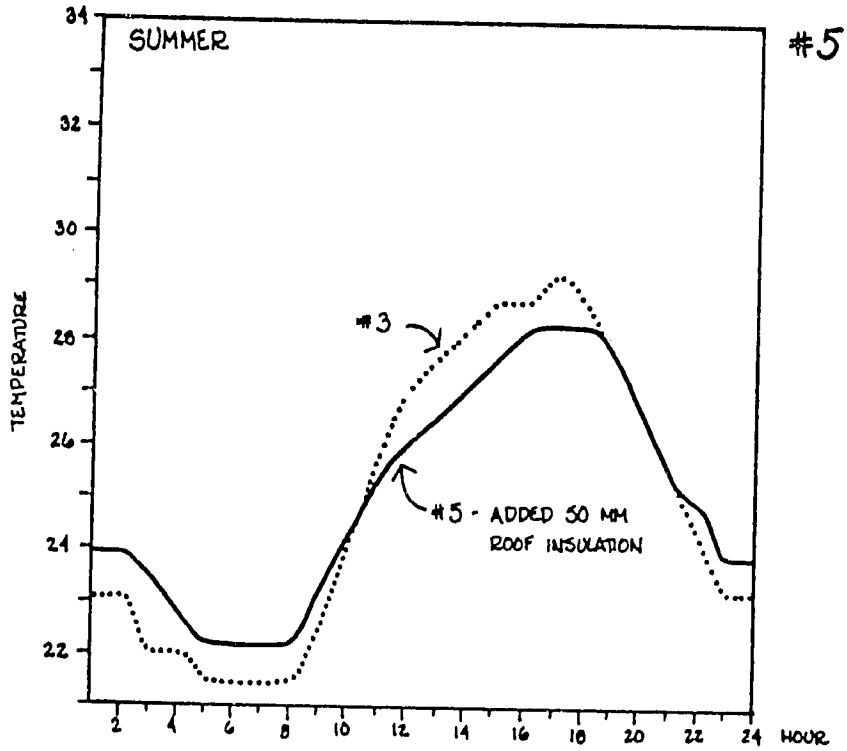

WINTER
(WINTER #2 NOT AVAILABLE)
#3
TEMPERATURE
26
24
22
20
18
16
14
12
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

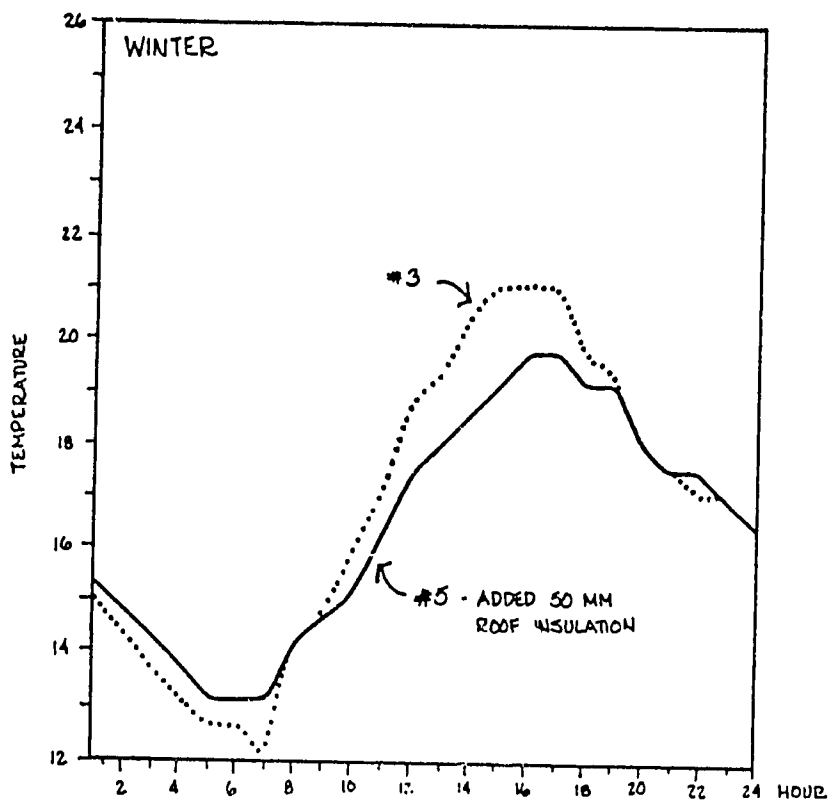
150


SUMMER
#4
#4 - INFILTRATION REDUCED BY HALF
#3
TEMPERATURE
34
32
30
28
26
24
22
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

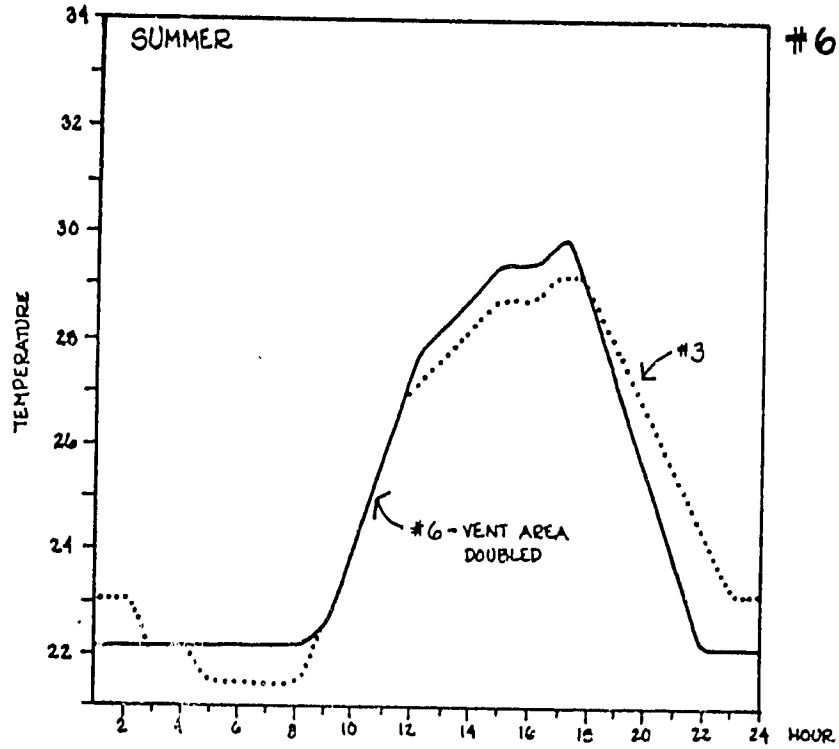

WINTER
#4 - INFILTRATION REDUCED BY HALF
#3
TEMPERATURE
26
24
22
20
18
16
14
12
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

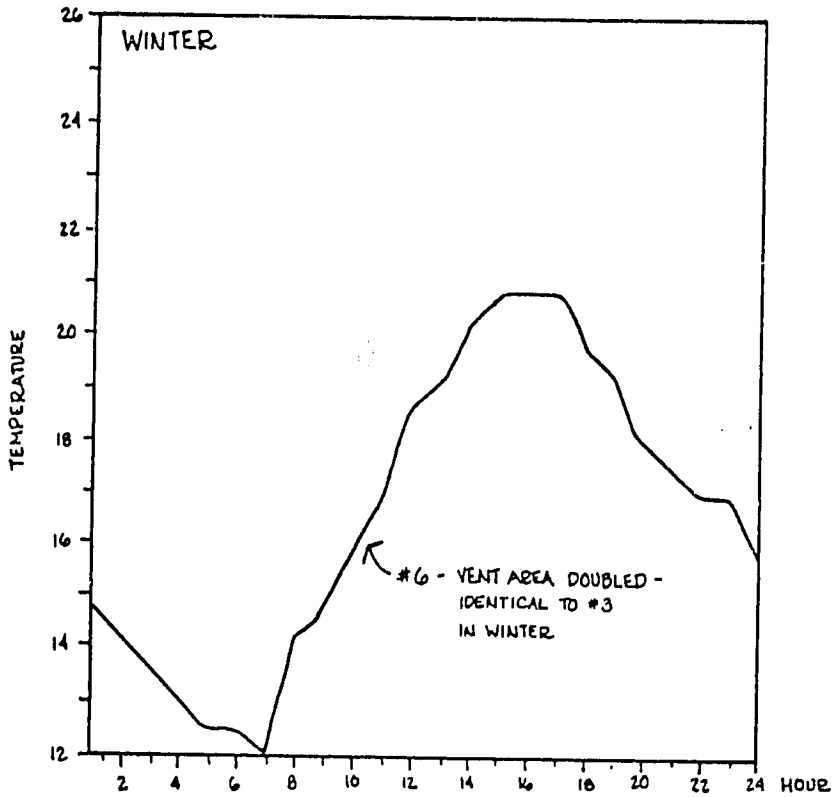
151

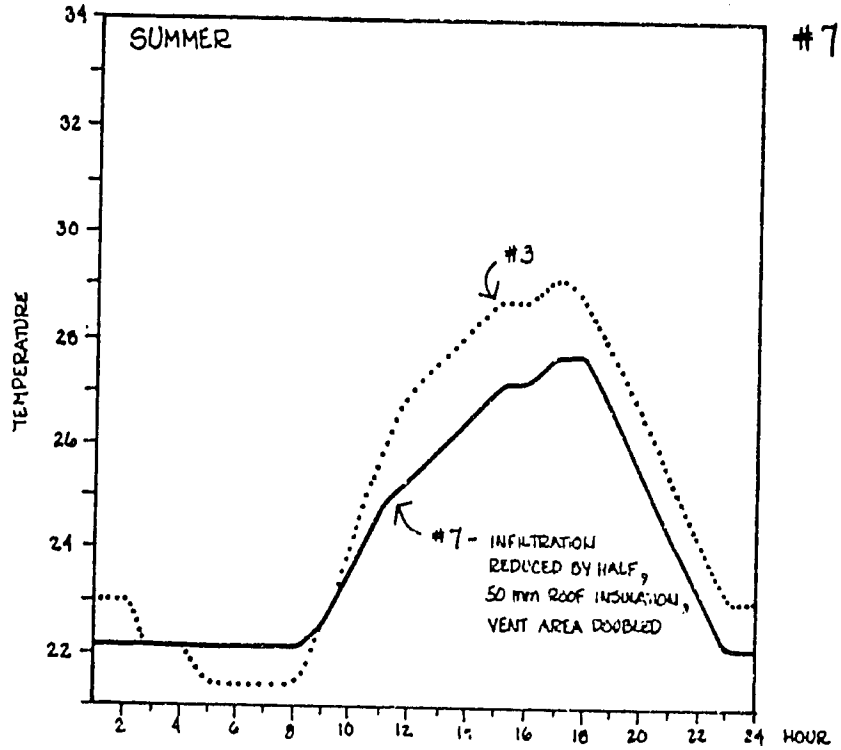

SUMMER
#5
TEMPERATURE
34
32
30
28
26
24
22
#3
#5 - ADDED 50 MM
ROOF INSULATION
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

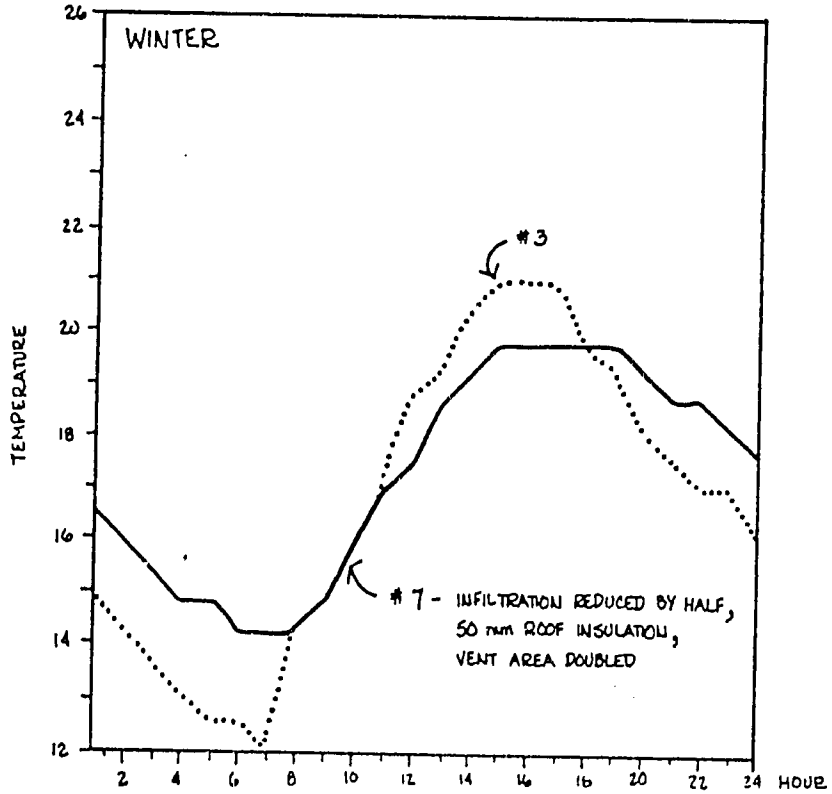

WINTER
TEMPERATURE
26
24
22
20
18
16
14
12
#3
#5 - ADDED 50 MM
ROOF INSULATION
2
4
6
8
10
14
16
18
20
22
24
HOUR

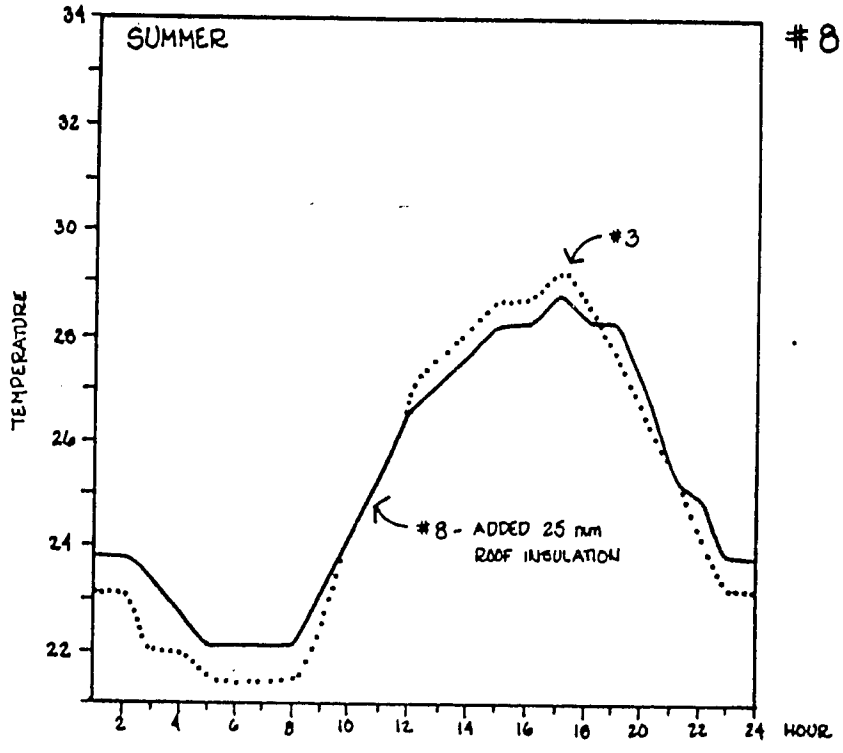
152

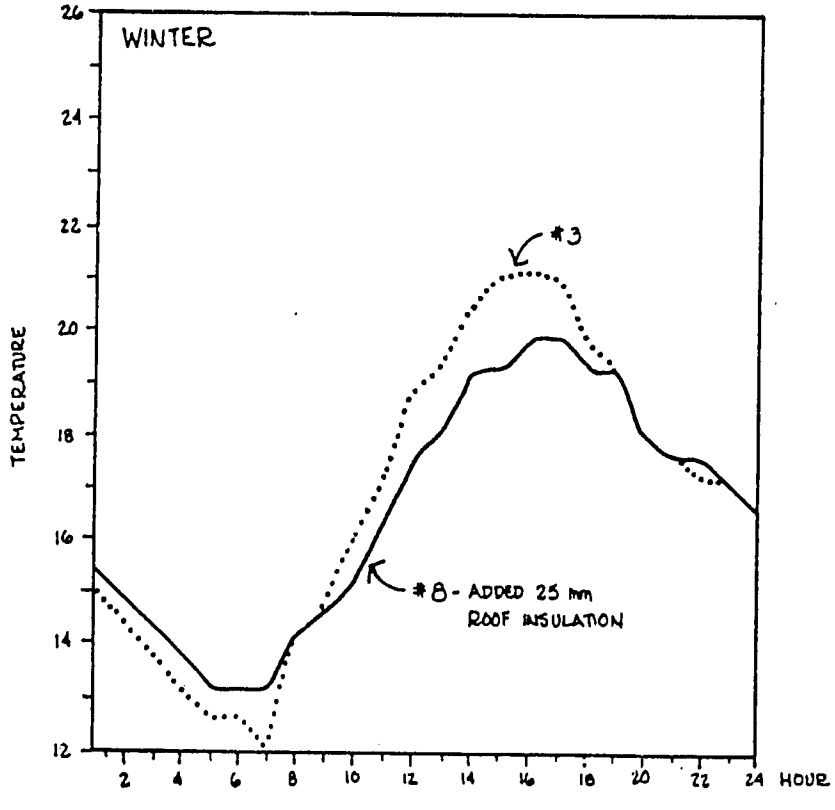

SUMMER
#6
TEMPERATURE
34
32
30
28
26
24
22
#3
#6 - VENT AREA DOUBLED
2
4
6
8
10
12
14
16
18
20
22
24
HOUR


WINTER
TEMPERATURE
26
24
22
20
18
16
14
12
#6 - VENT AREA DOUBLED - IDENTICAL TO #3 IN WINTER
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

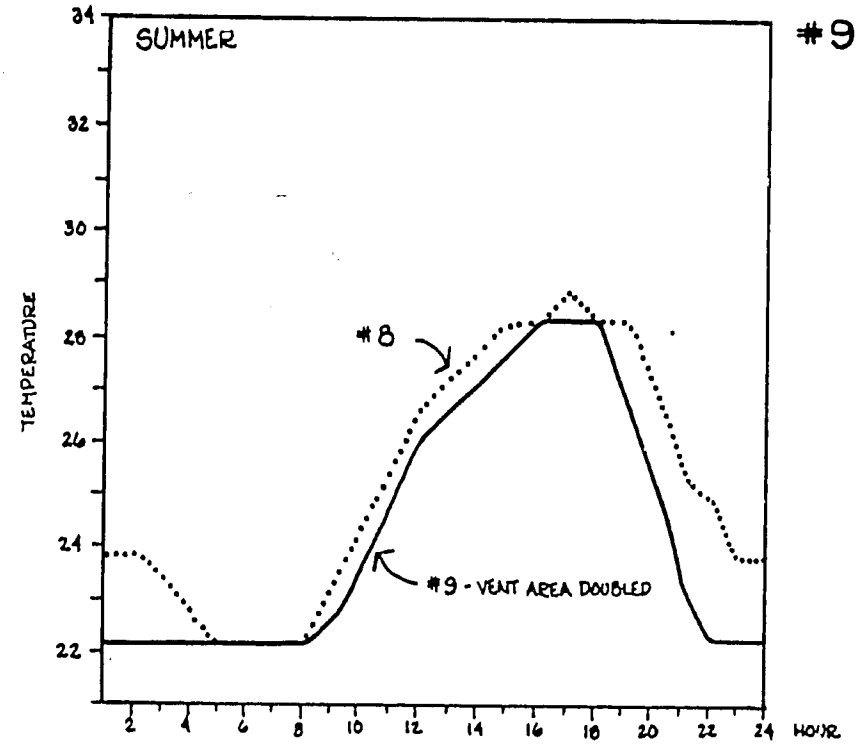

SUMMER
#7
#3
#7 - INFILTRATION REDUCED BY HALF, 50 mm ROOF INSULATION, VENT AREA DOUBLED
TEMPERATURE
HOUR

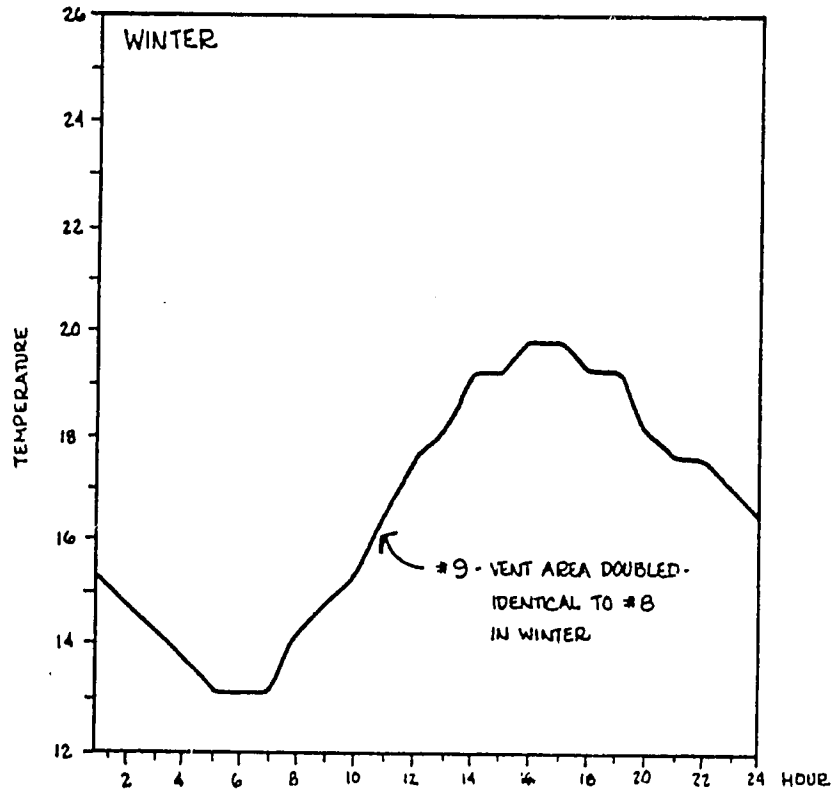

WINTER
#3
#7 - INFILTRATION REDUCED BY HALF, 50 mm ROOF INSULATION, VENT AREA DOUBLED
TEMPERATURE
HOUR

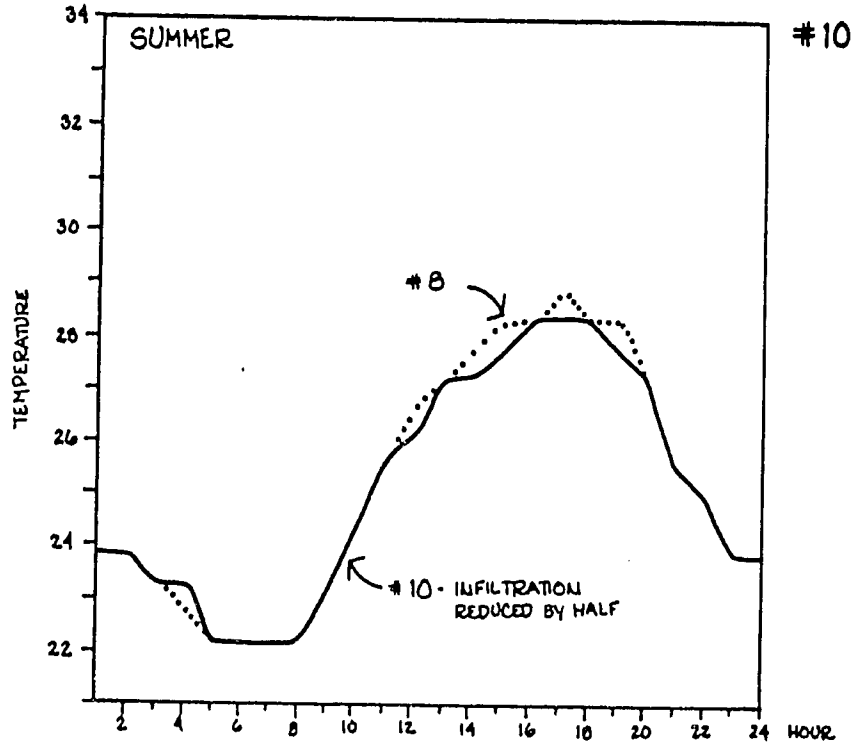

SUMMER
#8
#3
#8 - ADDED 25 mm
ROOF INSULATION
TEMPERATURE
HOUR
34
32
30
28
26
24
22
2
4
6
8
10
12
14
16
18
20
22
24

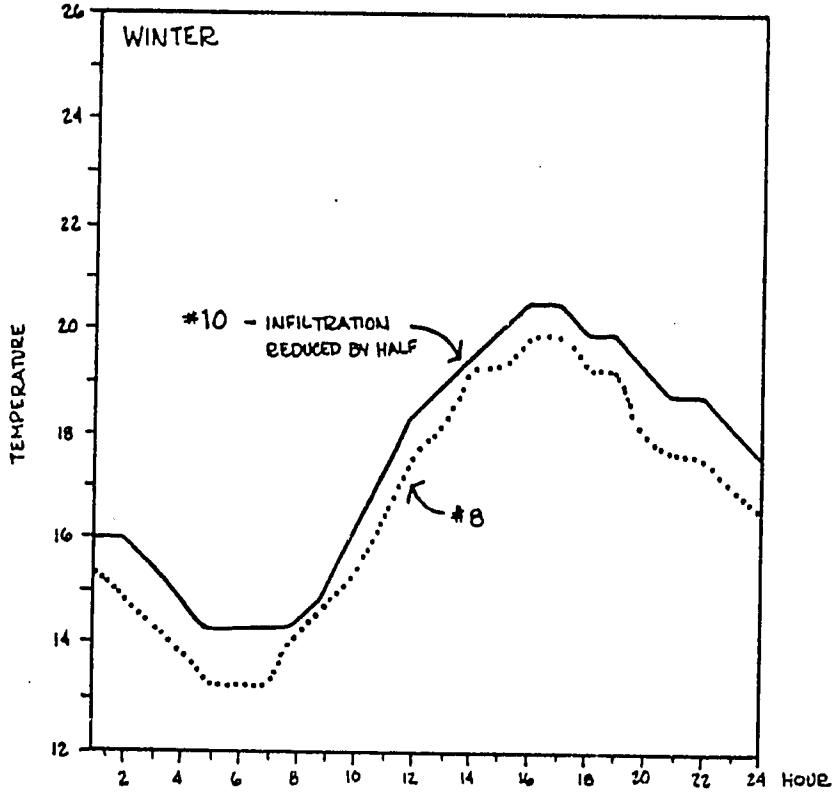

WINTER
#3
#8 - ADDED 25 mm
ROOF INSULATION
TEMPERATURE
HOUR
26
24
22
20
18
16
14
12
2
4
6
8
10
12
14
16
18
20
22
24

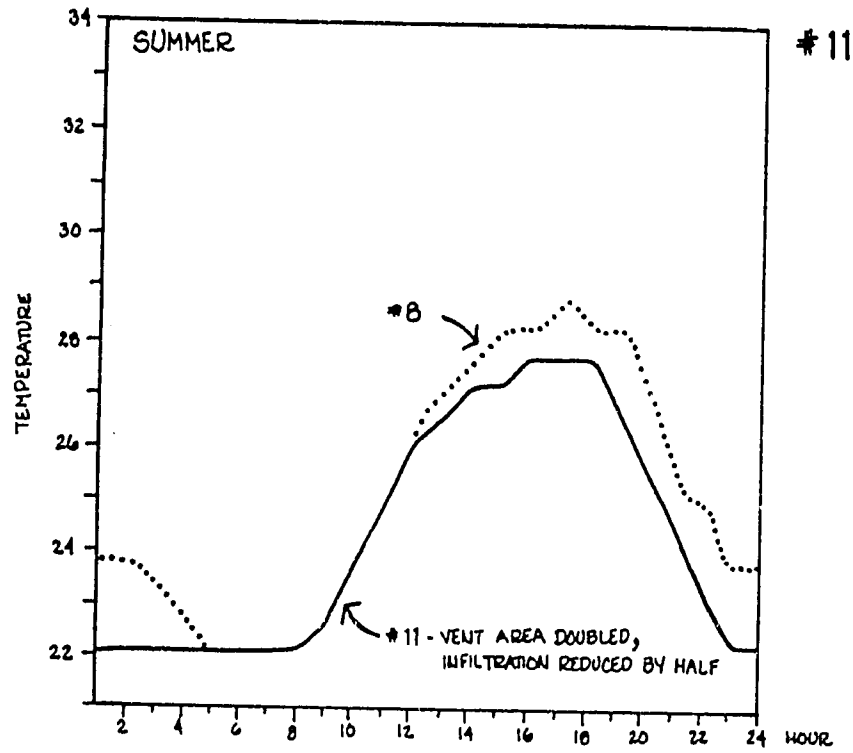
153

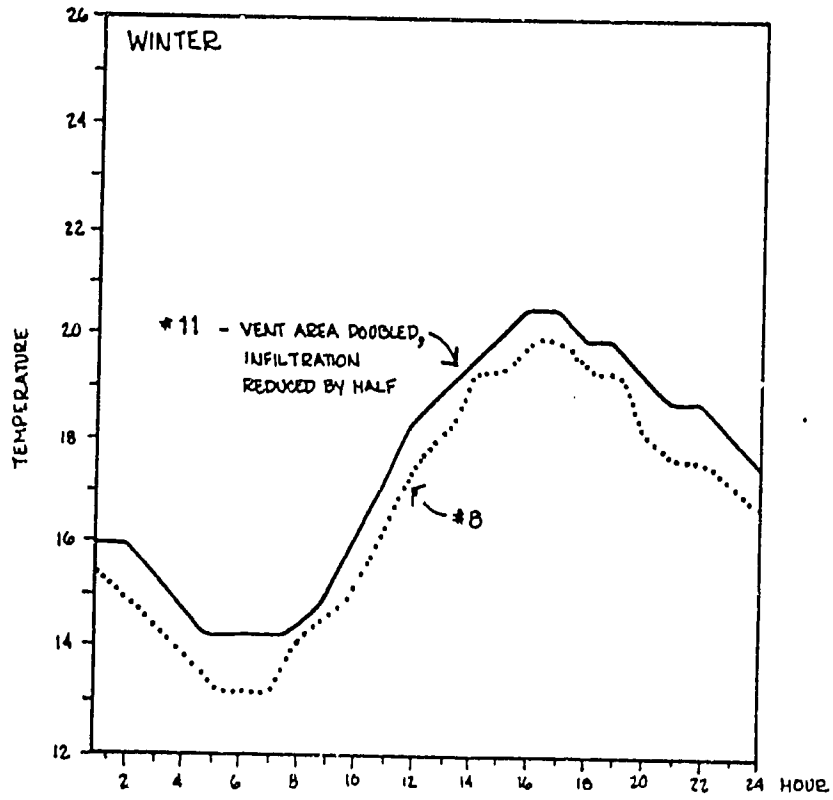

SUMMER
#9
TEMPERATURE
34
32
30
28
26
24
22
#8
#9 - VENT AREA DOUBLED
2
4
6
8
10
12
14
16
18
20
22
24
HOUR


WINTER
TEMPERATURE
26
24
22
20
18
16
14
12
#9 - VENT AREA DOUBLED -
IDENTICAL TO #8
IN WINTER
2
4
6
8
10
12
14
16
18
20
22
24
HOUR


SUMMER
#10
#8
#10 - INFILTRATION REDUCED BY HALF
TEMPERATURE
34
32
30
28
26
24
22
2
4
6
8
10
12
14
16
18
20
22
24
HOUR


WINTER
#10 - INFILTRATION REDUCED BY HALF
#8
TEMPERATURE
26
24
22
20
18
16
14
12
2
4
6
8
10
12
14
16
18
20
22
24
HOUR


SUMMER
#11
TEMPERATURE
34
32
30
28
26
24
22
#8
#11 - VENT AREA DOUBLED, INFILTRATION REDUCED BY HALF
2
4
6
8
10
12
14
16
18
20
22
24
HOUR


WINTER
TEMPERATURE
26
24
22
20
18
16
14
12
#11 - VENT AREA DOUBLED, INFILTRATION REDUCED BY HALF
#8
2
4
6
8
10
12
14
16
18
20
22
24
HOUR

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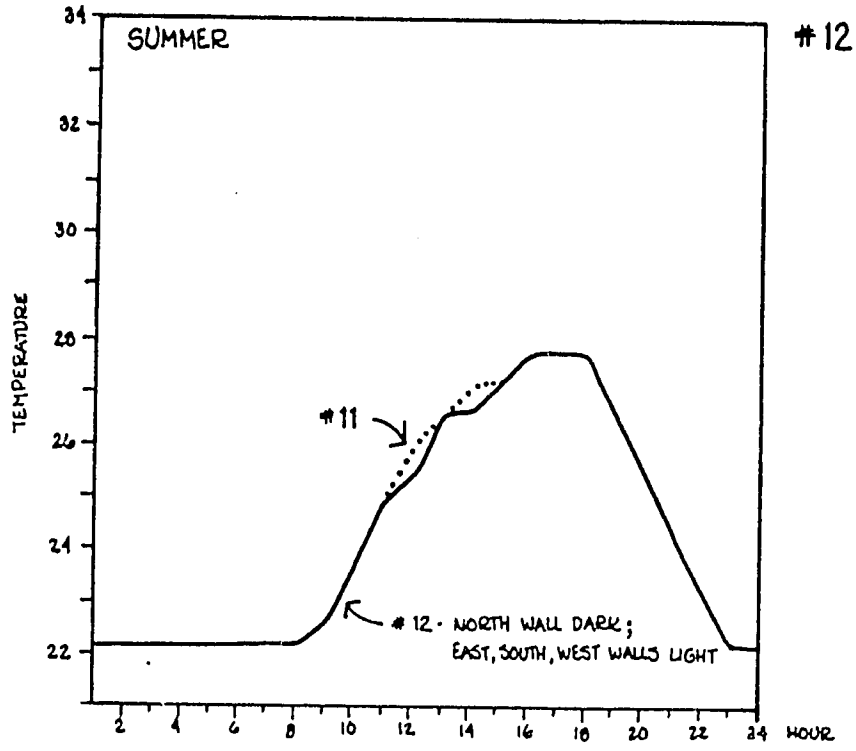
SUMMER
#12
TEMPERATURE
34
32
30
28
26
24
22
#11
12 - NORTH WALL DARK;
EAST, SOUTH, WEST WALLS LIGHT
2
4
6
8
10
12
14
16
18
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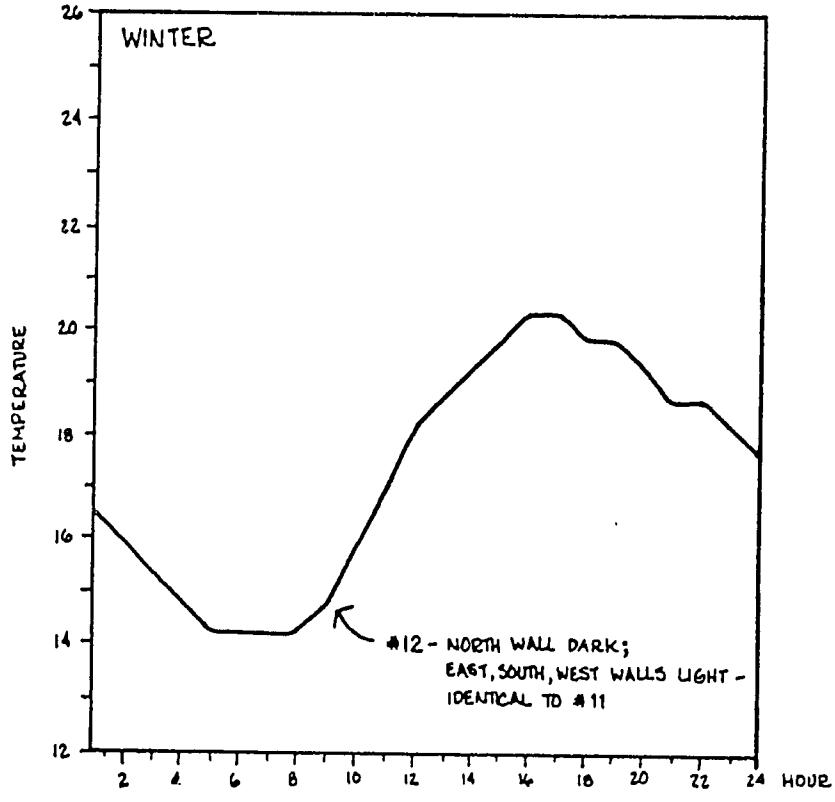
22
24
HOUR


WINTER
TEMPERATURE
26
24
22
20
18
16
14
12
#12 - NORTH WALL DARK;
EAST, SOUTH, WEST WALLS LIGHT -
IDENTICAL TO #11
2
4
6
8
10
12
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16
18
20
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24
HOUR

10. BUILDING ENERGY ECONOMICS

BUILDING ENERGY ECONOMICS

by Rick McGowan

This section on economics points out some of the more important issues which must be considered by decision makers as well as designers for determining the economic and financial value of energy conserving housing designs. An outline of the advantages and disadvantages of the incorporation of these designs is given on the following pages. Both macro and micro economic perspectives are mentioned. Different analytical figures of merit are defined. The limitations of the application of economic analysis to energy conserving building designs are examined.

Finally, a detailed analytical method for the financial evaluation of a particular design option is presented. An example of the method is worked through, and formulas are given for the calculation of each the interim steps in the method. This method is quite suitable for use with a calculator, and a program has been written for the HP-41CV (a listing of this program is available from BRET).

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ECONOMICS OUTLINE

I. Reasons to Consider Energy Conserving Passive Design

A. Incentives

1. Reduces dependence on imported energy resources.
2. Increased comfort levels in buildings.
3. Frequently high return on relatively small incremental initial investment.
4. Reduces average and peak loading conditions for utilities, precluding unnecessary expansion of capacity expenditures.
5. Labor as opposed to capital intensive investment (supplies much-needed jobs).

B. Disincentives

1. Higher initial capital investment for builder.
2. Non-standard construction techniques/designs require additional training of architects/contractors/builders.
3. Some design options (i.e. direct gain) must overcome social resistance to their use (due to privacy concerns).

II. Economic Analysis Techniques

A. General Approach

1. Purpose.

2. Quantifying Costs and Benefits:

   a. Estimate both cooling/heating loads for base case and design options,

   b. Estimate contruction cost for each option,

   c. Obtain energy cost estimates (coal, electrical, etc.) from local utility or retailer.

3. Hard-to-Quantify Costs/Benefits (e.g. comfort levels).

4. Different Perspectives:

   a. home/owner/renter -

      i) increased mortgage payment or rent,

      ii) reduced energy expenses over long term,

      iii) difficulty obtaining additional capital required for construction.

   b. government/utility -

      i) load reduction increases grid reliability,

      ii) savings both in average fuel burned as well as reduction in capacity requirements,

      iii) need to finance R&D, demonstration/dissemination,

      iv) increased political/economic independence,

      v) centralized nature of construction industry provides opportunity for rapid dissemination of designs and construction techniques.

   c. micro-economic (e.g. high initial cost vs. life cycle savings) vs. macro-economic (recognizing value of reduced pollution, dimunition of scarce resources, greater political independence, etc.).

5. List <u>all</u> assumptions made in analysis (discount and inflation rates, labor costs, expected lifetimes, etc.).

6. Limiations:

   a. Lack of precise data on energy costs,

   b. Lack of precise data on energy use,

   c. Necessity to extrapolate economic descriptors (such as inflation, discount rates, etc.).

. Specific Techniques for Economic Analysis

1. Life Cycle Costing.

2. Net Benefits Minus Costs.

3. Benefit/Cost Ratio.

4. Payback Time Analysis.

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ECONOMIC ANALYSIS TECHNIQUES

I. Life Cycle Costing

Compares a base case conventional building to an energy-conserving passive-designed building, by assigning a time value to money (inflation, discount rate), considering all costs over the system's lifetime and discounting those costs to the present.

The system with the lower total life-cycle costs, while still within the spending constraints of the builder and consumer, is the preferred system.

It can also be used to compare life-cycle costs of different design options against each other, to determine the most economically desirable option as a fuction of respective energy savings.

2. Net Benefit Minus Costs

Computes the difference between energy savings and total system costs over the economic lifetime of the building. Can be computed for total benefits minus costs or on an annual basis.

The system with the higher net benefits minus costs is the preferred system. The computed value should be positive for net positive savings to be realized.

Can be used to compare conventional versus energy-conserving buildings, or to compare the usefulness of two (or more) energy-conserving design options.

3. Benefit/Cost Ratio

Computes the ratio of the benefits derived from the system in terms of energy savings to all costs accrued over the economic

lifetime of the system. This ratio must be greater than one for net positive savings to be realized.

The system (or design option) with the higher benefit/cost ratio is the preferred system.

4. Payback Time Analysis

Measure elapsed time between point of initial investment and the point at which accumulated savings, net or accumulated costs, equal initial investment cost.

The shorter the payback time, the better the investment.

Can be computed using either undiscounted uninflated costs (simple payback), or including the time value of money (undiscounted payback).

LIMITATIONS OF APPLYING ECONOMIC ANALYSIS TO ENERGY-CONSERVING BUILDING DESIGNS

1. Results can be sensitive to many variables, the values of which are not well known (rates of general and fuel cost inflation, discount rates, etc.) as well as highly variable (construction labor costs in rural versus urban areas).

2. It is often difficult to separate the cost of passive design features from other building costs. For example, a trombe wall acts both as a heat collector/dissipator as well as a structural element. Only the additional costs of passive design features should be considered in economic analysis.

3. For low- and some middle-income dwellings, no actual reduction in energy use would occur by using passive designs, at least regarding the cooling load. No energy expenditures (e.g. air conditioning) are being replaced. Design changes simply result in increased comfort levels, the value of which is difficult to quantify.

4. Since individual builders are unlikely to adopt unfamiliar designs, government must bear the cost of research, development, demonstration and dissemination work. These additional costs will not be included in individual building micro-economic analyses.

FINANCIAL ANALYSIS WORKSHEET

Inflation Rate: ___%; Discount Rate: ___%; Lifetime: ___ years

Option Number-	1	2	3	4
A. Initial Capital Cost of Option (P)				
B. Annual Costs for Operation and Maintenance, 1st Year Payment (P)				
C. Present Worth of Additional Discounted Costs for Replacement/Repairs (P)				
D. Annual Energy Saved (MJ)				
E. Value of Annual Energy Saved @ P 0.___ per MJ *				
F. Net Annual Benefits (P) *				
G. Net Present Worth of Benefit Stream (P) *				
H. Net Present Worth of Benefits Minus Costs (P) *				
I. Benefit/Cost Ratio				

*Notes:

1. E=D times cost per MJ of energy
2. F=E-B
3. G=PWF(N,i,d) times F where PWF(N,id)=present worth factor for N=years, i=inflation rate and d=discount rate. (from tables or calculated from formula given in text)
4. H=G-A-C
5. I=PWF(N,i,d) times E divided by the sum of PWF(N,i,d) times B, A, and C.

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An example of the use of this procedure for determining the Benefit Cost Ratio of a particular design feature is the following. Look at the options given on page 9-2. Assume that Building Energy Option #10 is being considered. That is, we are considering reducing infilitration by one half, after having decided to include everything up through Option #8 (using the process we are now examining).

For simplicity (although actual cost values should be chosen in a real analysis), let us assume that reducing the infiltration rate by one half will require an additional capital and labor expenditure of P75.00. This value is entered on Line A, Initial Capital Cost of Option. Assume there is no additional annual cost (such as annual replacement of weather stripping) so that Line B is zero. It is, hoever, necessary to spend P10.00 after five years to do minor repairs. We are using a 10% inflation rate and a 15% discount rate over a ten year amortization period, and the following formula can be used to find the Present Worth of a single payment:

$$\text{Present Worth(Single Payment)(PWSP)} = \frac{A(1+i)^{N-1}}{(1+d)^{N}}$$

where "A" is the cost in the first year, "i" is the assumed rate of inflation, "d" is the discount rate and "N" is the year at the end of which the expense occurs. In our example, the present worth of the P10.00 spent at the end of year 5 for repairs is:

$$\text{PWSP} = \frac{(10.00)(1+0.10)^{5-1}}{(1+0.15)^{5}} = \text{P}7.28$$

This is the entry in Line C.

Next we have to consider what energy gain will be made and at what incremental cost in the initial outlay for construction of the building. From the computer runs for the building (given on page 9-2) we can see that 3215 MJ will be saved over the heating season (i.e. 7640-4425 MJ) but that an additional 831 MJ will be added to the cooling load (i.e. 10410-11241 MJ). In order to calculate any costing figures for Option #10, the cost of the displaced energy will have to be determined.

Let us assume that the energy load in the winter will be met by electric resistance heaters, and that the summer load will be met by air conditioners. Further assume that the COP (coefficient of performance) of the air conditioner is 2.0. In other words, for each MJ of electrical energy consumed, the air conditionerit meets 2 MJ of the cooling load. This is fairly standard performance for an air conditioner.

Then, in order to determine overall annual electrical savings, we consider all of the heating load reduction (3215 MJ) and subtract half of the cooling load increase or (831/2=415 MJ). This gives a net savings of 2800 MJ displaced. This is the value entered in

Line D, Annual Energy Saved. If electrical energy is available at P0.08/kWh (and 1 kWh equals 3.6 MJ) then electricity costs P0.022/MJ. This value is entered in the blank on the left side of Line E.

The Value of Annual Energy Saved is the product of the cost per MJ and the total MJs saved over the year (Line D). This value is then entered on Line E. If there are annual costs, they are subtracted from the Value of Annual Energy Saved to give Line F, the Net Annual Benefits.

Next, the Present Worth of Benefit Stream is calculated over the entire amortization period, which is ten years in this example. The present worth factor PWF(N,i,d), where N=years, i=inflation rate and d=discount rate, can be calculated from:

$$PWF(N,i,d) = \begin{cases} \frac{1}{(d-i)}\left(1 - \left(\frac{1+i}{1+d}\right)^N\right) & \text{if "i" not equal to "d"} \\ N(1+i)^{-1} & \text{if } i=d \end{cases}$$

This is the standard definition of the present worth of a series of payments. Putting in the appropriate values, then multiplying the PWF(10,.10,.15) by the value on Line F (P52.45) gives the value on Line G (P376.44). Line H is calculated by subtracting the remaining costs (Line A and Line C) from the value of the benefit stream in Line G. This gives P294.16.

The Benefit/Cost Ratio on Line I is the ratio of the present worth of all benefits divided by the present worth of all costs incurred over the amortization period. The magnitude of this figure can be used to rank competing strategies given the constraints of a limited resource base. The higher the Benefit/Cost Ratio for a particular strategy the more advantageous it is to the homeowner, and one would assume, to the economy of Botswana.

Similar calculations can be carried out for each of the strategies being considered for a particular project. More likely, after a contractor gets experience with the use of this method, standard designs which incorporate the more obvious energy saving (or comfort level increasing) options can be established by previous computation. These will serve as the basis for standard housing designs. Builders who wish to incorporate additional features will still have the opportunity and skills necessary to evaluate other features which the homeowner may desire.

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COMPLETED EXAMPLE

FINANCIAL ANALYSIS WORKSHEET

Inflation Rate: ___%; Discount Rate: ___%; Lifetime: ___ years

Option Number-	1	2	3	4
A. Initial Capital Cost of Option (P)	75.00			
B. Annual Costs for Operation and Maintenance, 1st Year Payment (P)	0.00			
C. Present Worth of Additional Discounted Costs for Replacement/Repairs (P)	7.28			
D. Annual Energy Saved (MJ)	2384			
E. Value of Annual Energy Saved @ P 0.___ per MJ *	52.45			
F. Net Annual Benefits (P) *	52.45			
G. Net Present Worth of Benefit Stream (P) *	376.44			
H. Net Present Worth of Benefits Minus Costs (P) *	294.16			
I. Benefit/Cost Ratio	4.58			

*Notes:
1. E=D times cost per MJ of energy
2. F=E-B
3. G=PWF(N,i,d) times F where PWF(N,id)=present worth factor for N=years, i=inflation rate and d=discount rate. (from tables or calculated from formula given in text)
4. H=G-A-C
5. I=PWF(N,i,d) times E divided by the sum of PWF(N,i,d) times B, A, and C.

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Table A-1 Present Worth Factors for $N = 5$

d, Market Discount Rate, percent	i, Annual Inflation Rate, percent												
	0	1	2	3	4	5	6	7	8	9	10	11	12
0	5.000	5.101	5.204	5.309	5.416	5.526	5.637	5.751	5.867	5.985	6.105	6.228	6.353
1	4.853	4.950	5.049	5.150	5.253	5.358	5.466	5.575	5.686	5.799	5.915	6.033	6.153
2	4.713	4.807	4.902	4.999	5.098	5.199	5.302	5.407	5.514	5.623	5.734	5.847	5.962
3	4.580	4.669	4.761	4.854	4.950	5.047	5.146	5.246	5.349	5.454	5.561	5.669	5.780
4	4.452	4.538	4.626	4.716	4.808	4.901	4.996	5.093	5.192	5.293	5.395	5.500	5.606
5	4.329	4.413	4.497	4.584	4.672	5.762	4.853	4.947	5.042	5.139	5.238	5.338	5.441
6	4.212	4.292	4.374	4.457	4.542	4.629	4.717	4.807	4.898	4.992	5.087	5.183	5.282
7	4.100	4.177	4.256	4.336	4.418	4.501	4.586	4.673	4.761	4.851	4.942	5.036	5.131
8	3.993	4.067	4.143	4.220	4.299	4.379	4.461	4.545	4.630	4.716	4.804	4.894	4.986
9	3.890	3.961	4.035	4.109	4.185	4.263	4.342	4.422	4.504	4.587	4.672	4.759	4.847
10	3.791	3.860	3.931	4.003	4.076	4.151	4.227	4.304	4.383	4.464	4.545	4.629	4.714
11	3.696	3.763	3.831	3.900	3.971	4.043	4.117	4.191	4.268	4.345	4.424	4.505	4.586
12	3.605	3.669	3.735	3.802	3.870	3.940	4.011	4.083	4.157	4.231	4.308	4.385	4.464
13	3.517	3.580	3.643	3.708	3.774	3.841	3.909	3.979	4.050	4.122	4.196	4.271	4.347
14	3.433	3.493	3.555	3.617	3.681	3.746	3.812	3.879	3.948	4.018	4.089	4.161	4.235
15	3.352	3.410	3.470	3.530	3.592	3.655	3.719	3.784	3.850	3.917	3.986	4.056	4.127
16	3.274	3.331	3.388	3.447	3.506	3.567	3.629	3.691	3.755	3.821	3.887	3.954	4.023
17	3.199	3.254	3.309	3.366	3.424	3.482	3.542	3.603	3.665	3.728	3.792	3.857	3.924
18	3.127	3.180	3.234	3.288	3.344	3.401	3.459	3.518	3.577	3.638	3.700	3.764	3.828
19	3.058	3.109	3.161	3.214	3.268	3.323	3.379	3.436	3.493	3.552	3.612	3.673	3.736
20	2.991	3.040	3.091	3.142	3.194	3.247	3.301	3.357	3.413	3.470	3.528	3.587	3.647

Table A-2 Present Worth Factors for $N = 10$

d, Market Discount Rate, percent	i, Annual Inflation Rate, percent												
	0	1	2	3	4	5	6	7	8	9	10	11	12
0	10.000	10.462	10.950	11.464	12.006	12.578	13.181	13.816	14.487	15.193	15.937	16.722	17.549
1	9.471	9.901	10.354	10.831	11.335	11.865	12.425	13.014	13.635	14.289	14.979	15.705	16.470
2	8.983	9.383	9.804	10.248	10.716	11.209	11.728	12.275	12.851	13.458	14.097	14.770	15.479
3	8.530	8.903	9.295	9.709	10.144	10.603	11.085	11.594	12.129	12.692	13.286	13.910	14.567
4	8.111	8.459	8.825	9.210	9.615	10.042	10.492	10.965	11.462	11.986	12.537	13.117	13.727
5	7.722	8.046	8.388	8.748	9.126	9.524	9.942	10.383	10.846	11.334	11.847	12.386	12.953
6	7.360	7.664	7.983	8.319	8.672	9.043	9.434	9.845	10.277	10.731	11.208	11.710	12.238
7	7.024	7.308	7.607	7.921	8.251	8.598	8.962	9.346	9.749	10.172	10.618	11.085	11.577
8	6.710	6.976	7.256	7.550	7.859	8.184	8.525	8.883	9.259	9.655	10.070	10.507	10.965
9	6.418	6.667	6.930	7.205	7.495	7.798	8.118	8.453	8.805	9.174	9.562	9.970	10.398
10	6.145	6.379	6.625	6.884	7.155	7.440	7.739	8.053	8.382	8.728	9.091	9.472	9.872
11	5.889	6.110	6.341	6.584	6.838	7.105	7.386	7.680	7.989	8.313	8.652	9.009	9.383
12	5.650	5.858	6.075	6.303	6.543	6.793	7.057	7.333	7.622	7.926	8.244	8.578	8.929
13	5.426	5.622	5.826	6.041	6.266	6.502	6.749	7.008	7.280	7.565	7.864	8.177	8.505
14	5.216	5.400	5.593	5.795	6.007	6.229	6.462	6.705	6.961	7.228	7.509	7.803	8.111
15	5.019	5.193	5.374	5.565	5.765	5.974	6.193	6.422	6.662	6.914	7.177	7.453	7.743
16	4.833	4.997	5.169	5.349	5.537	5.734	5.940	6.156	6.383	6.619	6.867	7.127	7.399
17	4.659	4.814	4.976	5.146	5.323	5.509	5.704	5.908	6.121	6.344	6.577	6.822	7.077
18	4.494	4.641	4.794	4.955	5.123	5.298	5.482	5.674	5.875	6.085	6.305	6.536	6.776
19	4.339	4.478	4.623	4.775	4.934	5.100	5.273	5.455	5.644	5.843	6.050	6.267	6.494
20	4.192	4.324	4.462	4.606	4.756	4.913	5.077	5.248	5.428	5.615	5.811	6.016	6.230

Table A-3 Present Worth Factors for $N = 15$

d, Market Discount percent	i, Annual Inflation Rate, percent												
	0	1	2	3	4	5	6	7	8	9	10	11	12
0	15.000	16.097	17.293	18.599	20.024	21.579	23.276	25.129	27.152	29.361	31.772	34 405	37.280
1	13.865	14.851	15.926	17.098	18.375	19.767	21.285	22.942	24.748	26.718	28.867	31.212	33.770
2	12.849	13.738	14.706	15.759	16.906	18.156	19.517	21.000	22.616	24.377	26.297	28.389	30.669
3	11.938	12.741	13.614	14.563	15.596	16.719	17.942	19.273	20.722	22.300	24.017	25.888	27.925
4	11.118	11.845	12.634	13.492	14.423	15.435	16.536	17.733	19.035	20.451	21.991	23.667	25.491
5	10.380	11.039	11.754	12.530	13.372	14.286	15.279	16.357	17.529	16.802	20.187	21.691	23.327
6	9.712	10.311	10.960	11.664	12.426	13.254	14.151	15.125	16.182	17.329	18.575	19.929	21.399
7	9.108	9.654	10.244	10.883	11.575	12.325	13.138	14.019	14.974	16.010	17.134	18.354	19.677
8	8.559	9.057	9.595	10.177	10.807	11.488	12.225	13.024	13.889	14.826	15.842	16.943	18.137
9	8.061	8.516	9.007	9.538	10.111	10.731	11.402	12.127	12.912	13.76[illegible]	[illegible]	15.678	16.757
10	7.606	8.023	8.473	8.958	9.481	10.046	10.657	11.317	12.030	12.8[illegible]	13.636	14.539	15.516
11	7.191	7.574	7.986	8.430	8.909	9.425	9.982	10.584	11.233	11.935	12.694	13.514	14.400
12	6.811	7.163	7.541	7.949	8.387	8.860	9.369	9.919	10.511	11.151	11.842	12.587	13.393
13	6.462	6.786	7.135	7.509	7.912	8.345	8.812	9.314	9.856	10.440	11.070	11.749	12.483
14	6.142	6.441	6.762	7.107	7.477	7.875	8.303	8.764	9.260	9.794	10.370	10.990	11.659
15	5.847	6.124	6.420	6.738	7.079	7.445	7.839	8.262	8.717	9.206	9.733	10.300	10.911
16	5.575	5.831	6.105	6.399	6.714	7.051	7.413	7.803	8.220	8.670	9.153	9.672	10.231
17	5.324	5.561	5.815	6.087	6.378	6.689	7.024	7.382	7.767	8.180	8.623	9.100	9.612
18	5.092	5.312	5.547	5.799	6.069	6.357	6.665	6.996	7.351	7.731	8.136	8.577	9.048
19	4.876	5.081	5.300	5.533	5.783	6.050	6.336	6.641	6.969	7.320	7.696	8.099	8.532
20	4.675	4.867	5.070	5.288	5.519	5.767	6.032	6.315	6.618	6.942	7.289	7.661	8.059

Table A-4 Present Worth Factors for $N = 20$

d, Market Discount Rate, percent	i, Annual Inflation Rate, percent												
	0	1	2	3	4	5	6	7	8	9	10	11	12
0	20.000	22.019	24.297	26.870	29.778	33.066	36.786	40.995	45.762	51.160	57.275	64.203	72.052
1	18.046	19.802	21.780	24.009	26.524	29.362	32.568	36.190	40.284	44.913	50.150	56.074	62.778
2	16.351	17.885	19.608	21.546	23.728	26.186	28.958	32.084	35.612	39.594	44.093	49.174	54.917
3	14.877	16.221	17.727	19.417	21.317	23.453	25.857	28.564	31.613	35.050	38.926	43.299	48.232
4	13.590	14.771	16.092	17.571	19.231	21.093	23.185	25.536	28.180	31.156	34.506	38.279	42.531
5	12.462	13.503	14.665	15.965	17.419	19.048	20.874	22.922	25.222	27.806	30.710	33.977	37.651
6	11.470	12.391	13.417	14.562	15.840	17.269	18.868	20.659	22.665	24.916	27.442	30.277	33.463
7	10.594	11.411	12.320	13.332	14.459	15.717	17.122	18.692	20.448	22.414	24.617	27.086	29.856
8	9.818	10.546	11.353	12.250	13.247	14.358	15.596	16.977	18.519	20.242	22.169	24.325	26.740
9	9.129	9.779	10.498	11.296	12.181	13.164	14.258	15.476	16.834	18.349	20.039	21.928	24.040
10	8.514	9.096	9.739	10.450	11.238	12.112	13.082	14.160	15.359	16.694	18.182	19.841	21.693
11	7.963	8.487	9.063	9.700	10.403	11.182	12.044	13.001	14.063	15.243	16.556	18.018	19.647
12	7.469	7.941	8.460	9.031	9.661	10.356	11.125	11.977	12.920	13.967	15.129	16.421	17.857
13	7.025	7.451	7.919	8.433	8.998	9.622	10.310	11.070	11.910	12.841	13.872	15.017	16.287
14	6.623	7.009	7.432	7.896	8.406	8.966	9.583	10.263	11.014	11.844	12.762	13.779	14.906
15	6.259	6.610	6.994	7.414	7.874	8.379	8.934	9.545	10.217	10.959	11.779	12.685	13.687
16	5.929	6.249	6.597	6.978	7.395	7.851	8.352	8.902	9.506	10.172	10.905	11.714	12.608
17	5.628	5.920	6.238	6.585	6.963	7.376	7.829	8.325	8.870	9.468	10.126	10.851	11.650
18	5.353	5.620	5.911	6.227	6.572	6.947	7.358	7.807	8.298	8.838	9.430	10.081	10.798
19	5.101	5.347	5.613	5.902	6.216	6.558	6.932	7.339	7.784	8.272	8.806	9.392	10.036
20	4.870	5.096	5.340	5.605	5.893	6.205	6.545	6.916	7.320	7.762	8.245	8.774	9.355

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Table A-5 Present Worth Factors for $N = 25$

d, Market Discount Rate, percent	i, Annual Inflation Rate, percent												
	0	1	2	3	4	5	6	7	8	9	10	11	12
0	25.000	28.243	32.030	36.459	41.646	47.727	54.864	63.249	73.106	84.701	98.347	114.413	133.334
1	22.023	24.752	27.929	31.633	35.958	41.014	46.933	53.869	62.003	71.550	82.762	95.935	111.419
2	19.523	21.832	24.510	27.622	31.245	35.470	40.401	46.164	52.906	60.800	70.051	80.897	93.621
3	17.413	19.375	21.644	24.272	27.322	30.867	34.994	39.804	45.417	51.974	59.639	68.606	79.104
4	15.622	17.298	19.229	21.459	24.038	27.028	30.498	34.531	39.224	44.693	51.071	58.516	67.213
5	14.094	15.532	17.184	19.085	21.277	23.810	26.740	30.137	34.079	38.660	43.990	50.197	57.431
6	12.783	14.024	15.444	17.072	18.943	21.098	23.585	26.458	29.784	33.639	38.112		49.350
7	11.654	12.729	13.954	15.356	16.961	18.803	20.923	23.364	26.183	29.440	33.210	37.578	42.645
8	10.675	11.611	12.674	13.885	15.269	16.851	18.666	20.750	23.148	25.912	29.103	32.791	37.058
9	9.823	10.641	11.568	12.620	13.817	15.182	16.743	18.530	20.580	22.936	25.648	28.774	32.382
10	9.077	9.796	10.607	11.525	12.566	13.749	15.097	16.636	18.396	20.412	22.727	25.388	28.452
11	8.422	9.056	9.769	10.574	11.482	12.512	13.682	15.012	16.530	18.264	20.248	22.523	25.134
12	7.843	8.405	9.035	9.743	10.540	11.440	12.459	13.615	14.929	16.425	18.133	20.086	22.321
13	7.330	7.830	8.388	9.014	9.716	10.506	11.398	12.406	13.548	14.846	16.322	18.005	19.926
14	6.873	7.320	7.817	8.372	8.993	9.689	10.473	11.356	12.353	13.483	14.764	16.220	17.878
15	6.464	6.865	7.309	7.803	8.355	8.971	9.662	10.439	11.314	12.301	13.417	14.683	16.119
16	6.097	6.457	6.856	7.298	7.790	8.338	8.950	9.636	10.406	11.272	12.249	13.353	14.602
17	5.766	6.092	6.451	6.848	7.283	7.776	8.321	8.929	9.609	10.372	11.230	12.197	13.288
18	5.467	5.762	6.086	6.444	6.839	7.277	7.763	8.304	8.907	9.582	10.339	11.189	12.146
19	5.195	5.463	5.758	6.081	6.437	6.830	7.266	7.749	8.286	8.886	9.556	10.306	11.148
20	4.948	5.192	5.460	5.753	6.075	6.430	6.822	7.255	7.735	8.269	8.864	9.529	10.272

Table A-6 Present Worth Factors for $N = 30$

d, Market Discount Rate, percent	i, Annual Inflation Rate, percent												
	0	1	2	3	4	5	6	7	8	9	10	11	12
0	30.000	34.785	40.568	47.575	56.085	66.439	79.058	94.461	113.283	136.307	164.494	199.021	241.333
1	25.808	29.703	34.389	40.042	46.878	55.164	65.225	77.462	92.367	110.545	132.735	159.843	192.981
2	22.396	25.589	29.412	34.002	39.529	46.201	54.270	64.050	75.922	90.353	107.916	129.313	155.400
3	19.600	22.235	25.374	29.126	33.624	39.029	45.541	53.404	62.914	74.435	88.413	105.392	126.034
4	17.292	19.481	22.076	25.163	28.846	33.254	38.541	44.900	52.563	61.813	73.000	86.545	102.965
5	15.372	17.203	19.363	21.919	24.955	28.571	32.891	38.065	44.276	51.746	60.748	71.513	84.744
6	13.765	15.307	17.116	19.246	21.765	24.751	28.302	32.537	37.601	43.668	50.953	59.716	70.272
7	12.409	13.716	15.241	17.028	19.131	21.612	24.549	28.037	32.190	37.147	43.076	50.182	58.715
8	11.258	12.372	13.667	15.176	16.942	19.017	21.461	24.351	27.778	31.951	36.704	42.499	49.433
9	10.274	11.230	12.335	13.618	15.111	16.856	18.904	21.313	24.157	27.523	31.518	36.271	41.937
10	9.427	10.253	11.202	12.299	13.569	15.046	16.771	18.792	21.166	23.965	27.273	31.192	35.848
11	8.694	9.411	10.232	11.175	12.262	13.520	14.982	16.687	18.681	21.022	23.776	27.027	30.873
12	8.055	8.682	9.395	10.211	11.147	12.225	13.472	14.918	16.603	18.572	20.879	23.590	26.786
13	7.496	8.046	8.670	9.379	10.190	11.119	12.188	13.423	14.855	16.520	18.464	20.738	23.407
14	7.003	7.489	8.037	8.658	9.363	10.169	11.091	12.151	13.375	14.792	16.438	18.356	20.599
15	6.566	6.997	7.482	8.028	8.646	9.347	10.147	11.063	12.115	13.327	14.729	16.356	18.250
16	6.177	6.562	6.992	7.475	8.019	8.633	9.331	10.126	11.035	12.078	13.279	14.667	16.275
17	5.829	6.174	6.558	6.987	7.468	8.009	8.621	9.315	10.104	11.007	12.041	13.231	14.605
18	5.517	5.827	6.171	6.554	6.981	7.460	7.999	8.608	9.298	10.083	10.979	12.005	13.184
19	5.235	5.515	5.825	6.168	6.550	6.976	7.453	7.990	8.596	9.282	10.061	10.951	11.968
20	4.979	5.233	5.513	5.822	6.165	6.545	6.970	7.446	7.980	8.583	9.265	10.040	10.922

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11. SHADING

SHADING

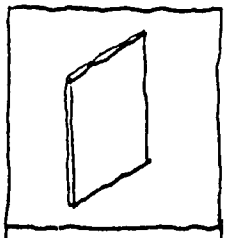
The purpose of the next section is to explore the impact, opticns and sizing techniques for architectural shading devices.

Shading devices come in a wide variety of configurations, largely a function of orientation (page 11-3) and a multitude of opacities, largely a function of how much sunlight is to be blocked out (page 11- Shapes range from simple fixed overhangs to movable combinations of vertical and horizontal louvers. Materials range from light loose fabrics to fully opaque metal louvers. Each device has a shading coefficient (SC) which is a measure of its ability to shade. The higher the SC, the more sunlight the device lets in. A panel of clear glass has an SC of 1 while an opaque metal panel has an SC of 0. For typical shading devices and their SC's see page 112.

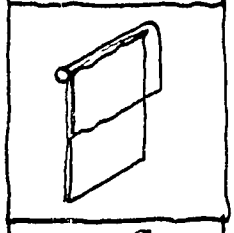
White interior shading devices have lower SC's than dark ones. External devices have uniformly lower SC's than internal devices. Trees have reasonably good SC's depending on the foliage density. Small element devices such as multiple horizontal louvers have lower SC's than large element devices such as fixed overhangs. Movable small element devices have the best SC's, providing they get moved.

Some typical external devices and their orientations are suggested on page 11-3. For external devices a light color is preferred because it will not heat up as readily as a dark one and it can reflect useful daylight indoors. A light metal shade is better than a concrete one because its mass does not store up daytime heat which is then radiated to the structure at night.

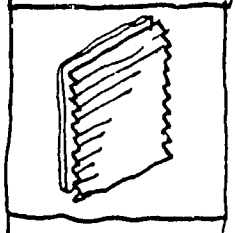
TYPICAL SHADING DEVICES & SHADING COEFFICIENTS (SC)



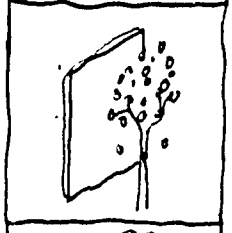
CLEAR GLASS
SC = 1.



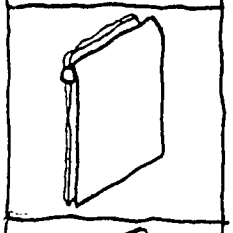
ROLLERSHADE HALF DRAWN - INSIDE
SC = .71



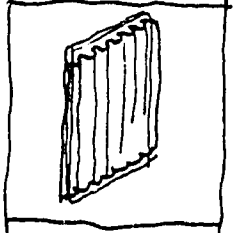
INSIDE WHITE VENETIAN BLINDS FULLY DRAWN
SC = .56



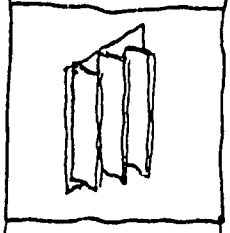
TREE PERFORMING LIGHT SHADE
SC = .60 - .50



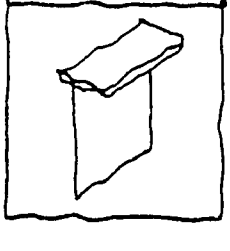
INSIDE WHITE ROLLER SHADE - FULLY DRAWN
SC = .41



FABRIC CURTAIN OFF WHITE
SC = .40

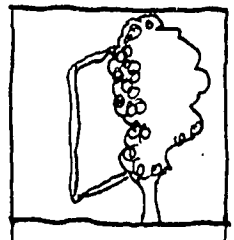


OUTSIDE VERTICAL FIXED LOUVERS - EAST & WEST
SC = .31

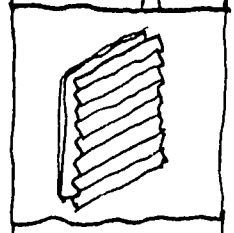


FIXED OVERHANG, CONTINUOUS ON NORTH
SC = .25

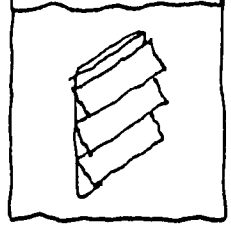
(Source: Olgyay)



DENSE TREE PERFORMING HEAVY SHADE
SC = .25 - .20



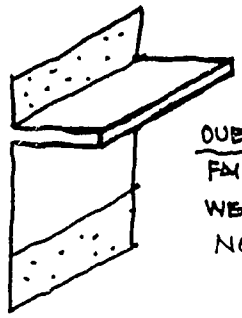
OUTSIDE VENETIAN BLIND WHITE CREAM COLOR
SC = .15



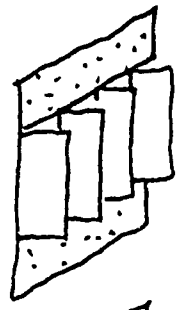
OUTSIDE MOVEABLE HORIZONTAL LOUVERS
SC = .13 - .10

SOME ARCHITECTURAL SHADING DEVICES

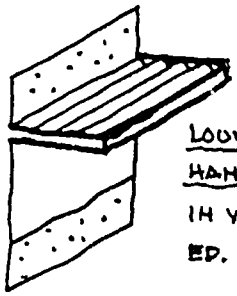
THIS IS A PARTIAL LIST OF SHADING DEVICES APPROPRIATE TO BOTSWANA INDICATING WHICH ORIENTATION THEY ARE MOST APPROPRIATE FOR.



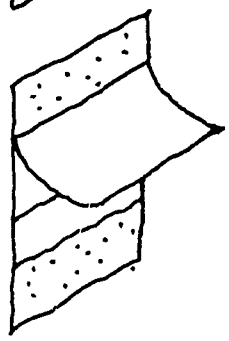
OVERHANG - FAIR ON EAST & WEST. BEST ON NORTH



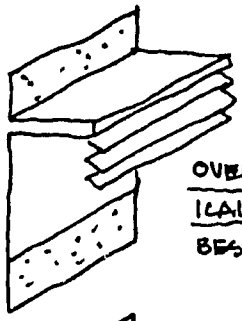
VERTICAL LOUVERS - BEST EAST & WEST - CUTS OFF LOW ANGLE DEEP AZIMUTH RISING & SETTING SUN



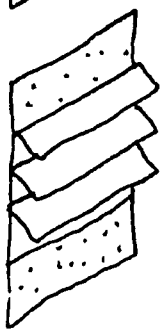
LOUVERED OVERHANG - LETS LIGHT IN WHEN NEEDED.



AWNING BEST ON NORTH. LETS SUN IN IN WINTER, KEEPS IT OUT IN SUMMER.



OVERHANG & VERTICAL LOUVERS - BEST ON EAST & WEST.



HORIZONTAL LOUVERS BEST ON EAST & WEST. IF ADJUSTABLE CAN CUT OFF LOW ANGLE SUN.

(Source: Evans)

SHADING DEVICES, A DETAILED SIZING TECHNIQUE

The following technique makes a key simplifying assumption which is that shading is required anytime during the year when the average hourly outdoor temperature exceed 20 degrees. Note that 20 degrees is at the low end of the thermal comfort zone, thus leaving a margin for thermal factors such as internal gains.

The hours in the year when the temperature exceeds 20 degrees are recorded on an annual isotherm chart (page 11-6). First, go to the meteorological charts and extract the monthly mean maximum and minimum temperatures. Then use the hourly temperature calculator on page 11-7 to determine mean hourly temperatures for each hour of each month and record them on the isotherm chart. Draw a line separating the overheated period (20 degrees plus) from the under-heated period (20 degrees minus).

Next plot the overheated isotherm line on the 24 degree south solar chart which is divided, like the isotherm chart, into hours and months. Darken in the overheated period, as illustrated on page 11-8. A clean 25 degree solar chart is available on page 11-13 for reproduction.

Next, reproduce the shadow protractor (page 11-12) onto clear acetate. Lay the shadow protractor over the solar chart. Rotate the protractor until its base line is oriented parallel with the plane of the window to be shaded. Read out until the first of the protractor's arced lines fully covers the darkened-in overheated period. Read off the shadow angle and transfer it to a scaled section drawing of the window. Extend the fixed overhang to meet the angle.

For the north elevation a simple fixed overhang will suffice. For the east elevation (page 11-9) the low shadow angle (45 degrees) requires shifting the design to a device where the shadow angle describes the spacing of the horizontal metal louvers. Remember: light weight, light color.

The west shading device presents a problem which even the horizontal louvers cannot overcome without their being too closely spaced. This is because the hottest overheated temperatures occur during the late afternoon when the sun is setting and its rays penetrate directly and easily into any unshaded west-facing glass. Both the technical difficulties and the thermal liabilities suggest that west-facing glass should be avoided if not eliminated altogether. Even so, west glass can be shaded.

First select a comfortable shadow angle; in this case the same 45 degree louver used for the east-shading device. Block out that part of the overheated period masked by the horizontal louvers. Next add a vertical louver as determined by the 0 and 30 degree shading angles and mask out their portions of the overheated period. Between the horizontal and vertical louvers, only a relatively small and acceptable portion of the overheated period remains unmasked. The result is an eggcrate-type shading device which is a traditional solution for west-facing glass.

GABORONE

	J	F	M	A	M	J	J	A	S	O	N	D
MONTHLY MEAN MAX	32.5	31.0	31.0	27.0	24.5	22.0	22.5	25.5	29.0	30.5	31.0	32.0
MONTHLY MEAN MIN	19.5	19	18	13.0	7.5	4.0	3.5	6.5	12.0	15.5	17.5	18.5

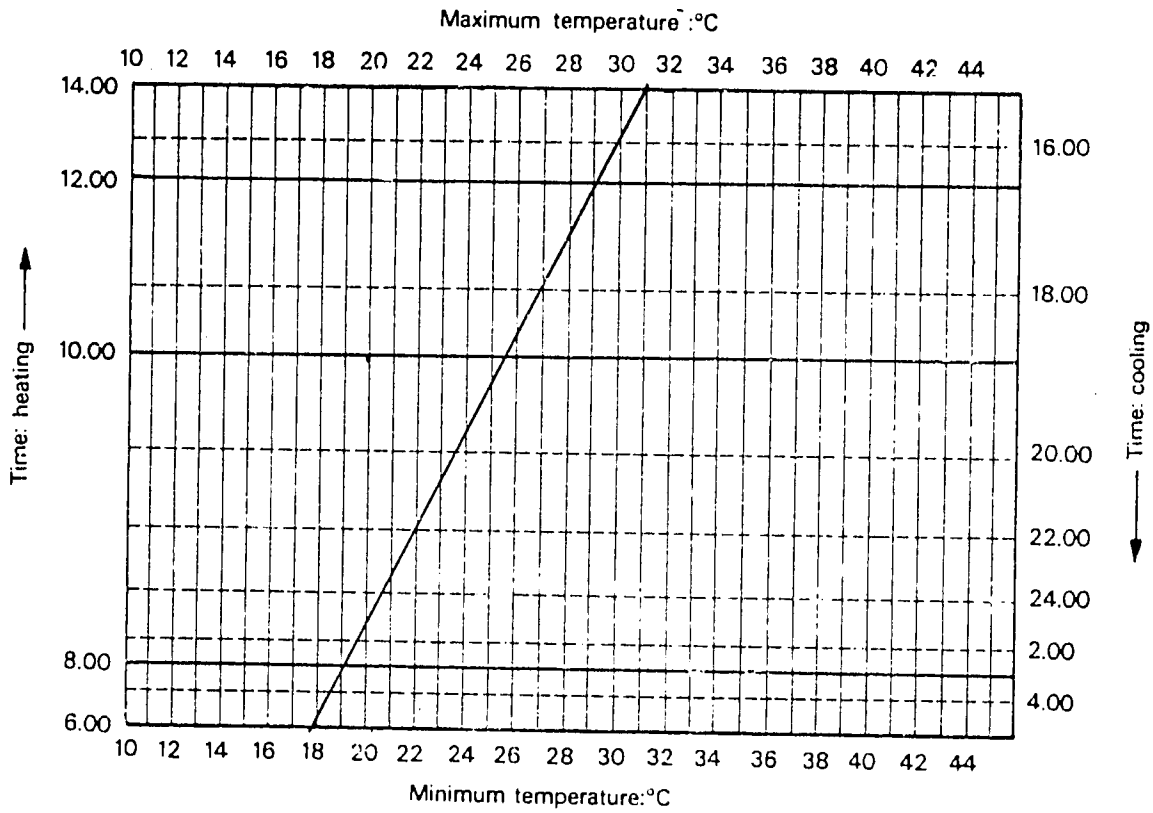
HOUR	J	F	M	A	M	J	J	A	S	O	N	D
2	21	21	17	13	13				14	17.5	19	20
4	20	17	16	11	9				13	16	18	19
6	19.5	19	18	13	7.5				12	15.5	17.5	18.5
8	21	20	19	14.5	11.				14	17	18	19
10	23	26	25	21	18.5	17	16	16	17	24	25	26
12	31	26	29	25	22.5	20	18	20	21	29	29	30
14	32.5	31	31	29	24.5	22	20	25.5	29	31	31	32
16	32	30	30	26	23			26	27	30	30	31
18	28	27	27	23	20			18	23	26	27	28
20	25	23	23	19	16				19	23	23	25
22	24	22	22	17.5	14.5				17	20	22	23
24	22	21	21	17	13				15	19	20	21

OVERHEATED PERIOD

MEAN AMBIENT HOURLY OUTDOOR TEMPERATURE (°C)

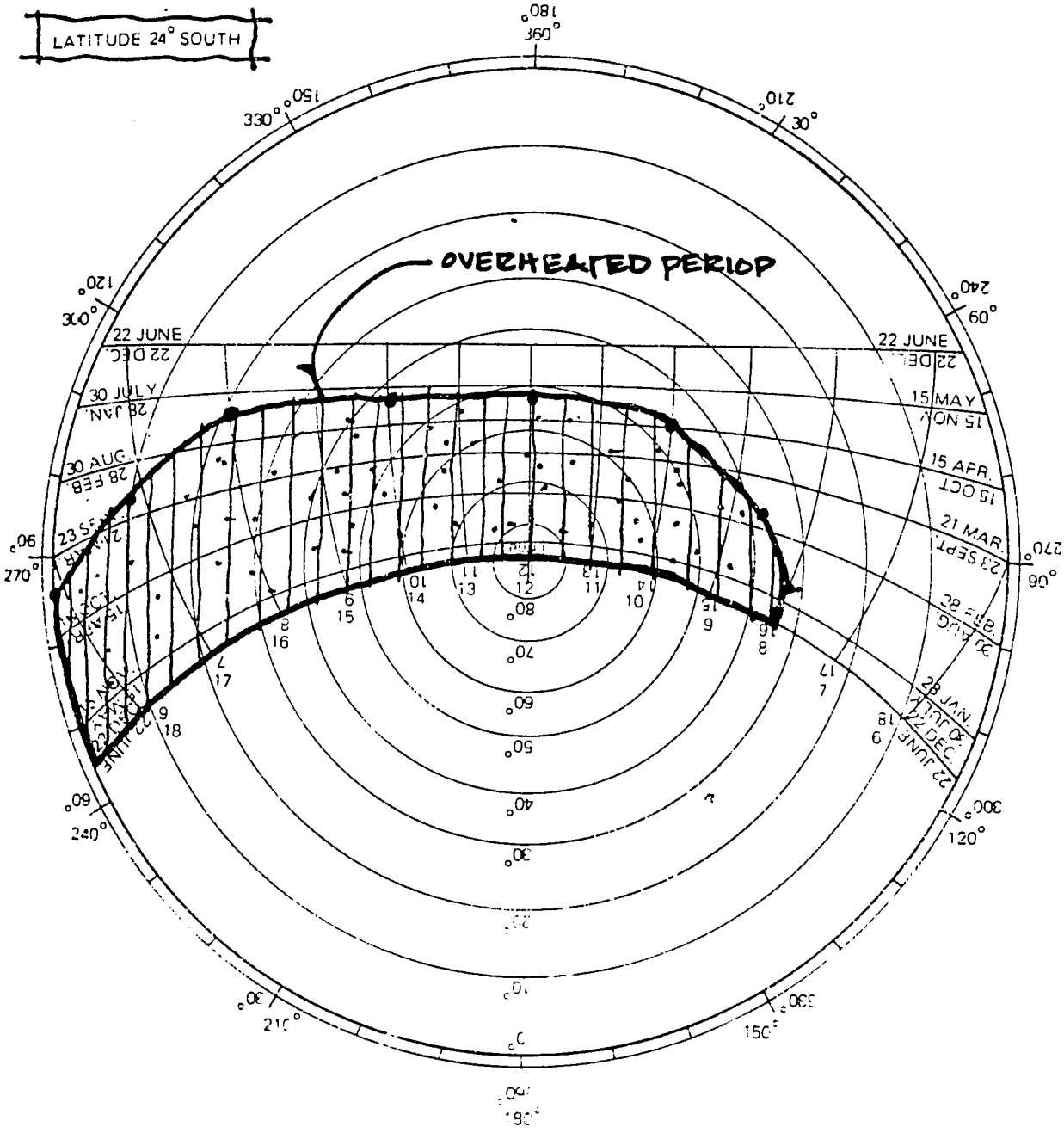
SHADING

Hourly temperature calculator



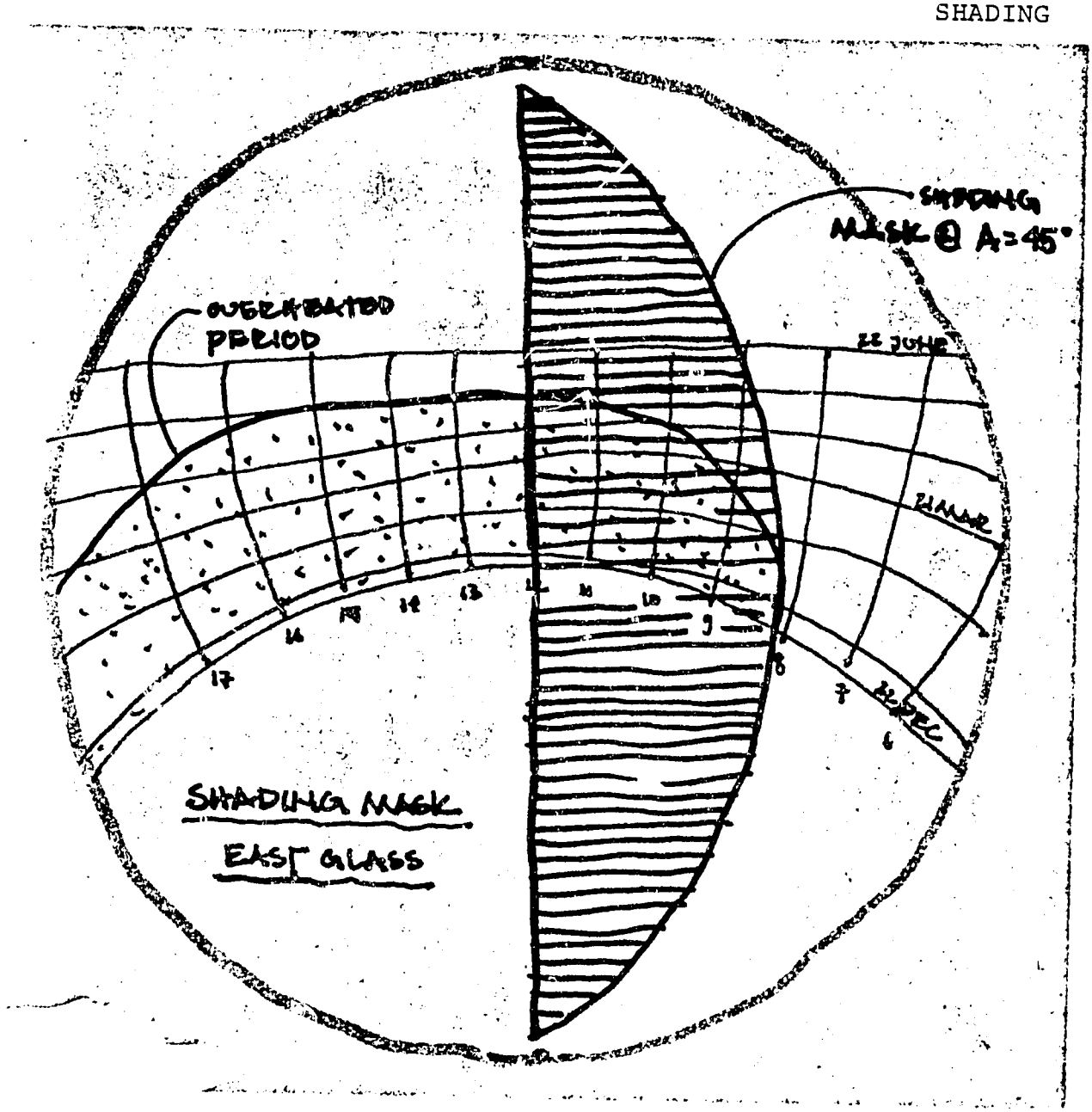
MARCH DAILY TEMPERATURE DISTRIBUTION.

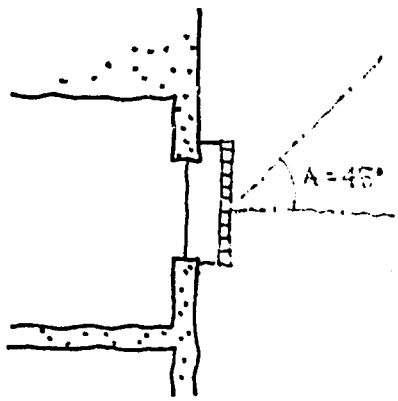
(Source: Koenigsberger)



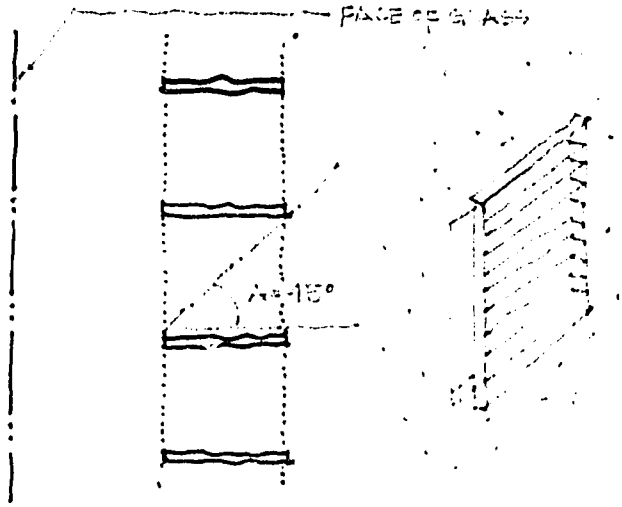
(Source: Koenigsberger)

SOLAR CHART FOR 24° SOUTH WITH OVERHEATED PERIOD PLOTTED ON IT

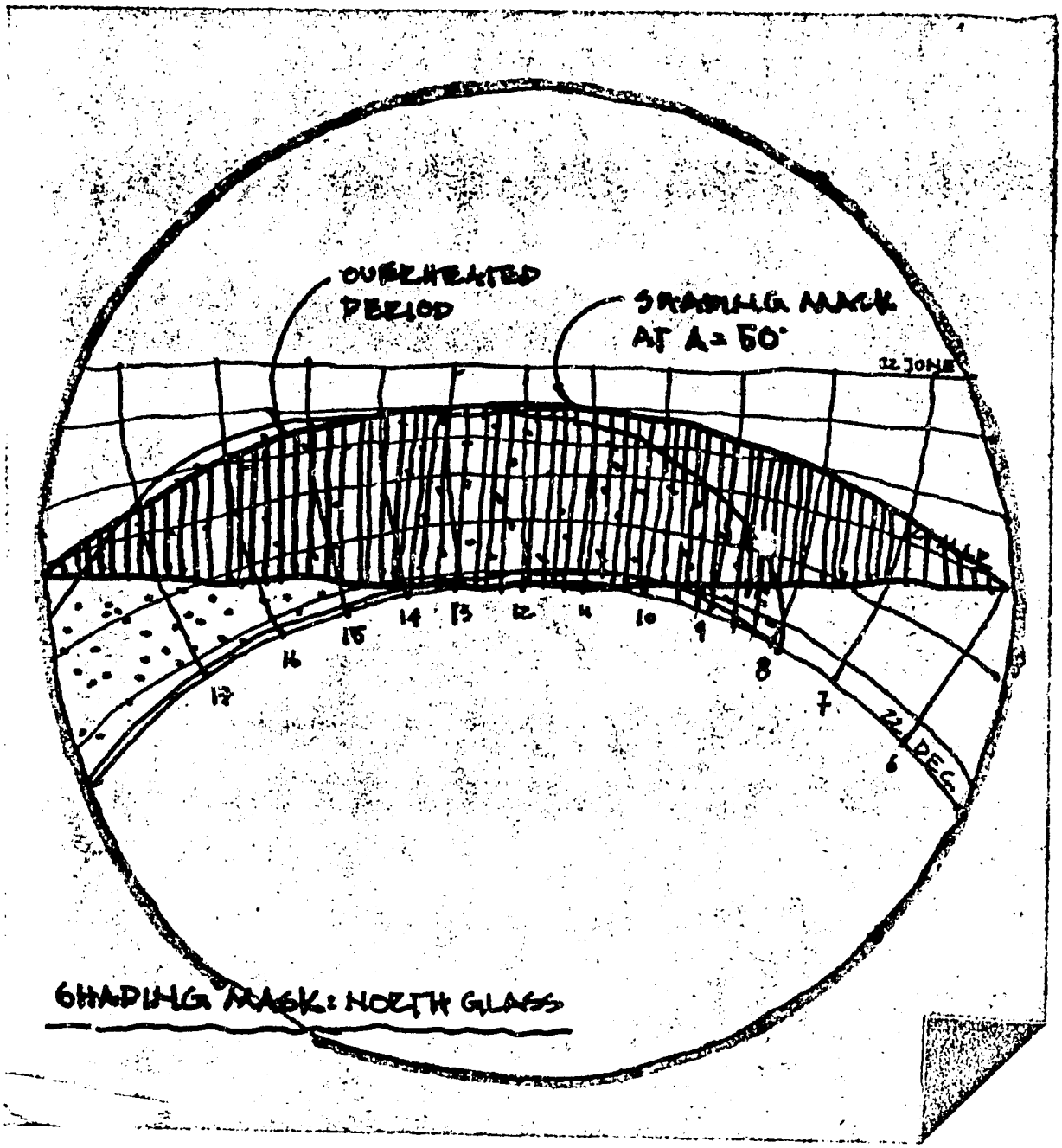


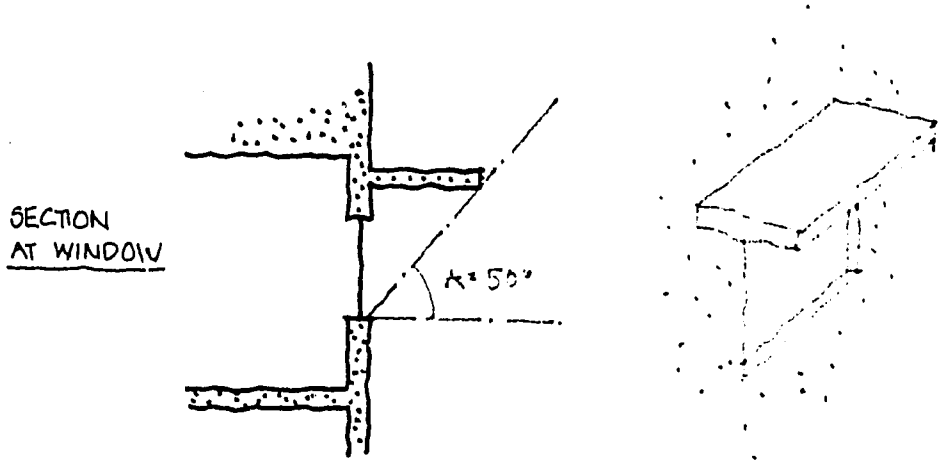


SECTION AT WINDOW

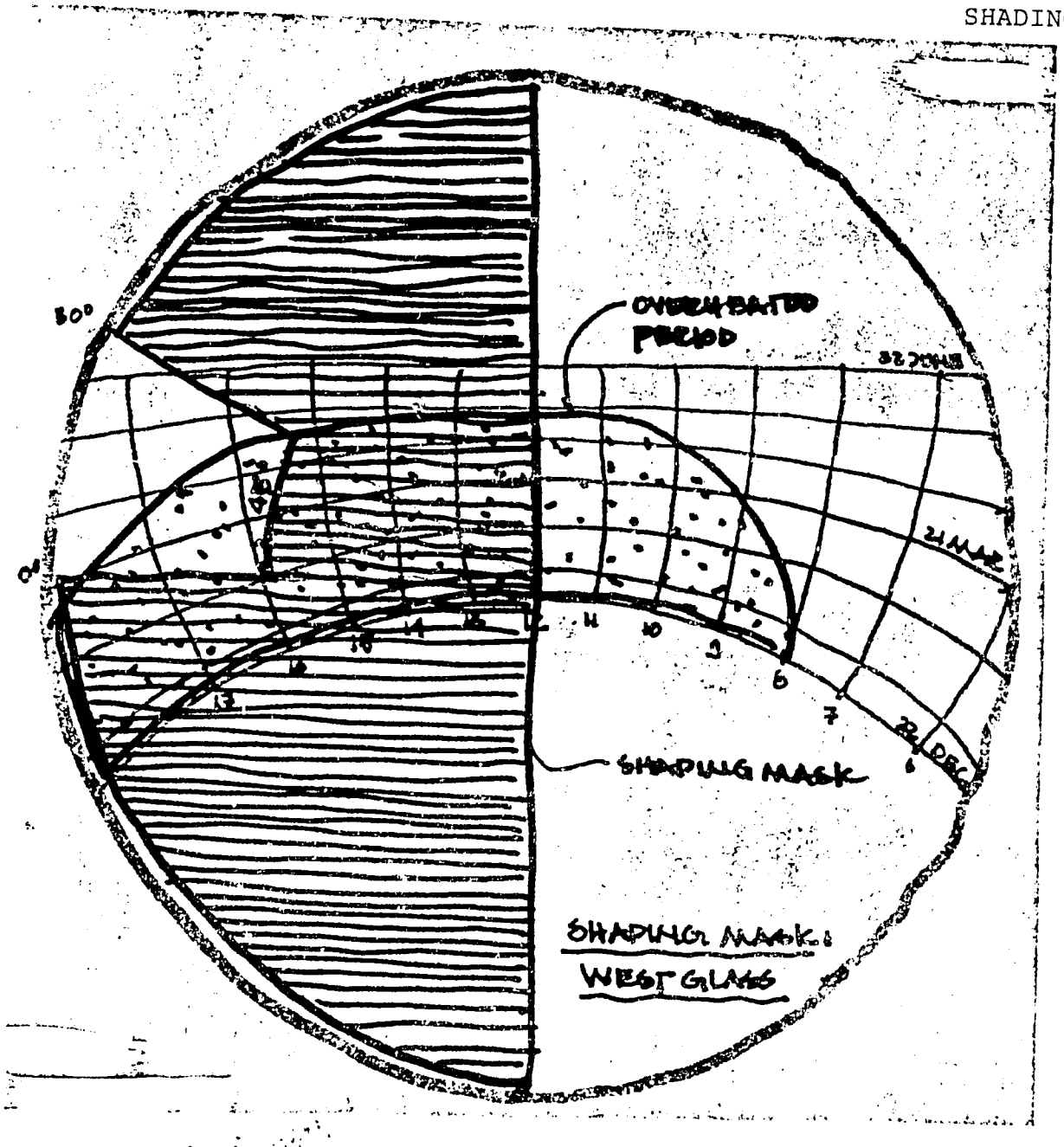


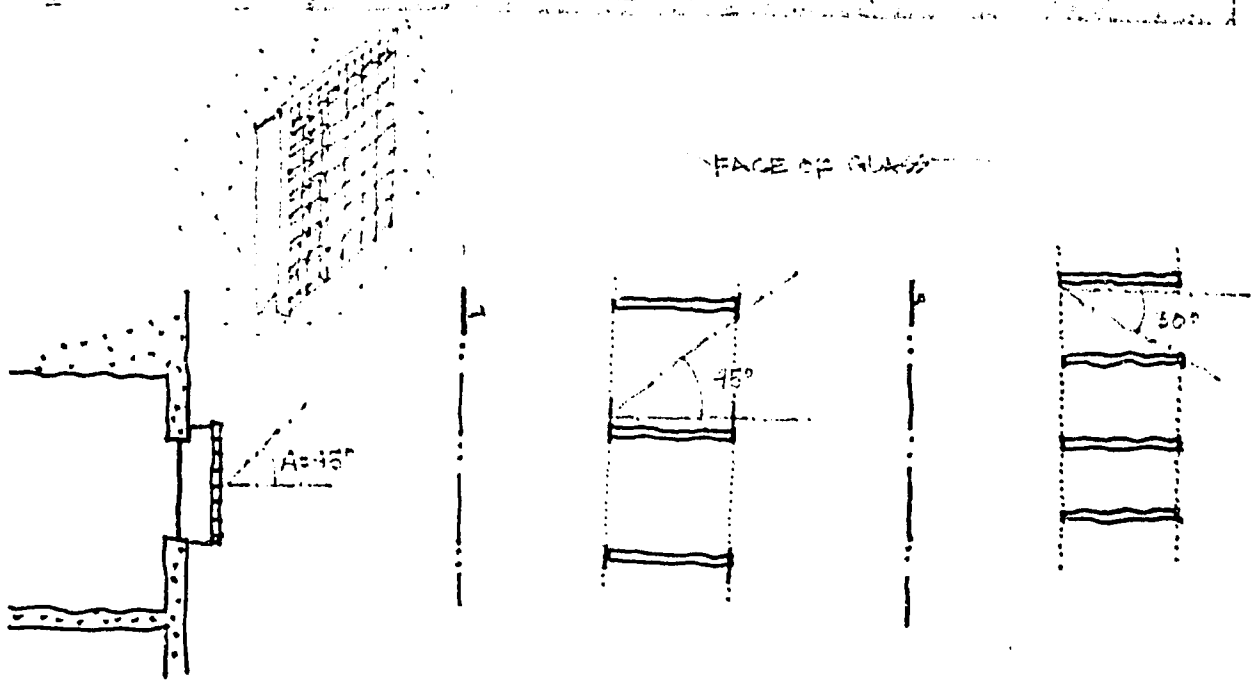
LOUVER DETAIL


OVERHEATED PERIOD
SHADING MASK AT A = 50°
22 JUNE
22 DEC
17
16
15
14
13
12
11
10
9
8
7
6
SHADING MASK: NORTH GLASS


SECTION AT WINDOW
A = 50°

185



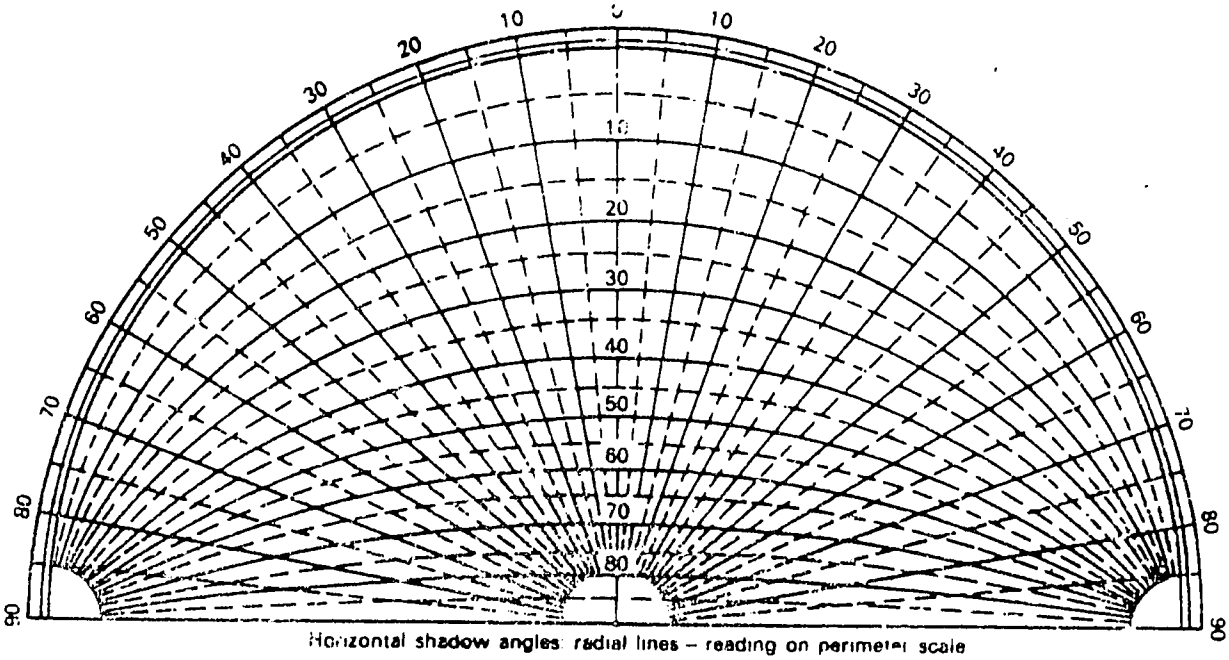


SECTION AT WINDOW

(HORIZONTAL) LOUVER DETAIL

(VERTICAL) LOUVER DETAIL

186

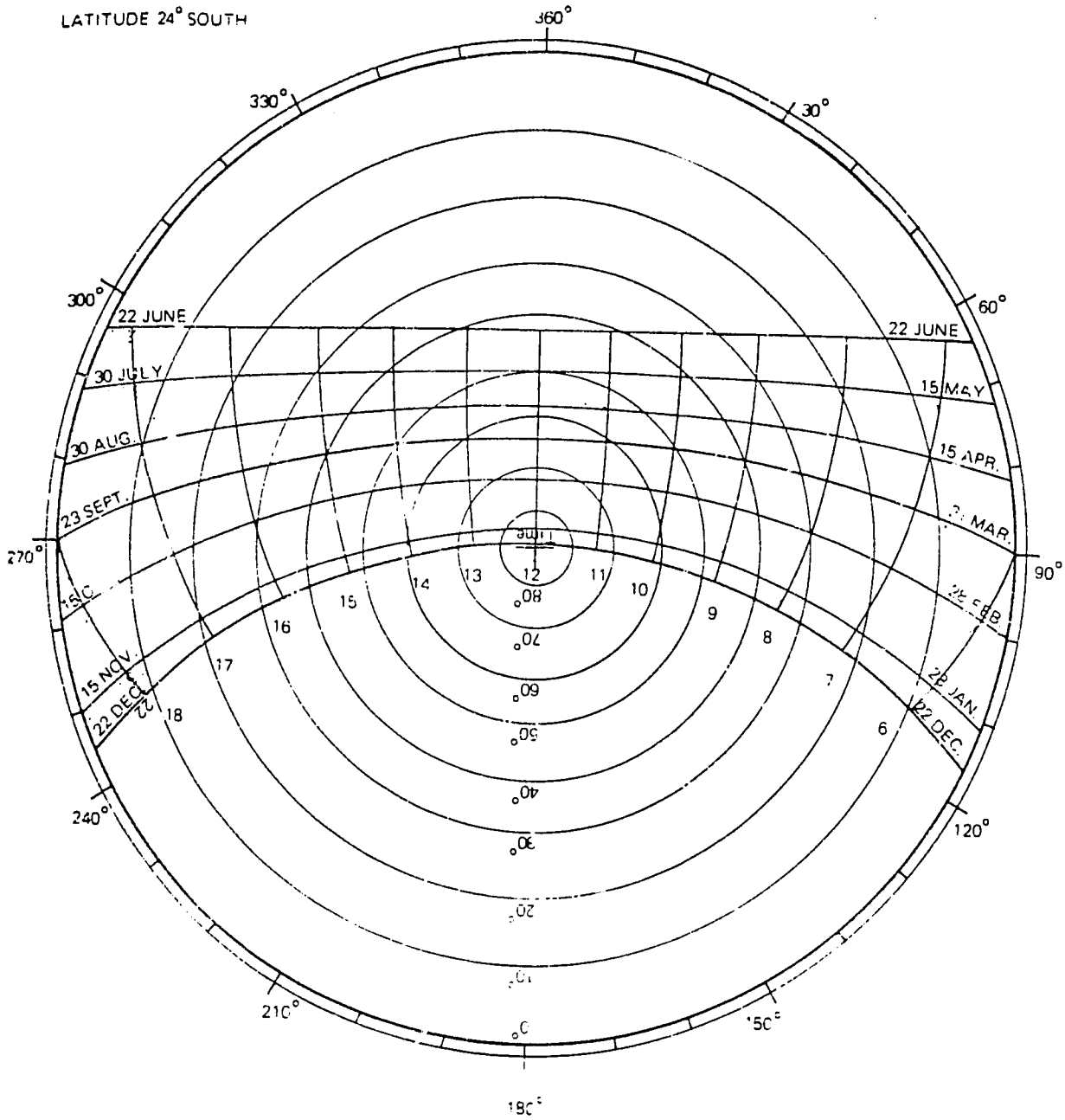


Horizontal shadow angles: radial lines – reading on perimeter scale

Vertical shadow angles: arcual lines – 90° at centre 0° at perimeter

SHADOW PROTRACTOR

TO USE XEROX ONTO A TRANSPARENCY



(Source: Koenigsberger)

24° SOUTH SOLAR CHART

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12. USE OF VEGETATION

VEGETATION

The purpose of the following section is to outline how vegetation, either that which exists already on the site or that which is planted as part of the building program, can improve thermal comfort. This is primarily accomplished by either direct shading of the structure itself or shading of the grounds immediately surrounding it. Additionally, trees and shrubs can channel cool breezes into and through the building.

Vegetation in general has a difficult time in Botswana given the scarcity of water. Added to that is peoples' tendency to uproot any vegetation close to the building other than canopied shade trees. Architecturally, this derives from the vegetationless tradition of the rondavel compound, while culturally it is rooted in a fear of snakes. This section cannot suggest how to overcome this bias against it, but can indicate vegetation's value in creating a more comfortable thermal environment.

The shading and cooling value of vegetation is undeniable as pointed out in the graphs on pages 12-2 and 3. The first graph records hourly daytime temperatures for all the surfaces of a small dwelling in Ogden, Utah exposed to the summer sun. The roof consistently reaches the highest hourly temperatures. East and west wall curves reflect the morning and afternoon solar impacts respectively. The north wall follows the south wall curve though its maximum temperature is minimal in comparison. The interior temperature slowly increased throughout the day until it peaks at about 10 pm.

The second graph records the temperatures of the same surfaces, but they are now shaded on the east by a row of Norway Maples,

a tree with very dense foliage and, therefore, excellent shading characteristics. All surfaces experience a drop in their maximum temperature along with a shift of the peak temperatures to later in the day. This is reflected in the interior temperature as well.

The effect of shading on surface temperature is further confirmed on page 12-4. In the upper left is an unshaded wall of white stucco with the average range of temperatures experienced by that wall during a typical hour of a summer day. On the right are the wall temperatures taken when shaded by a tree, shrub and vine respectively. The average drop in surface temperature is between 7 and 12 degrees where the vegetation intercepts the direct gains of the sun and 3 to 4 degrees for the indirect.

Pages 12-5 and 6 introduce some of the effects of vegetation on the flow of air around and through a building. The placement of plantings around the building should take into account their impact on air flow.

On page 12-7 there is a list of general criteria used to select vegetation. The balance of the chapter is devoted to selections of appropriate plantings for use in Botswana assembled by Gus Nelson of Sanitas, Pty.

VEGETATION

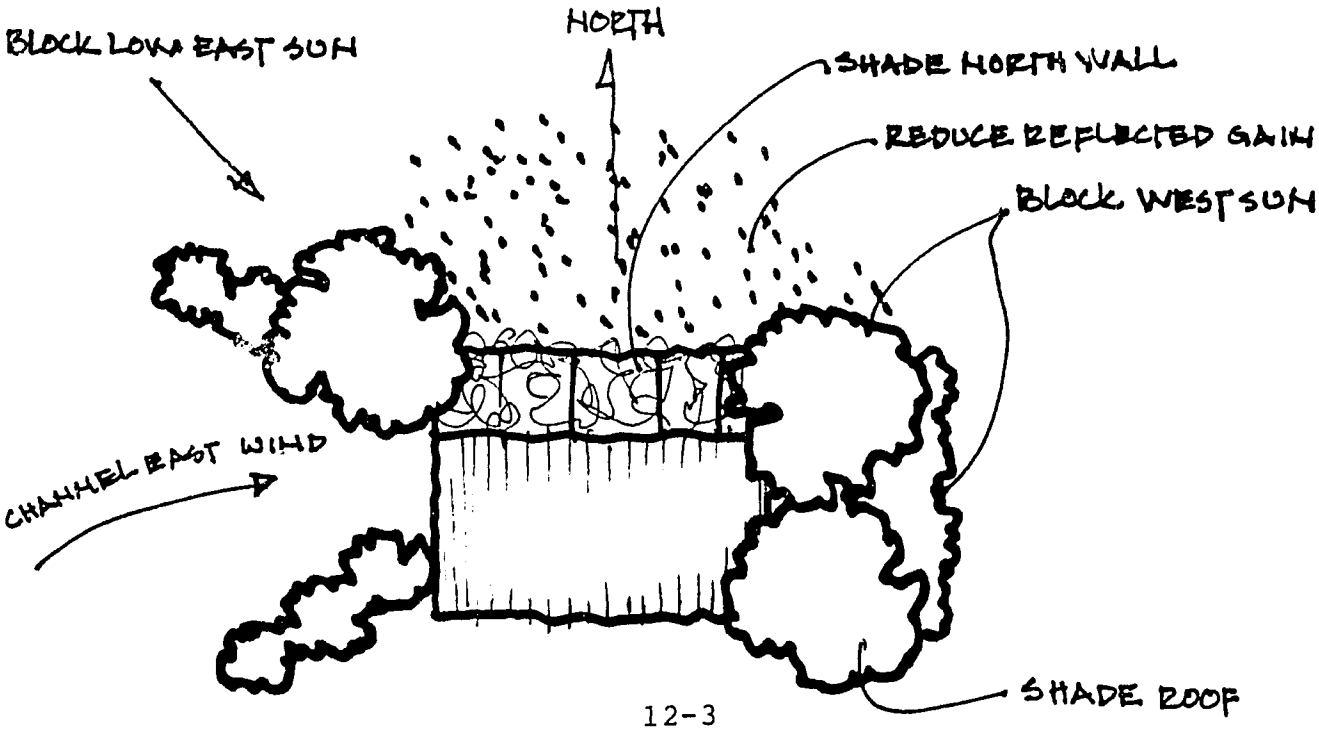
VEGETATION CAN BE A VALUABLE RESOURCE FOR COOLING OF PASSIVE STRUCTURES. IN ADDITION, IT CAN REDUCE GLARE, NOISE & WIND BORNE DUST, PROVIDE COLOR & TEXTURE & OFFER PRIVACY.

FROM AN ENERGY STANDPOINT VEGETATION IS MOST EFFECT WHEN USED:

- TO BLOCK OR CHANNEL WIND
- TO SHADE FROM SOLAR RADIATION

AN APPROPRIATE PLANTING PROGRAM FOR A HOUSE IN BOTSWANA WOULD BE:

- PLANT VINES (DECIDUOUS) TO NORTH
- PLANT HIGH CANOPY TREES TO EAST & WEST
- PLANT LOW SHRUBS OR VINES TO EAST & WEST
- PLANT TO CHANNEL EAST WINDS
- PLANT GROUND COVER TO NORTH, EAST & WEST



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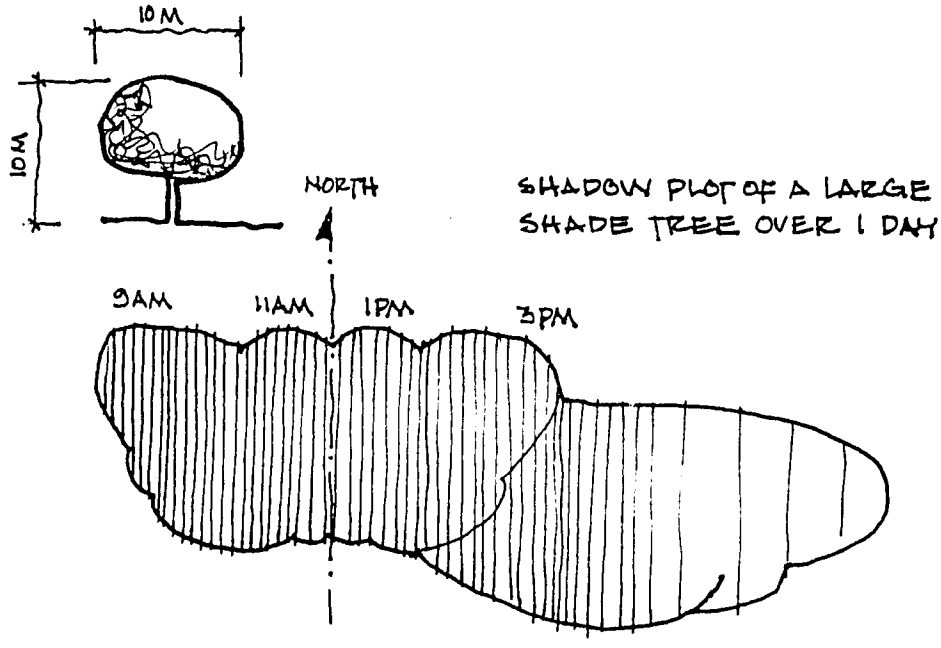
VEGETATION

VEGETATION IS AN IMPORTANT FACTOR IN COOLING. EVALUATE THE EXISTING VEGETATION WITH RESPECT TO ITS SHADING POTENTIAL.



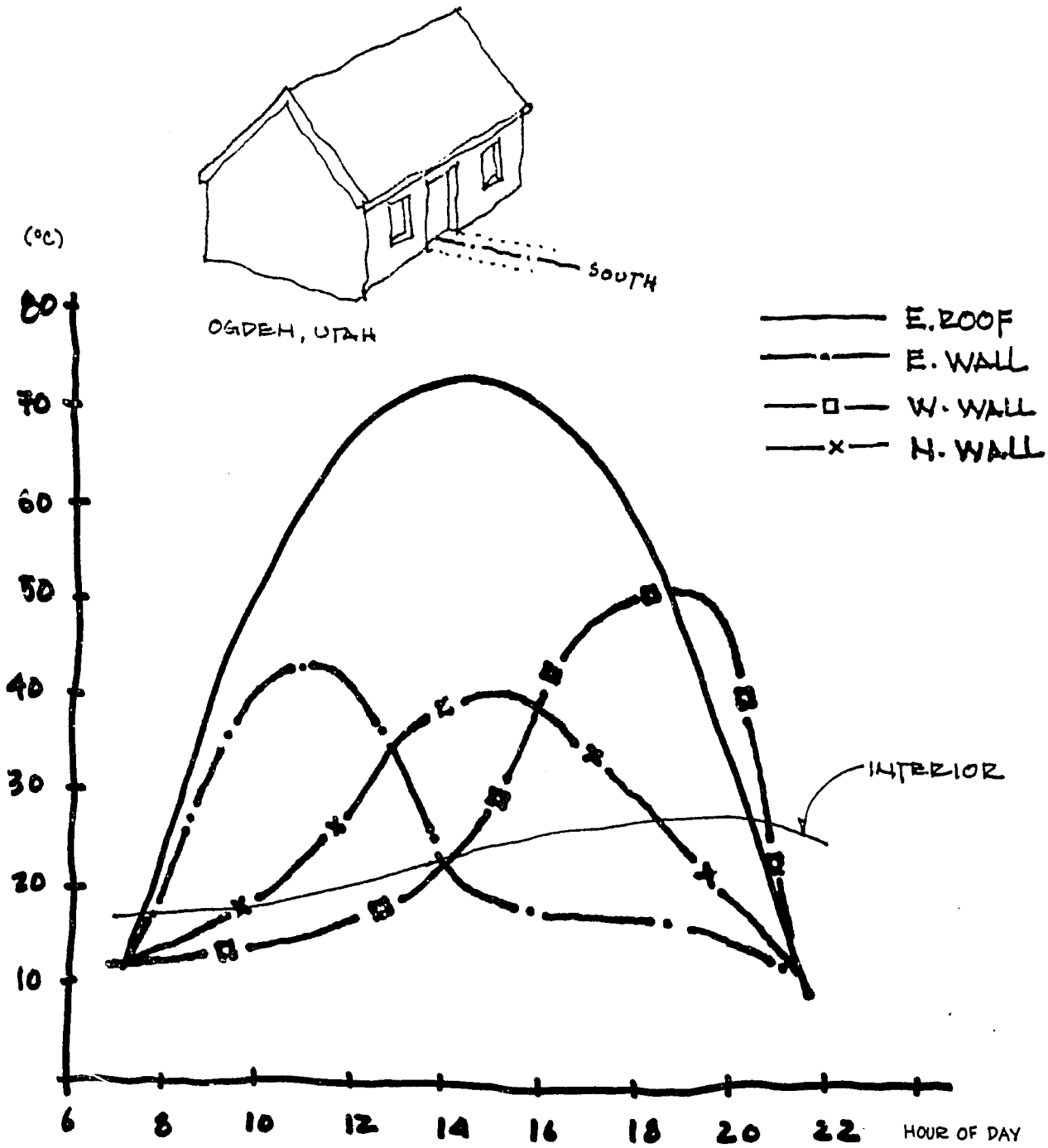
AVOID LOCATING EXISTING TREES LESS THAN 3M FROM THE HOUSE FOUNDATION. EXCAVATION COULD DAMAGE ROOTS AND ROOTS MIGHT EVENTUALLY DAMAGE THE FOUNDATION.

IF POSSIBLE, DETERMINE WHETHER OR NOT THE TREE DROPS ITS LEAVES IN WINTER. IF SO IT IS APPROPRIATE FOR USE ON THE NORTH. IF NOT USE IT ON THE EAST OR WEST ELEVATION OF THE BUILDING. NOTE THE DENSITY OF LEAVES.

NOTE ALSO ANY AVAILABLE GROUND COVER AS IT CAN REDUCE BY ABSORBTION THE AMOUNT OF REFLECTED GAIN.

193

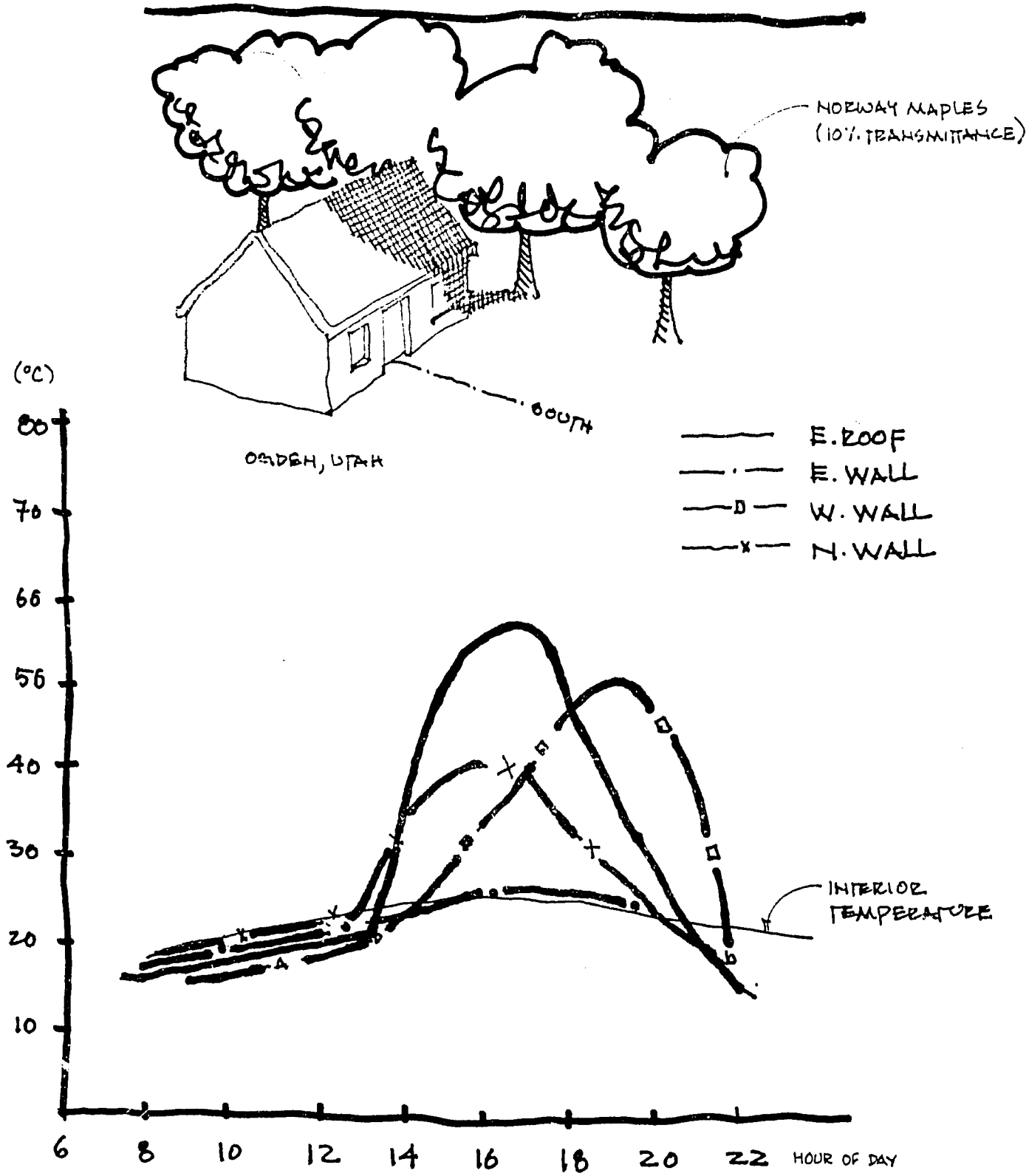
SURFACE TEMPERATURES UNSHADED



FROM THE EFFECTS OF ORIENTATION AND SHADING FROM TREES ON THE INSIDE & OUTSIDE TEMPERATURES OF MODEL HOMES, McPHERSON.

194

SURFACE TEMPERATURES SHADED



FROM THE EFFECTS OF ORIENTATION AND SHADING FROM TREES ON THE INSIDE & OUTSIDE TEMPERATURES OF MODEL HOMES, McPHERSON

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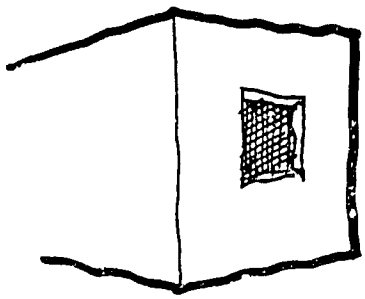
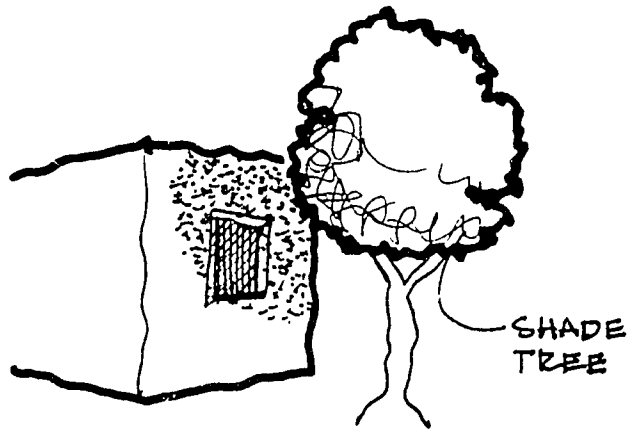
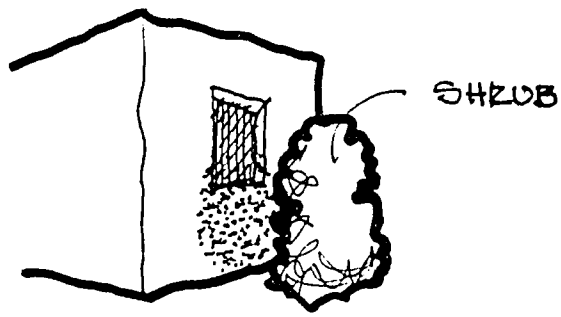
EFFECT OF VEGETATION ON WALL TEMPERATURE



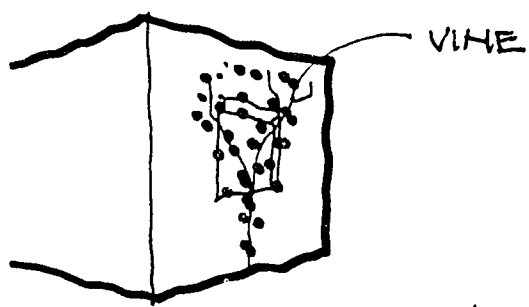
AVERAGE WALL TEMP.: 44-47°C
(WHITE STUCCO)



DIRECT - 10°C
INDIRECT - 3°C



DIRECT - 12°C
INDIRECT - 4°C



DIRECT - 7°C
INDIRECT - 4°C

(BASED ON STUDY BY JOHN PARKER, F.I.U., MIAMI FLORIDA)

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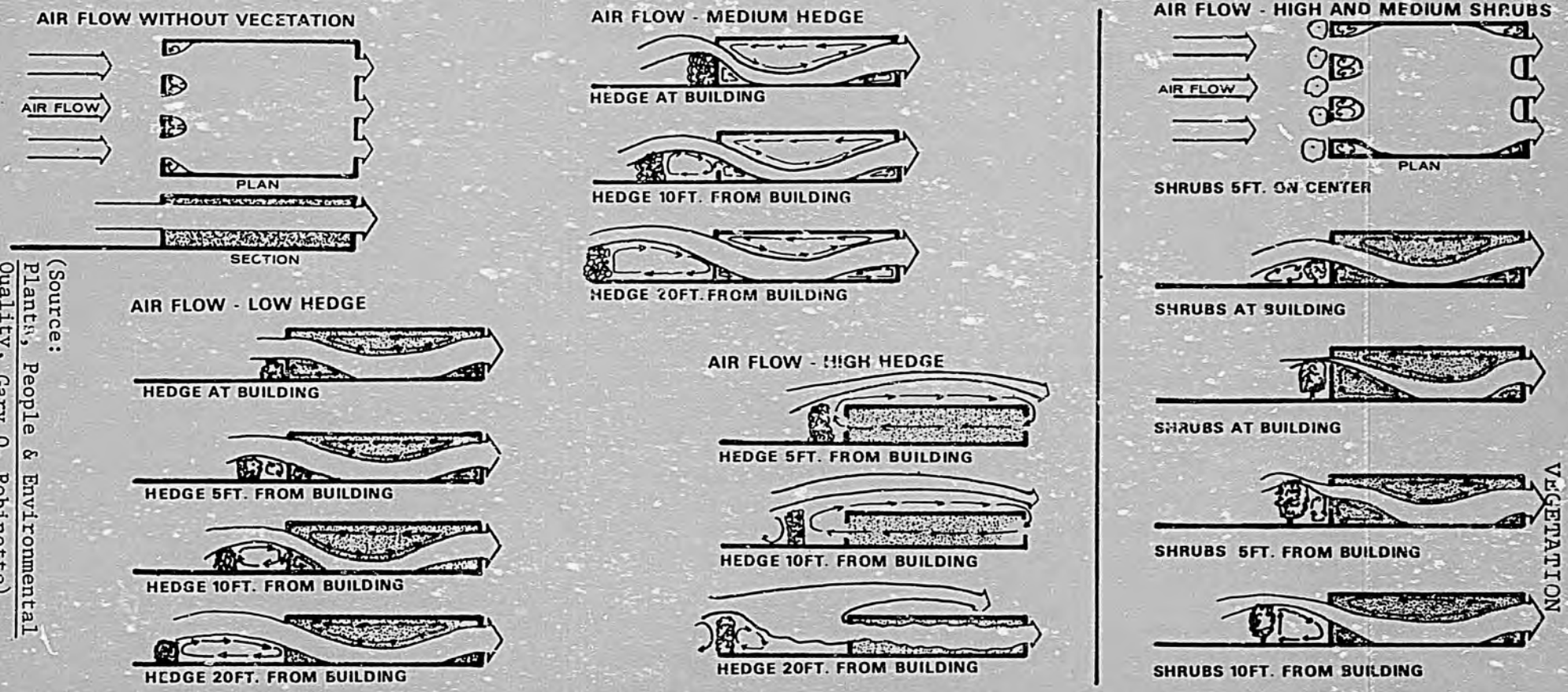
Plants Control Wind

Basically, plants control wind by obstruction, guidance, deflection, and filtration. The differentiation is not only one of the degree of effectiveness of plants, but of the techniques of placing plants. A number of references are available which refer to the ways in which plants control wind and their effectiveness in doing so. However, it must be remembered that plants as natural elements are not always absolutely predictable in their size, shape, and growth rate, and consequently in their absolute effectiveness.

Obstruction with trees, as with all other barriers, reduces windspeed by increasing the resistance to windflow. Coniferous and deciduous trees and shrubs used individually or in combination affect air movement.

Plants may be used in conjunction with landforms and architectural materials to alter the airflow over the landscape, and around or through buildings.

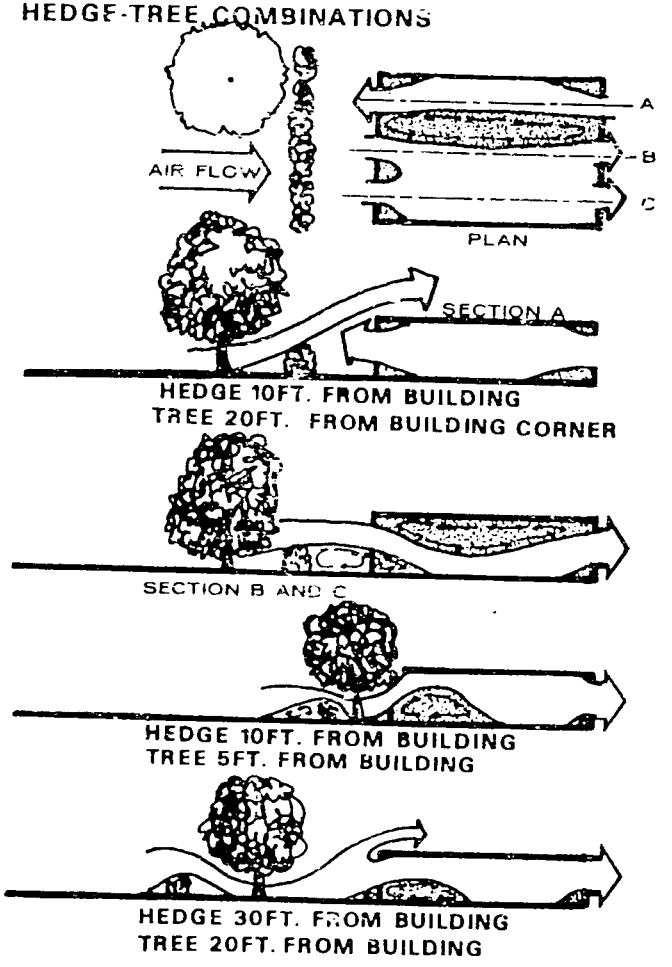
Guidance of wind is the subject of a number of studies on the placement of plants adjacent to buildings to enhance natural ventilation. The studies conducted by Robert F. White, landscape architect on the staff of the Texas Engineering Experiment Station, were primarily concerned with the wind control aspects of planting in relation to architecture to provide natural ventilation in warm areas of the world. White's research in-

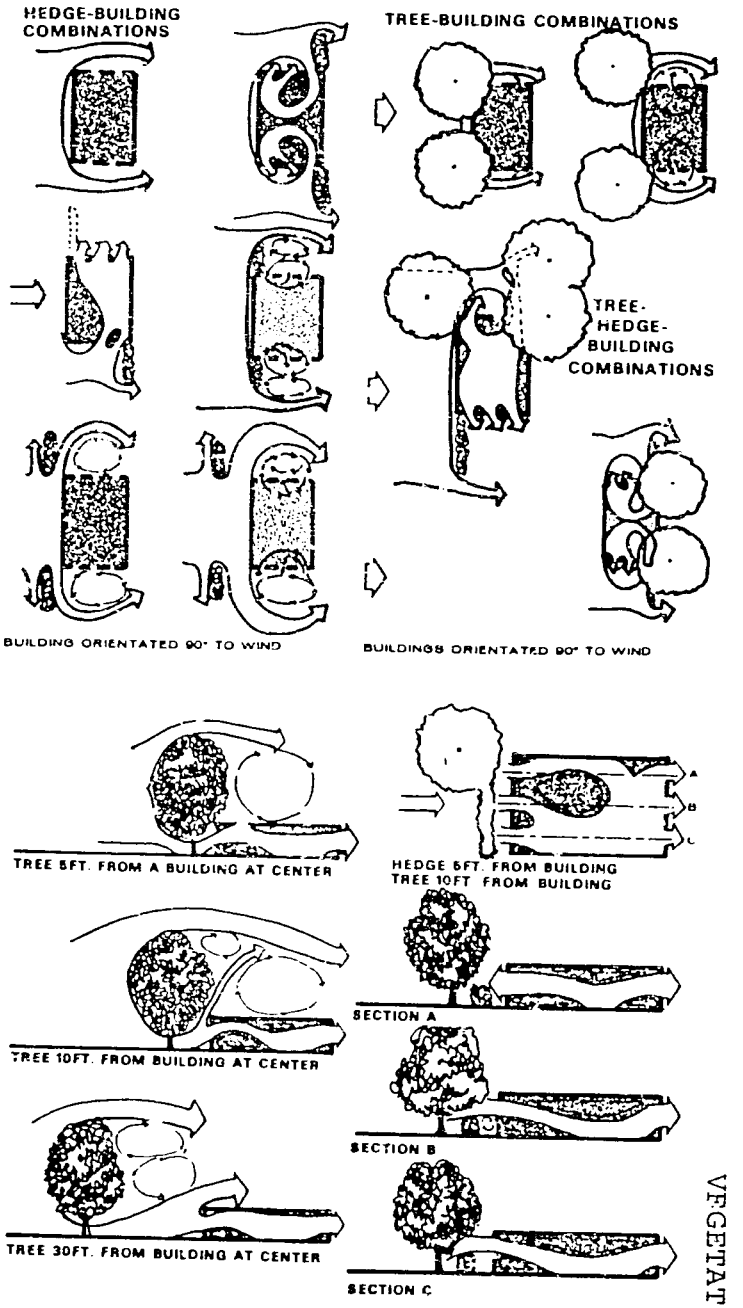


(Source: Plants, People & Environmental Quality, Gary O. Robinette)

dicated that: "(1) Planting can materially affect the movement of air through and about buildings, (2) Dependent on the way it is used, planting may either augment or reduce the natural airflow through the building, (3) Planting may cause actual change of direction of airflow within the building, (4) Planting on the lee side of buildings has little or no affect on the movement of air through the building unless it is in such a position that it obstructs the outlet openings." * The accompanying illustrations indicate air flow around and through a number of plants and building configurations.

HEDGE-TREE COMBINATIONS





*Robert F. White, *Effects of Landscape Development on the Natural Ventilation of Buildings and Their Adjacent Areas*, Texas Engineering Experiment Station, Research Report 45 (Austin, 1951), College Station, Texas, p. 21.

(Source: Plants, People & Environmental Quality, Gary O. Robinette)

VEGETATION SELECTION

In selecting the right tree, shrub or vine to shade a building, there are a number of important criteria to consider.

1. Mature Height. How big will it be when fully grown? Don't plant in a space which will not accommodate the mature specimen or place it too close (under 3m) to where mature roots will cause foundation problems.

2. Shape of the Crown. The crown is the leafy head of the tree and it comes in many different forms. Select the crown which best satisfies the job. A broad, thin and high crown might be appropriate for roof shading while a round, low and bushy one is best for a wall.

3. Growth Rate. Plan your overall shading strategy with short, medium and long-term plantings in mind. Select a fast growing vine for immediate wall shading while planting a slower growing tree to handle the job when the vine eventually dies. Don't select plants which are too slow growing.

4. Leaf Appearance and Fall Pattern. A broad thick leaf will block out more sun than a thin one. If you are in need of summer shade and winter gain, the tree's fall pattern must follow closely that of the heating and cooling season.

5. Density of Leaf Growth. Trees are shading devices whose capability is measured by the density of their foliage. The denser the better.

6. Distance from the Ground to the First Branch. If you are trying to shade the roof it does no good to select a tree which sprouts its branches just above the ground. Though pruning can compensate to some degree, it is much better to select wisely to begin with.

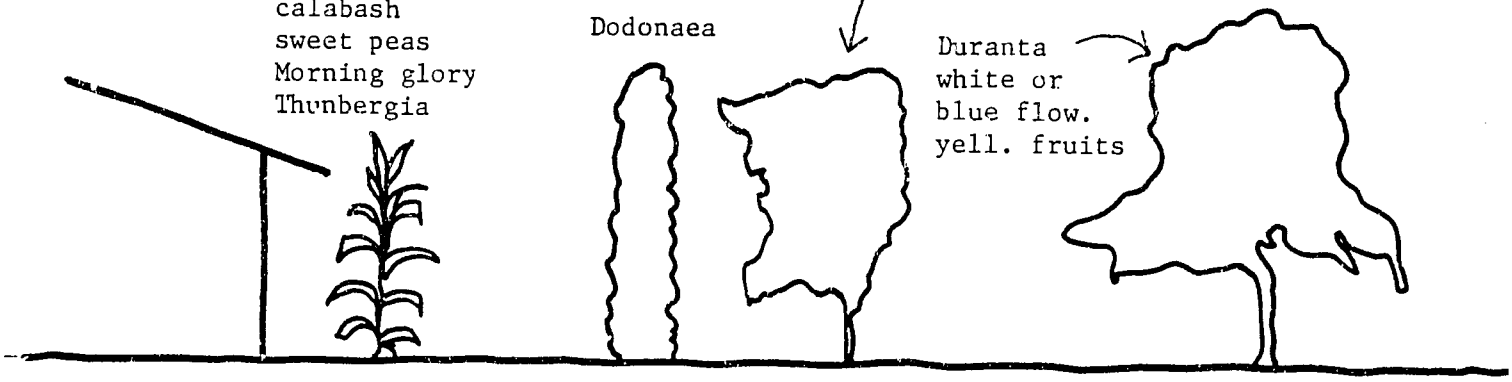
Examples of vegetation for shade

Fast growers: (annuals)
Hybrid maize e.g. SR 200 (8 feet)
Beans, cucumber,
calabash
sweet peas
Morning glory
Thunbergia

Dodonaea

Perennial hedges clipped or free growing

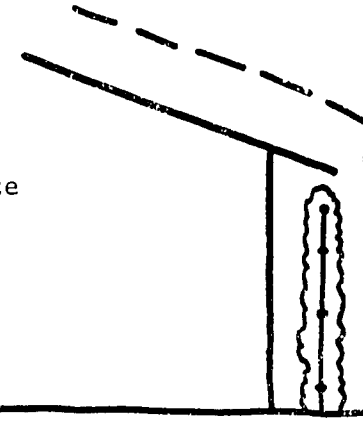
Duranta
white or
blue flow.
yell. fruits



Fruit producing climbers: Grapes
Grenadilla
(See above cucumber, calabash)

Perennial climbers (like annual) need support.
They can cover prt or the entire roof

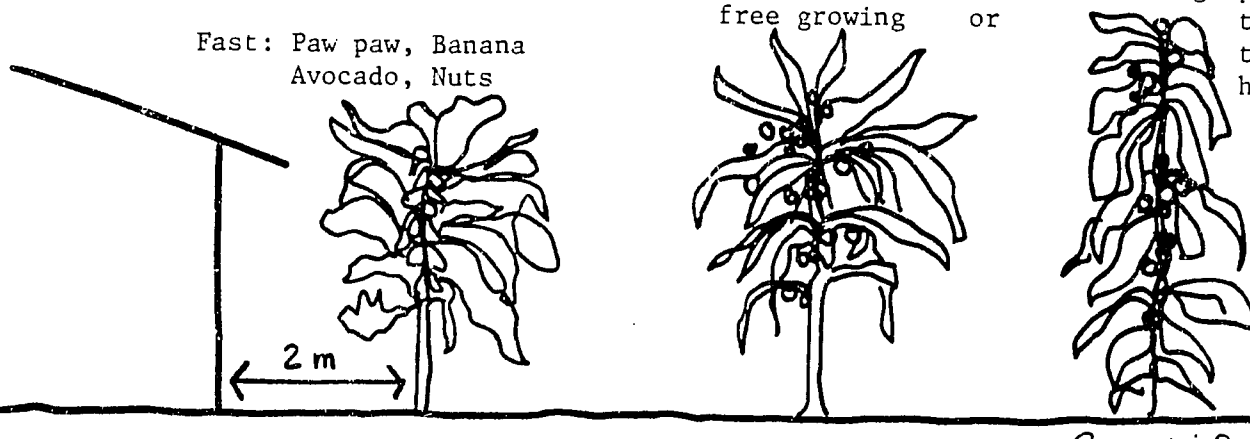
e.g. Lonicera (Europoean honeysucle)
Tecomaria capensis, Cape honeysucle in red, bronze and yellow
Bignonia (Clytostoma)
Hodera, Ivy, deep shade or shade
Jasminum, white, yellow, Bougainvilliea, etc.
Patrea, blue
Golden shower



Fruit trees for shade:

Fast: Paw paw, Banana
Avocado, Nuts

Slower: Oranges, lemon, lime, grapefruit
free growing or trimmed to a hedge



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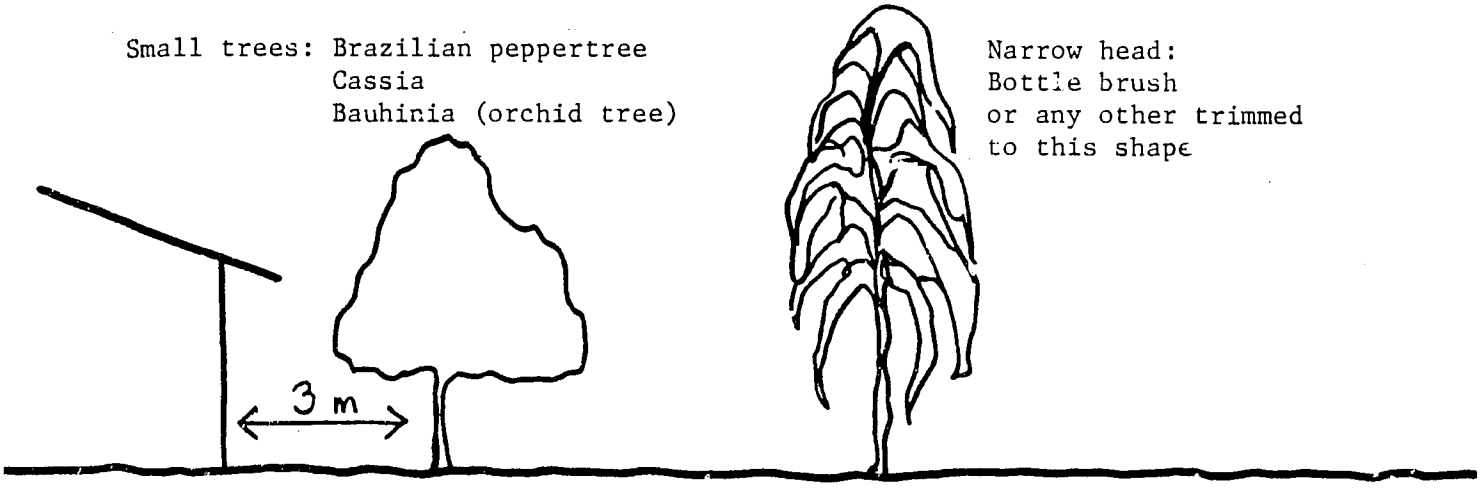
200

Small trees: Brazilian peppertree
Cassia
Bauhinia (orchid tree)

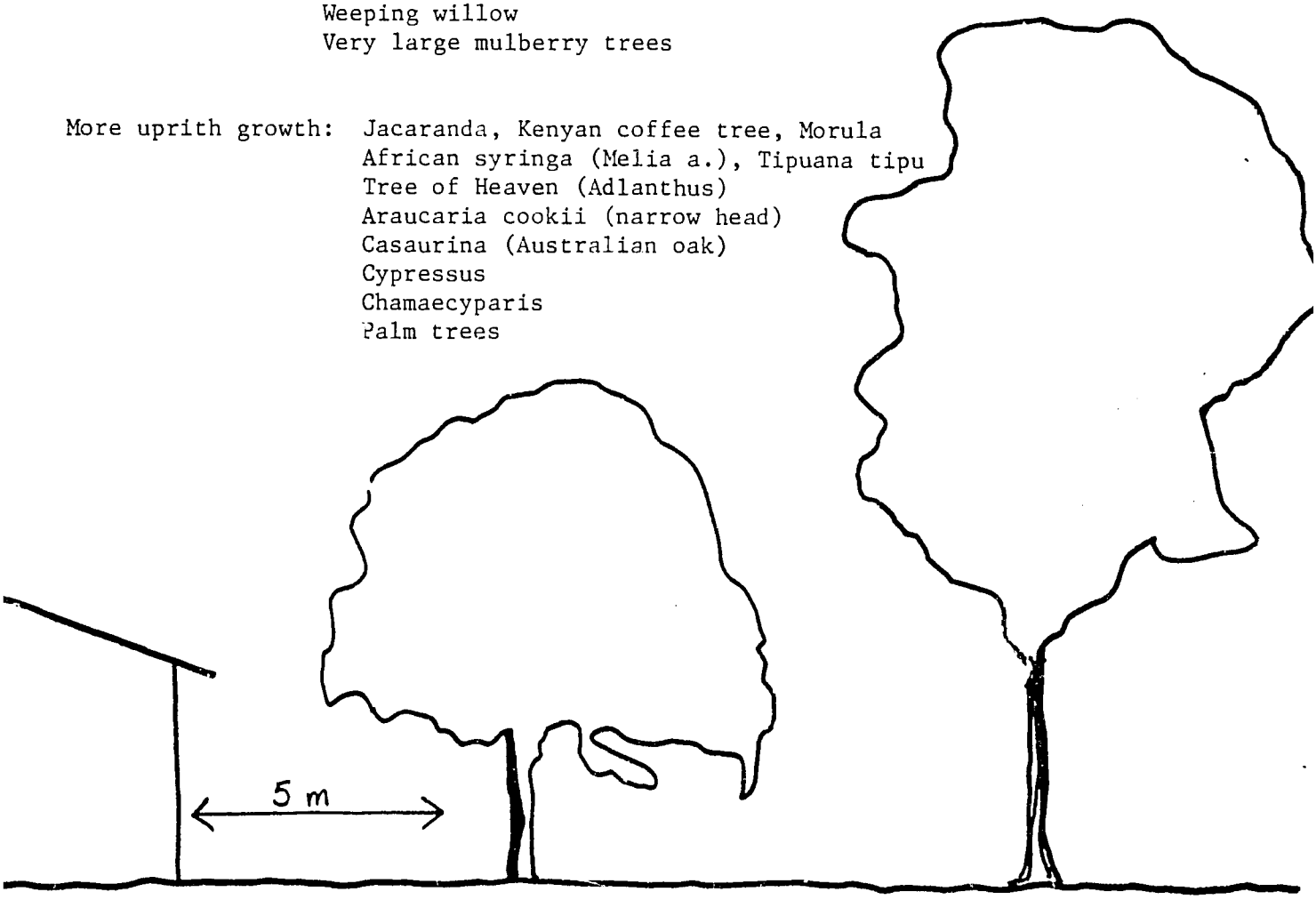
Narrow head:
Bottle brush
or any other trimmed
to this shape

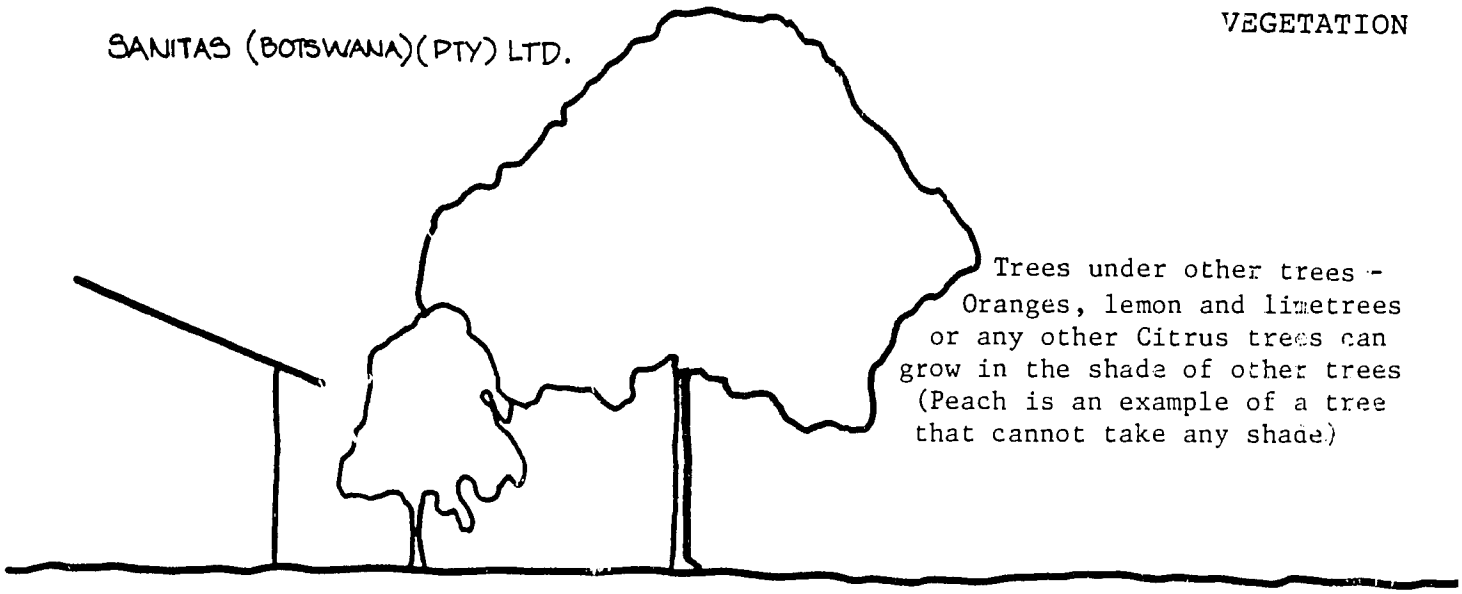


Larger trees: Flat head: e.g. Flamboyant trees
Acacia e.g. the Camel thorn of western Botswana
have heads up to 20 m in diameter

Hanging branches: Pepper trees
Weeping willow
Very large mulberry trees

More uprith growth: Jacaranda, Kenyan coffee tree, Morula
African syringa (Melia a.), Tipuana tipu
Tree of Heaven (Adlanthus)
Araucaria cookii (narrow head)
Casaurina (Australian oak)
Cypressus
Chamaecyparis
Palm trees



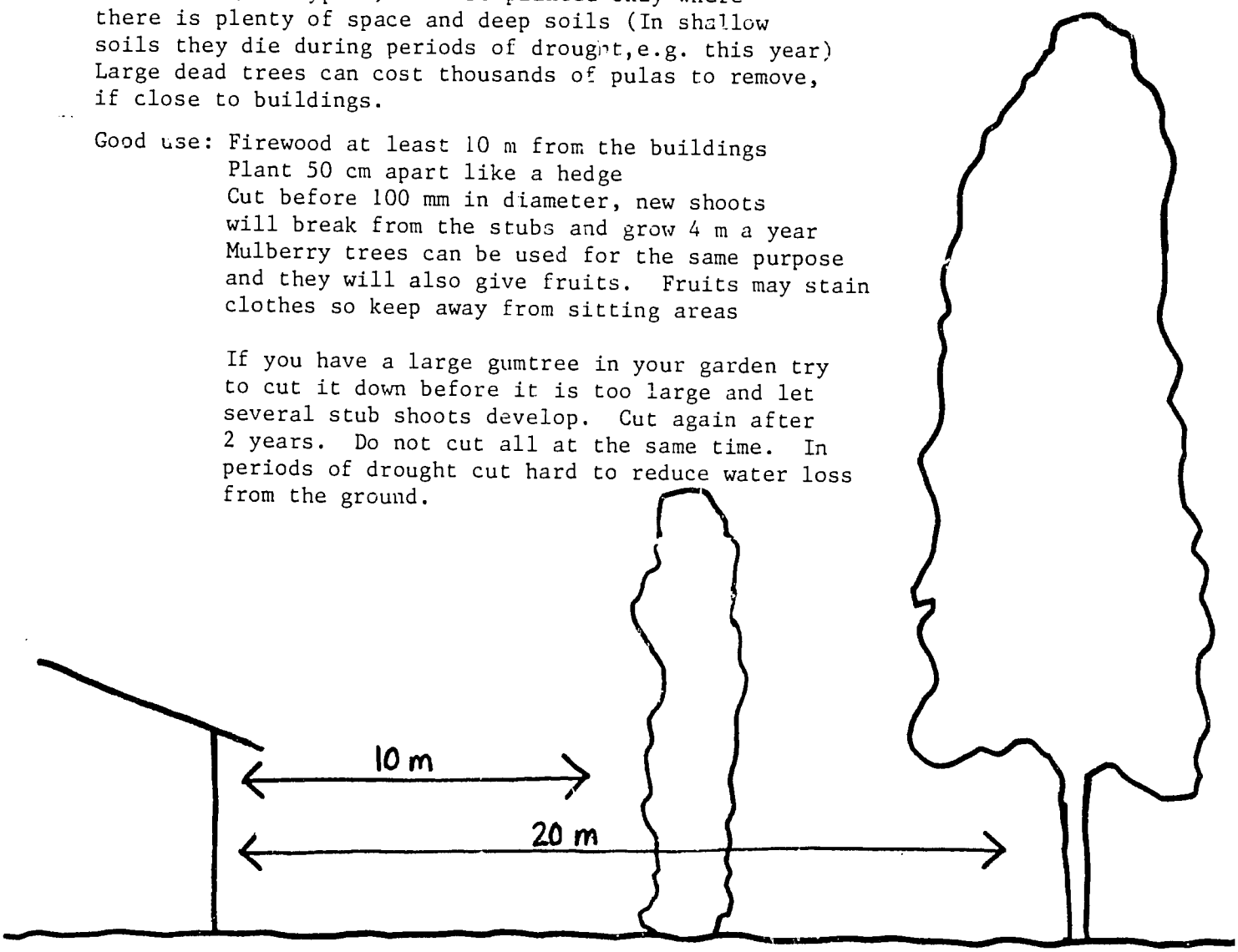


Trees under other trees - Oranges, lemon and limetrees or any other Citrus trees can grow in the shade of other trees (Peach is an example of a tree that cannot take any shade)

Gum trees (Eucalyptus) must be planted only where there is plenty of space and deep soils (In shallow soils they die during periods of drought, e.g. this year) Large dead trees can cost thousands of pulas to remove, if close to buildings.

Good use: Firewood at least 10 m from the buildings
Plant 50 cm apart like a hedge
Cut before 100 mm in diameter, new shoots will break from the stubs and grow 4 m a year
Mulberry trees can be used for the same purpose and they will also give fruits. Fruits may stain clothes so keep away from sitting areas

If you have a large gumtree in your garden try to cut it down before it is too large and let several stub shoots develop. Cut again after 2 years. Do not cut all at the same time. In periods of drought cut hard to reduce water loss from the ground.



13. DAYLIGHTING

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DAYLIGHTING FOR ENERGY CONSERVATION

The primary role for daylighting in energy conservation is to reduce the need for electric lighting. In Botswana, the amount of daylight available to this end is very high and its utilization is already widespread in buildings of all sizes. This section will give designers a better grasp on the architectural variables which affect the use of daylight in order that it might be used with greater sensitivity and have a larger impact on reduced consumption of costly electricity.

Most of the contents of this section are reproduced verbatim from the excellent text on daylighting entitled Daylight in Architecture, by B. Evans.

The graphs on page 13-3 bring out an interesting paradox which is that daylighting suggests an optimum north-south orientation while passive solar heating and cooling opts for an east-west orientation. The high levels of available daylight in Botswana are such that heating and cooling orientation must take precedence. The table on page 13-4 lists the illuminances recommended for various tasks and are to be used in the design of both the daylighting and traditional electric lighting.

Pages 13-5 to 7 outline some of the basic principles of daylighting. Pages 13-8 to 14 show the impact of window height, width, room depth, ceiling slope, sloped glass, interior surface color and overhangs on illumination.

Pages 13-15 to 18 suggest how daylight can be admitted to the building without introducing overheating and/or uncomfortable task illumination conditions.

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Next is an illumination nomogram (13-19 and 20) whose main virtue is its ease of use. This virtue is the result of a number of simplifying assumptions which include ground illuminance, sky illuminance, solar altitude, external shading device louver configuration, adjacency of neighboring buildings and the reflectance of all interior wall surfaces. Left to us is the size of the room and window and the rough location of the work plane where we wish to determine the illumination.

The most accurate way of obtaining illumination data at the design level is to build a model of the building or space at large scale, including all the finished colors. Take it out into the sun along with a light cell and photometer and take readings. See page 13-21 for a schematic and consult Daylight in Architecture by B. Evans (see Bibliography) for equipment suggestions and modeling technique.

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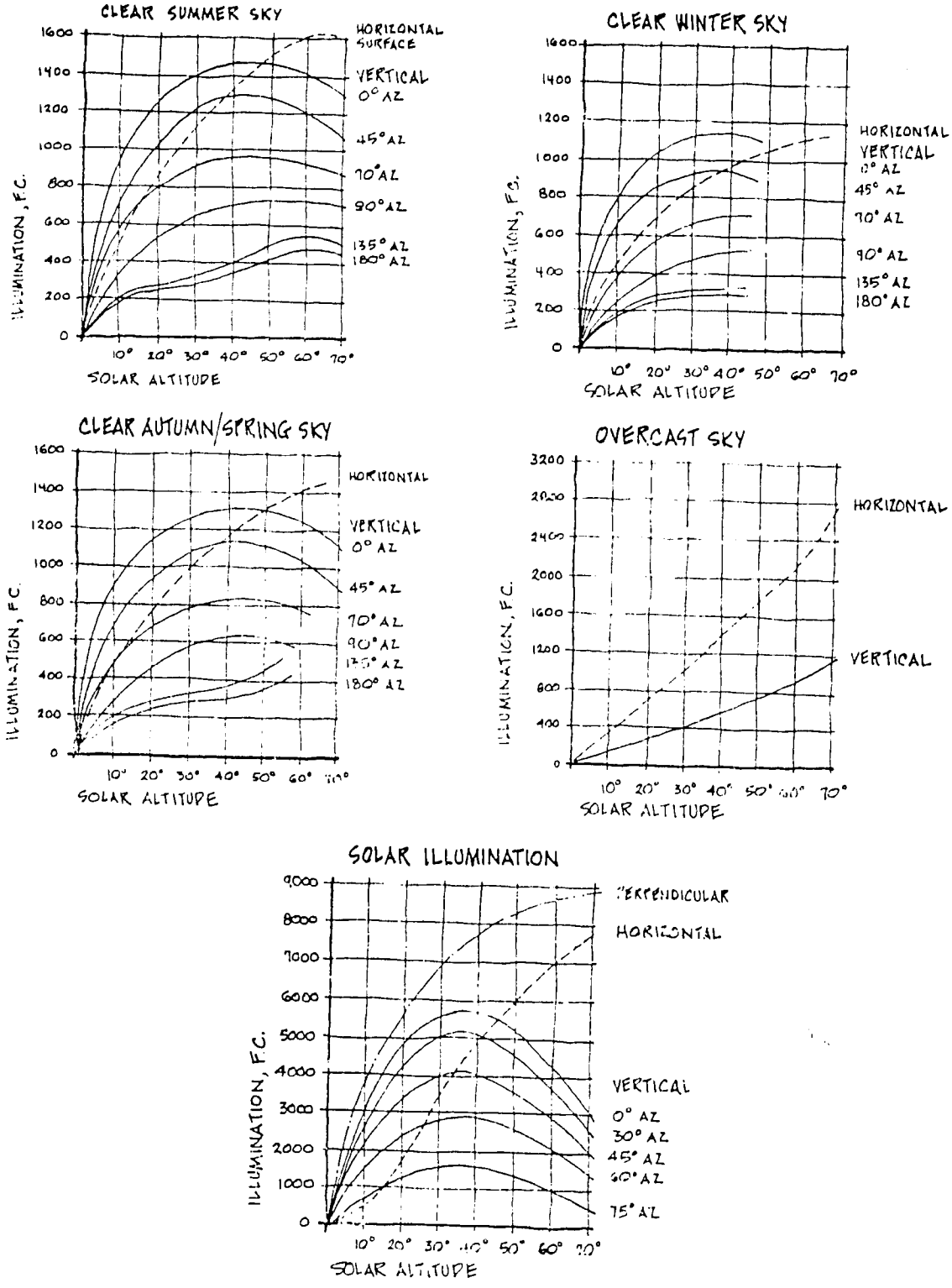

Graphs for predicting the illumination on the horizontal and vertical surfaces under various types of skies. Illumination from the sun is considered separately.

(Source: B. Evans)

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Illuminance Recommended for Use in Selecting Values for Interior Lighting Design*

Category	Range of Illuminances Maintained in Service in Lux (Footcandles)	Type of Activity
General lighting throughout room		
A	20-30-50 (2-3-5)	Public areas with dark surroundings
B	50-75-100 (5-7.5-10)	Simple orientation for short temporary visits
C	100-150-200 (10-15-20)	Working spaces where visual tasks are only occasionally performed
Illuminance on task		
D	200-300-500 (20-30-50)	Performance of visual tasks of high contrast or large size: reading printed material, typed originals, handwriting in ink and good xerography, rough bench and machine work; ordinary inspection, rough assembly
E	500-700-1000 (50-70-100)	Performance of visual tasks of medium contrast or small size: reading medium pencil handwriting, poorly printed or reproduced material, medium bench and machine work; difficult inspection; medium assembly
F	1000-1500-2000 (100-150-200)	Performance of visual tasks of low contrast or very small size: reading handwriting in hard pencil on poor-quality paper and very poorly reproduced material, highly difficult inspection
Illuminance on task, obtained by a combination of general and local (supplementary) lighting		
G	2000-3000-5000 (200-300-500)	Performance of visual tasks of low contrast and very small size over a prolonged period: fine assembly, very difficult inspection, fine bench and machine work
H	5000-7500-10,000 (500-750-1000)	Performance of very prolonged and exacting visual tasks: the most difficult inspection, extra-fine bench and machine work, extra-fine assembly
I	10,000-15,000-20,000 (1000-1500-2000)	Performance of very special visual tasks of extremely low contrast and small size: e.g., surgical procedures

*Adapted from Table 1.2, *Guide on Interior Lighting*, Publication CIE No. 29 (TC4.1), 1975.

(Source: B. Evans)

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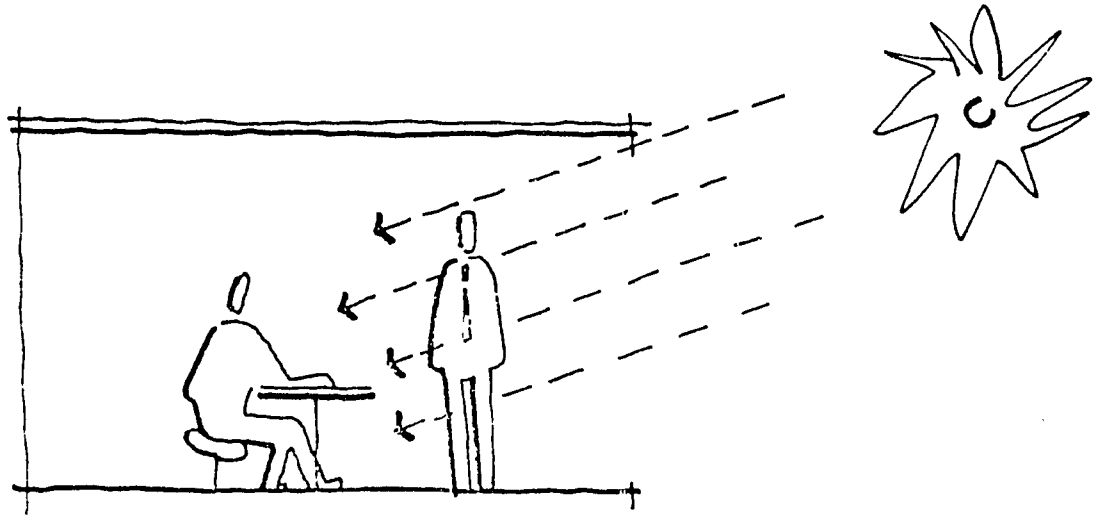
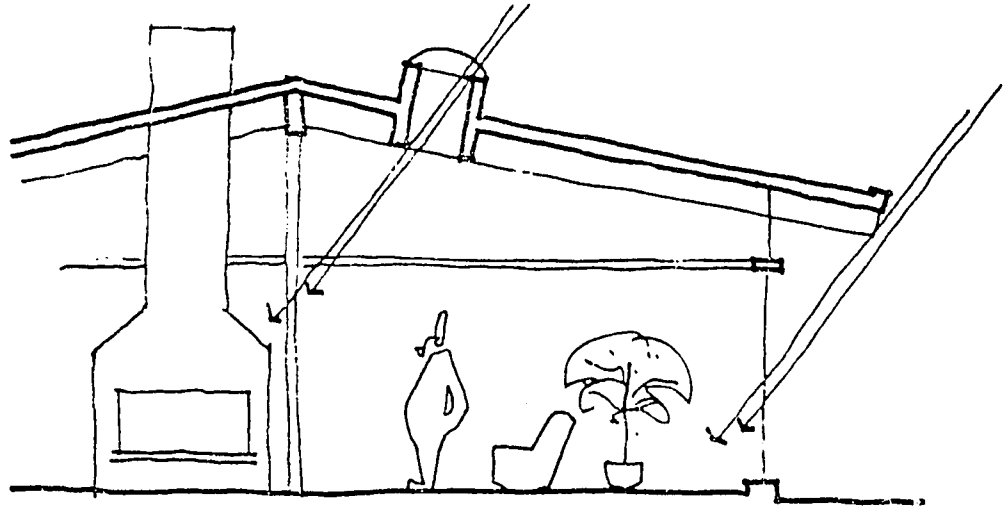
AVOID **DIRECT**
SUNLIGHT AND SKYLIGHT----



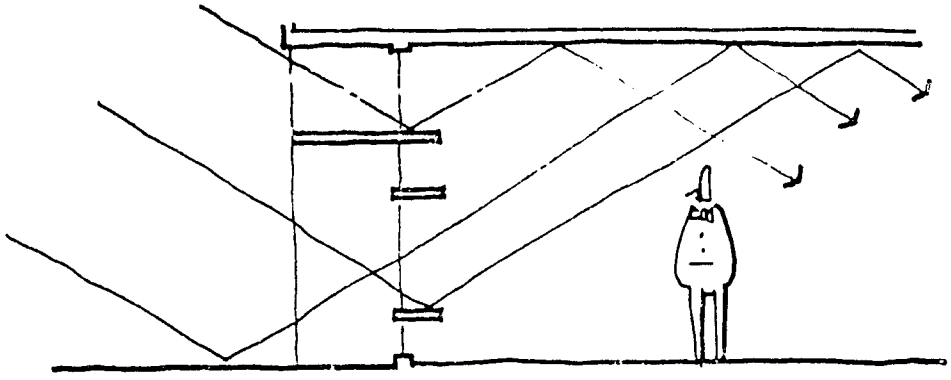
---WHICH CREATE
EXCESSIVE BRIGHTNESS DIFFERENCES

USE **DIRECT** SUNSHINE
SPARINGLY IN NON-CRITICAL TASK AREAS---



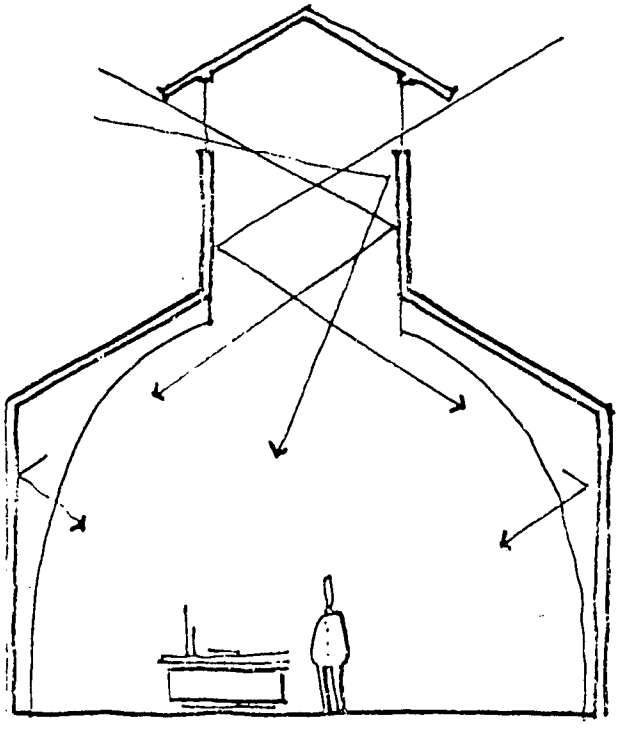
(Source: B. Evans)

BOUNCE DAYLIGHT OFF SURROUNDING SURFACES___



TO SOFTEN AND SPREAD IT

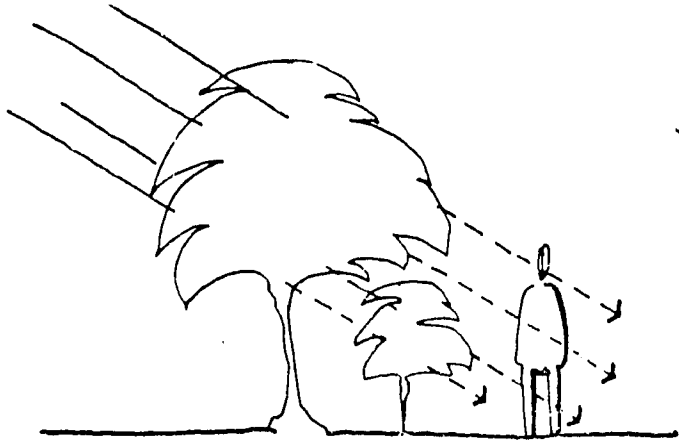
BRING DAYLIGHT IN **HIGH**___



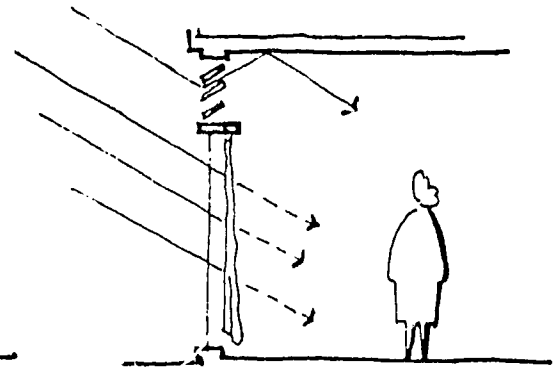
___ AND LET IT DOWN SOFTLY

(Source: B. Evans)

FILTER THE DAYLIGHT---

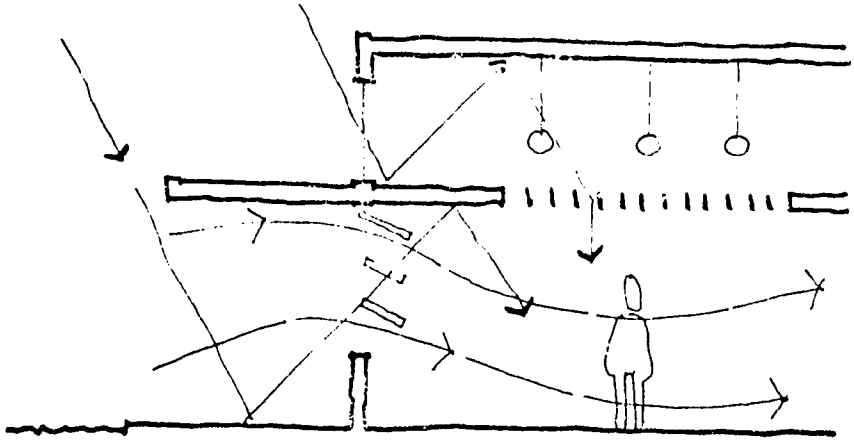


WITH TREES AND PLANTS---

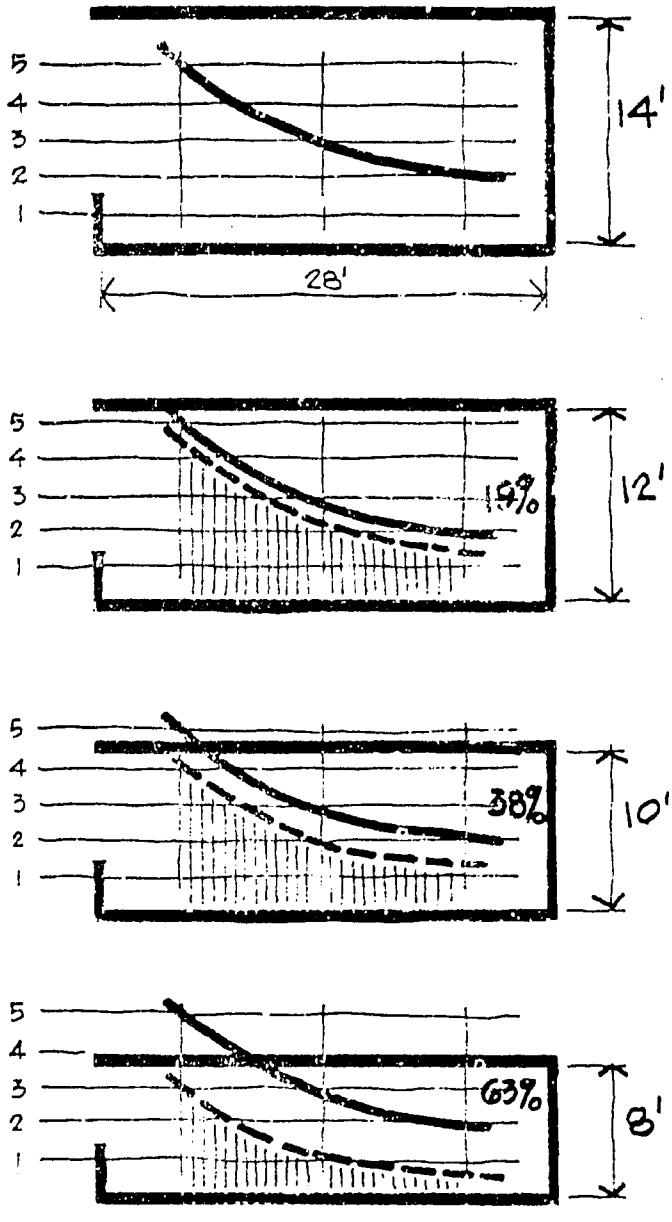


DRAPES OR SCREEN

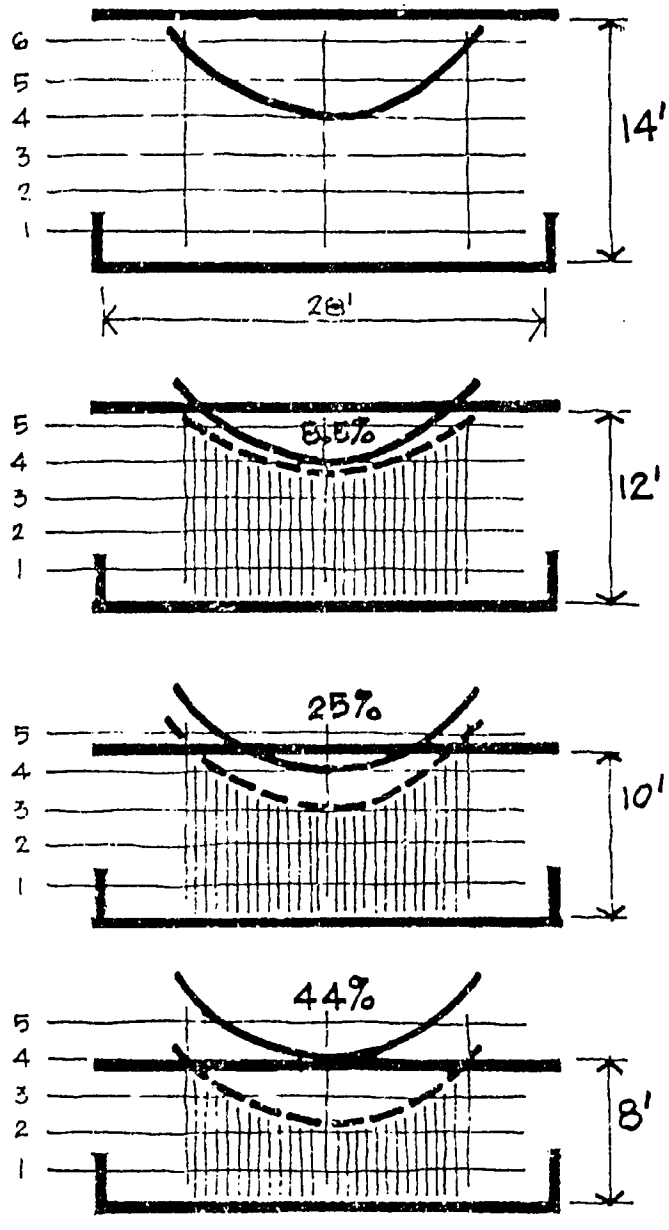
INTEGRATE DAYLIGHT WITH OTHER ENVIRONMENTAL CONCERNS---



(Source: B. Evans)



Window Height: As the height of the window is reduced from 14 feet to 12 feet, there is a 19 percent drop in illumination in the back of the unilaterally lighted room, as indicated on the graph superimposed on a cross section.



In the bilaterally lighted room, there is an 8.5 percent drop at the center of the room. Further lowering of the window height results in reduced illumination levels, but the reductions are not so pronounced as in the unilateral room.

(Source: B. Evans)

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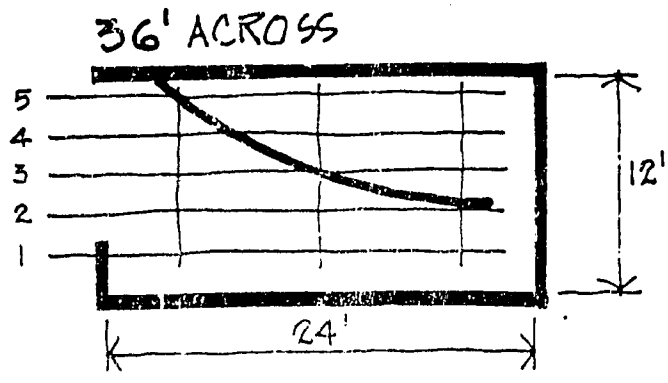
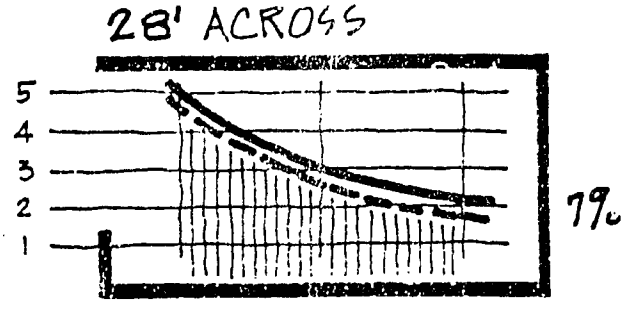
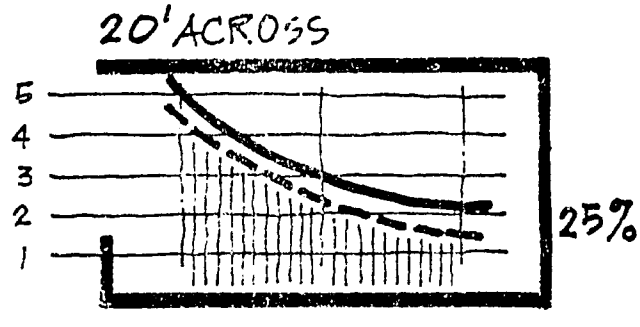
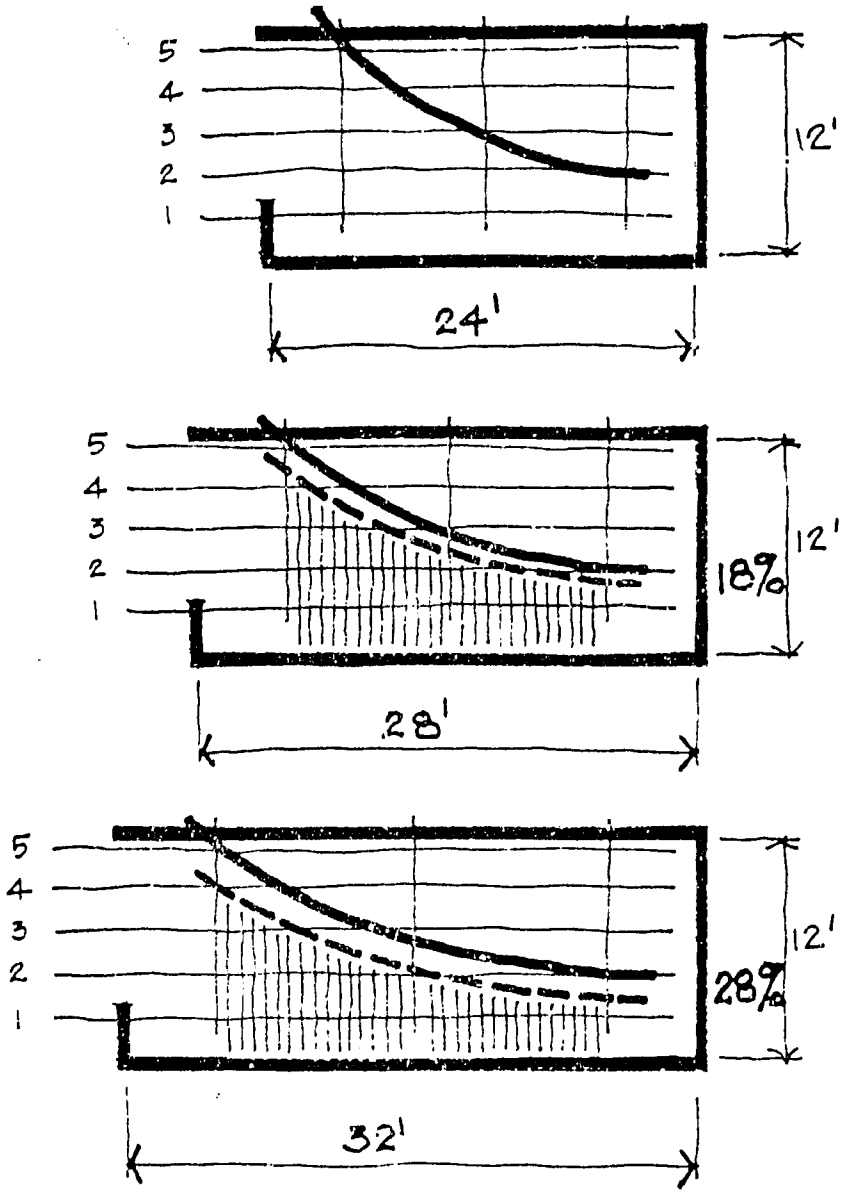






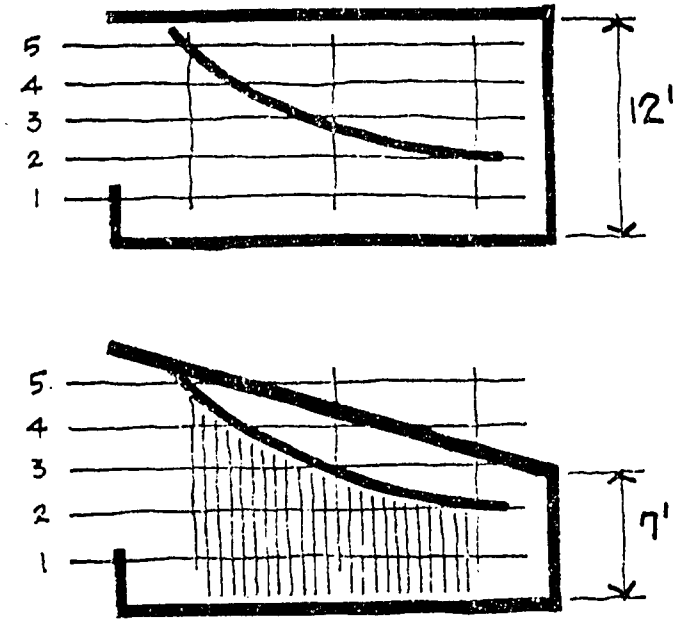
WINDOW WIDTH: WHEN THE WIDTH OF THE WINDOWS (AND ROOM) IS REDUCED, THE ILLUMINATION IN THE BACK OF THE ROOM IS ALSO REDUCED.

(Source: B. Evans)



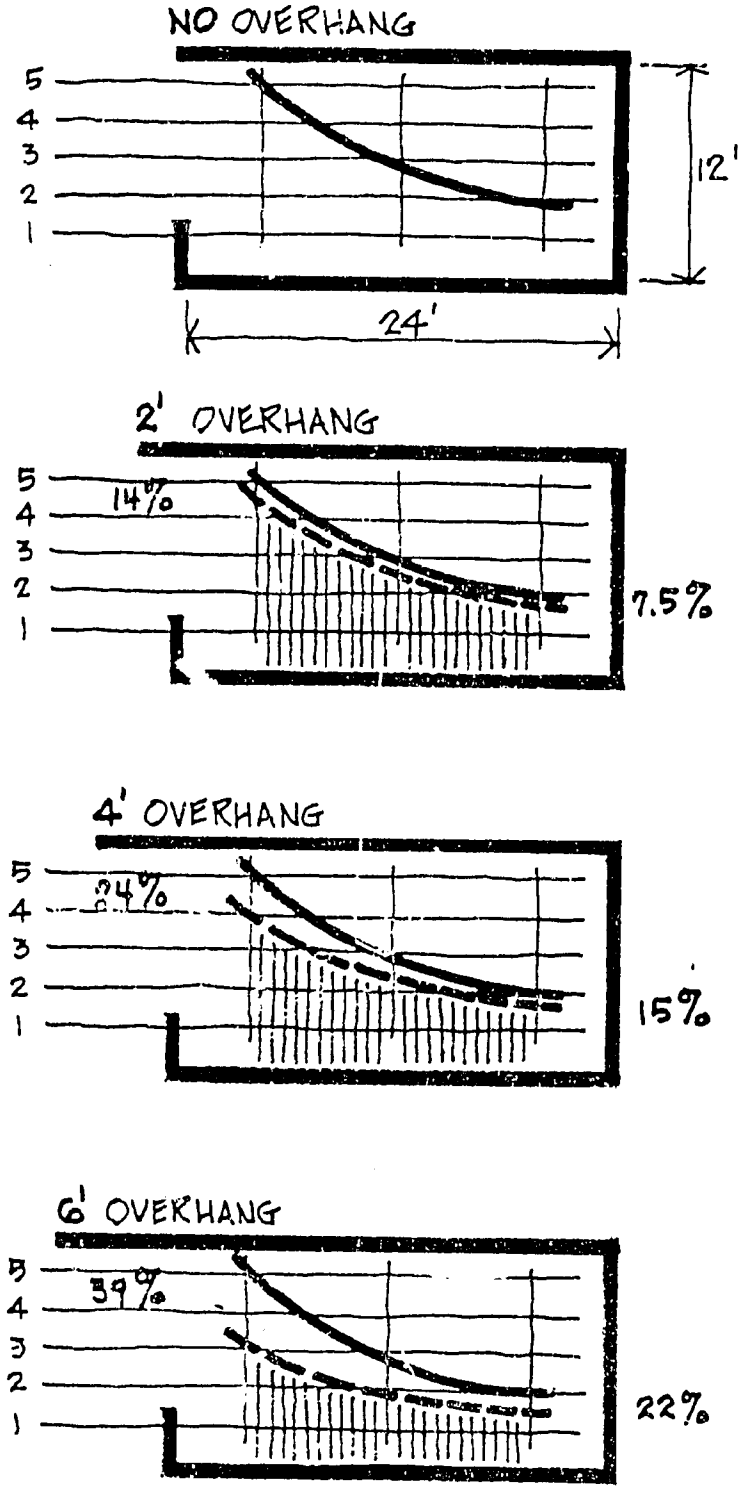
ROOM DEPTH: THE RESULT OF THE ROOMS WITH DIFFERENT DEPTHS SHOWS REDUCED DAYLIGHT LEVELS ON THE GRAPH SUPERIMPOSED ON A CROSS SECTION. THERE WAS A 28 PERCENT REDUCTION IN ILLUMINATION AT A POINT IN BACK OF THE ROOM AS THE DEPTH WAS INCREASED FROM 24 FEET TO 32 FEET.

(Source: B. Evans)



SLOPING CEILINGS:
SLOPING CEILINGS HAVE NO SIGNIFICANT EFFECT ON DAYLIGHT ON THE TASK.

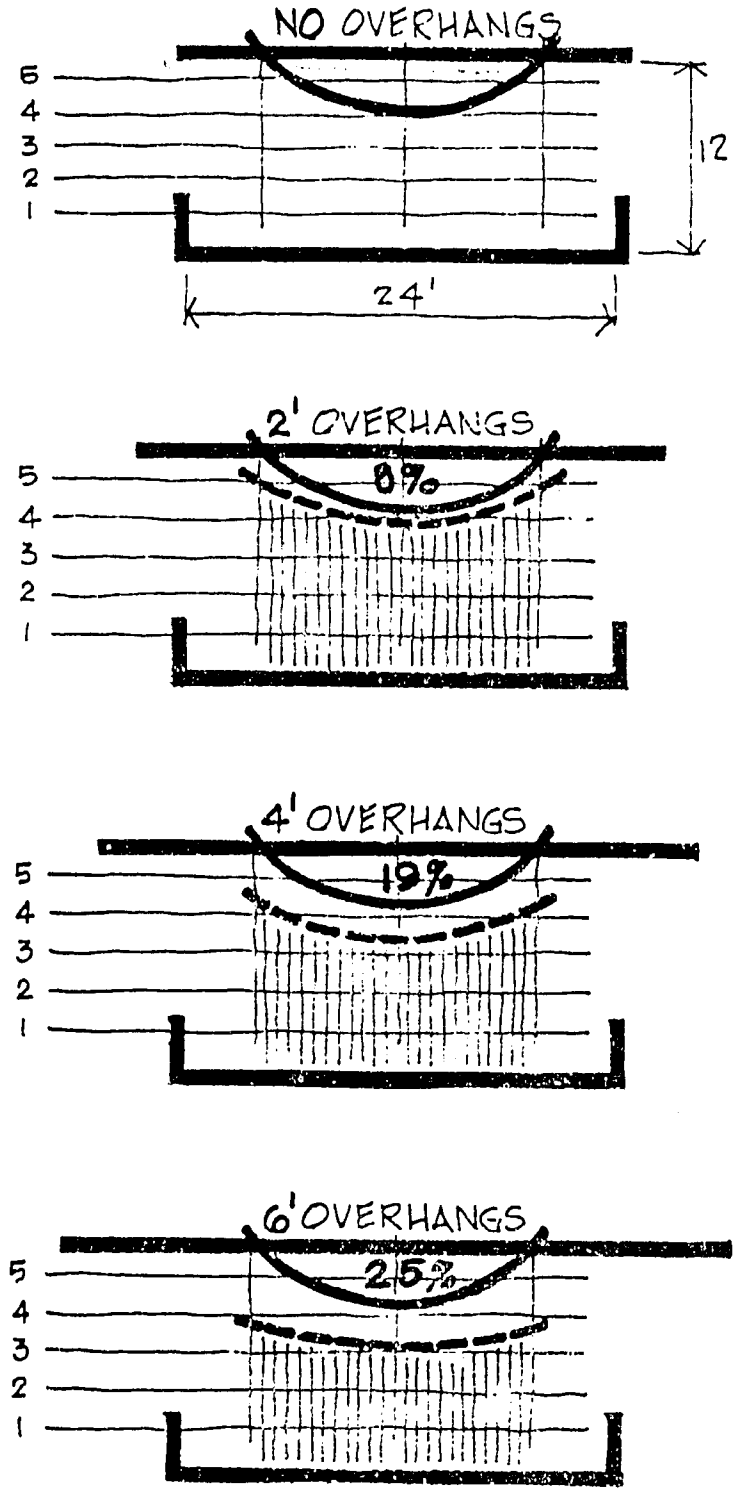
(Source: B. Evans)



OVERHANGS - UNILATERAL

OVERHANGS: A SIX-FOOT OVERHANG PRODUCES LESS OF A REDUCTION

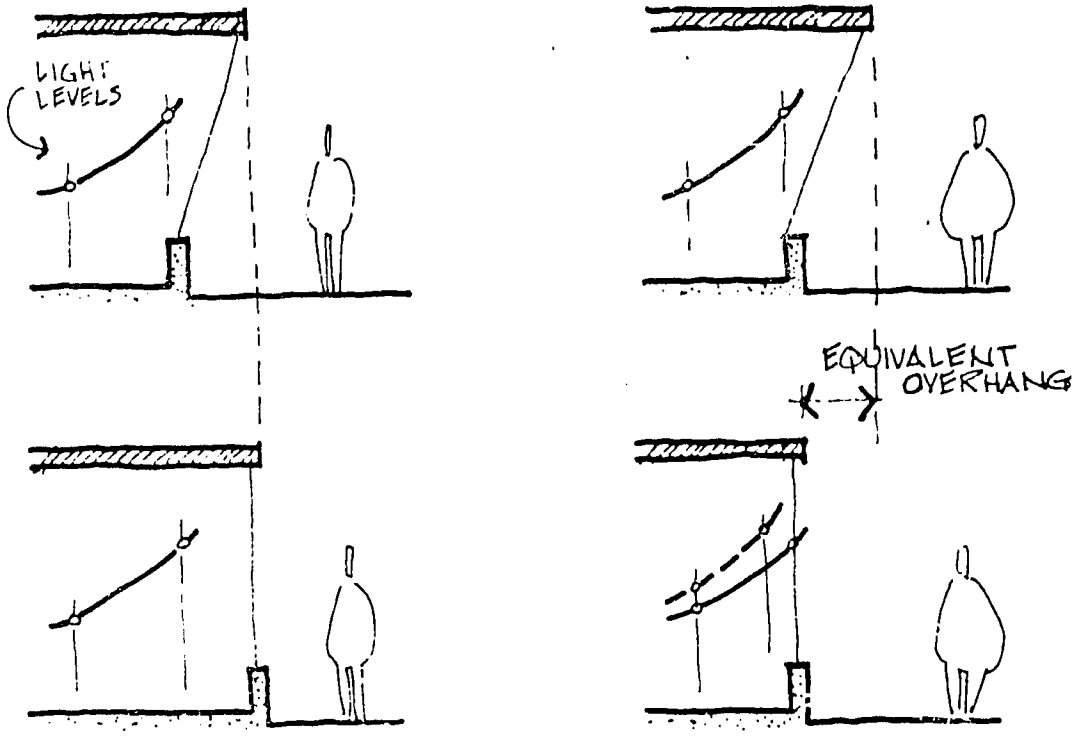
(Source: B. Evans)



OVERHANGS - BILATERAL

OF ILLUMINATION IN THE BACK OF THE ROOM THAN NEXT TO THE WINDOW WALL.

(Source: B. Evans)



SLOPING GLASS HAS NO EFFECT...

OVERHANG DOES AFFECT DAYLIGHTING LEV

SLOPED-GLASS WINDOWS DO NOT AFFECT TASK-LEVEL ILLUMINATION, BUT THE "OVERHANG" DOES.

(Source: B. Evans)

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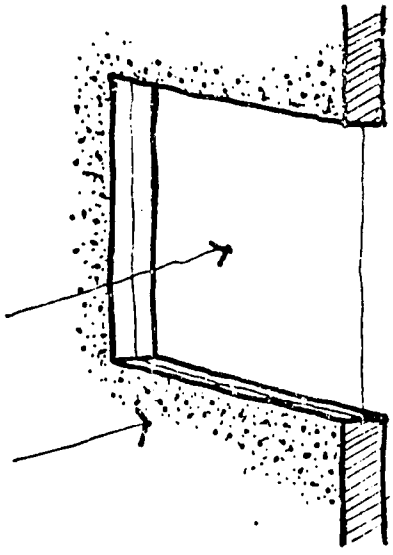
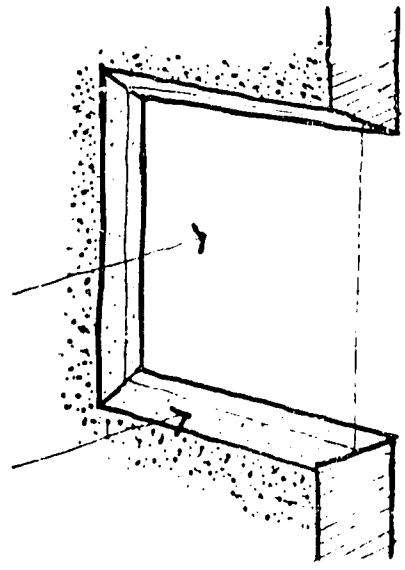
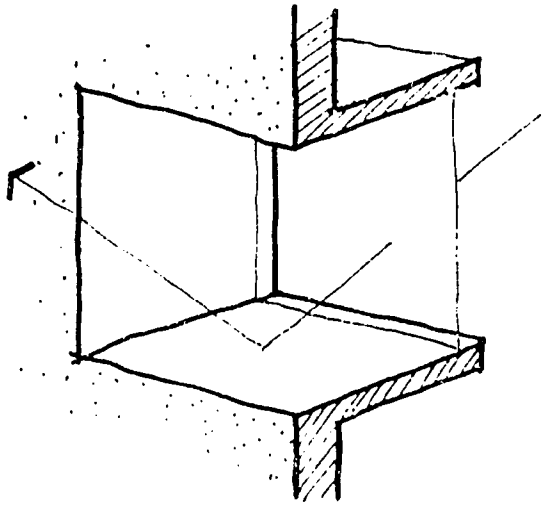


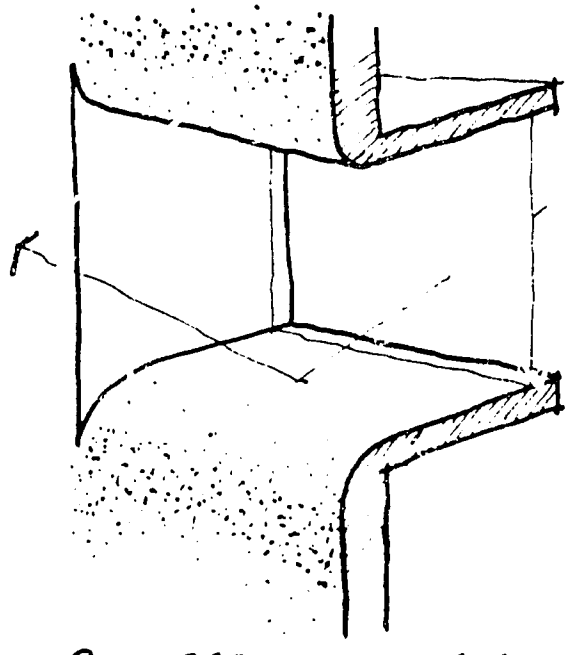
FLUSH OPENINGS PRODUCE SHARP CONTRASTS



SPLAYED WINDOW JAMBS SOFTEN CONTRASTS



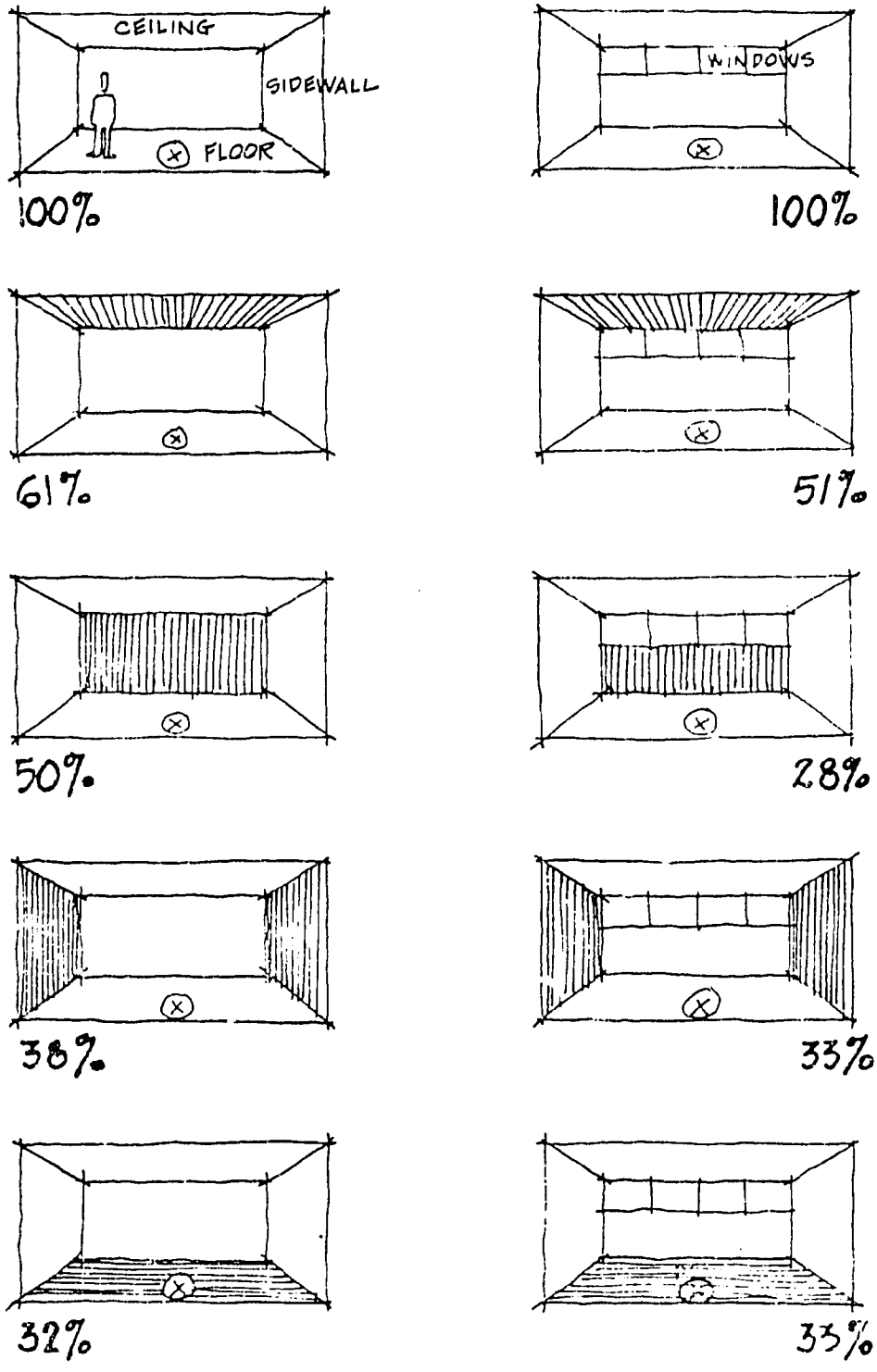
DEEP WINDOW WELLS HELP SOFTEN DAYLIGHT AND CONTRASTS



ROUNDED JAMBS HELP SOFTEN CONTRASTS

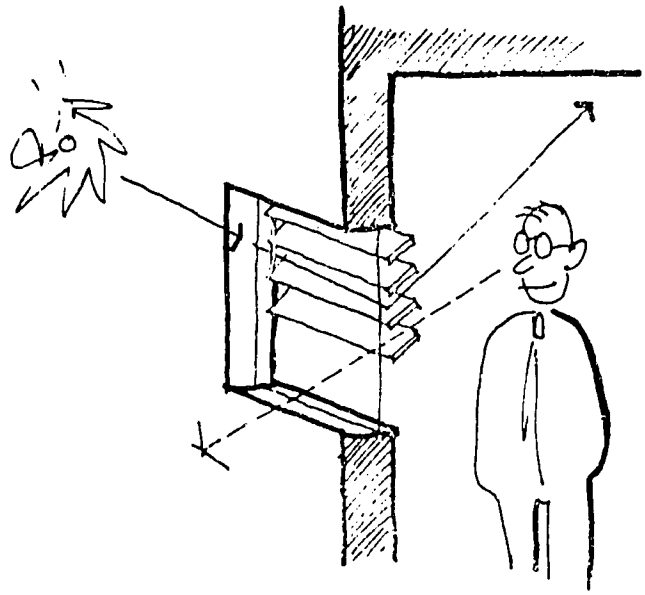
RECESSED WINDOWS AND SPLAYED JAMBS CAN BE EFFECTIVE ELEMENTS IN SOFTENING BRIGHTNESS CONTRASTS.

(Source: B. Evans)

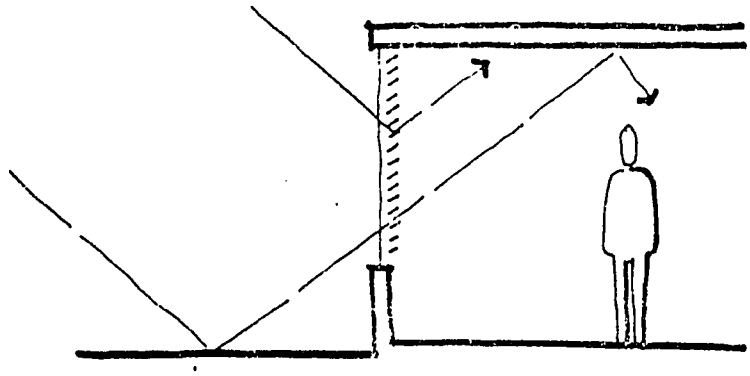


TESTS ON THE REDUCTION OF LIGHTING AT POINT "X" DUE TO VARIOUS BLACK-PAINTED WALLS SHOW WHICH SURFACES ARE MOST EFFECTIVE IN SUPPORTING TASK-LEVEL ILLUMINATION.

(Source: B. Evans)

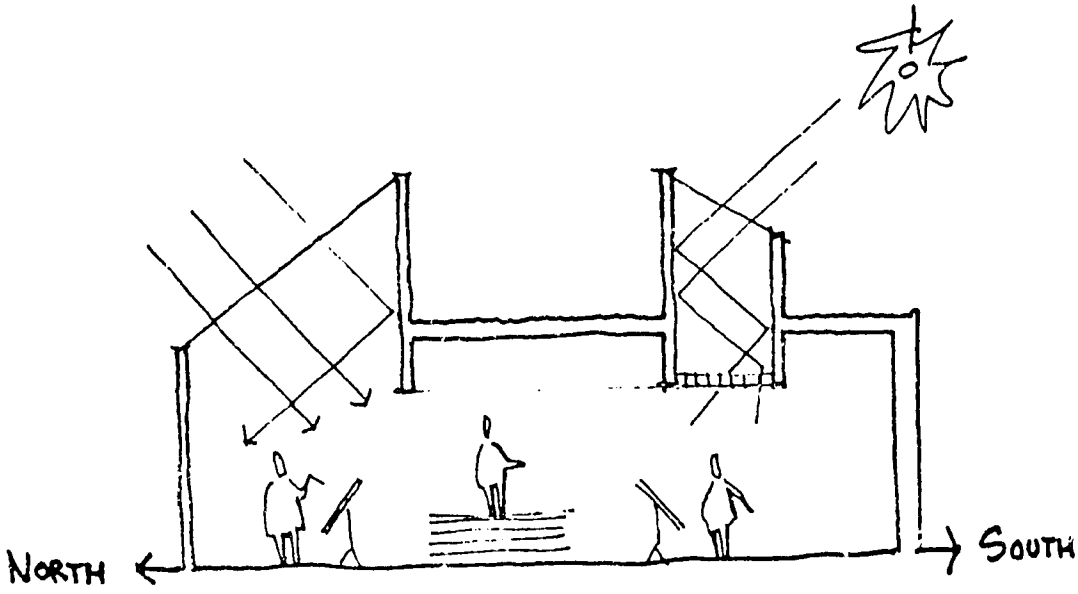


PROPERLY ADJUSTED VENETIAN BLINDS REFLECT DAYLIGHT TO THE CEILING AND DO NOT PREVENT A VIEW TO THE EXTERIOR



VENETIAN BLINDS TAKE ADVANTAGE OF REFLECTED GROUND LIGHT BY BOUNCING IT DEEP INTO THE INTERIOR OF THE SPACE

(Source: B. Evans)



NORTH LIGHT TENDS TO BE SOFTER AND **COOLER** AND MORE UNIFORM

SOUTH LIGHT TENDS TO BE MORE **INTENSE** AND MORE VARIABLE

---BUT ORIENTATION OF THE BUILDING HAS LITTLE EFFECT ON THE QUALITY OF INTERIOR DAYLIGHT IF DIRECT SUN IS PROPERLY CONTROLLED.

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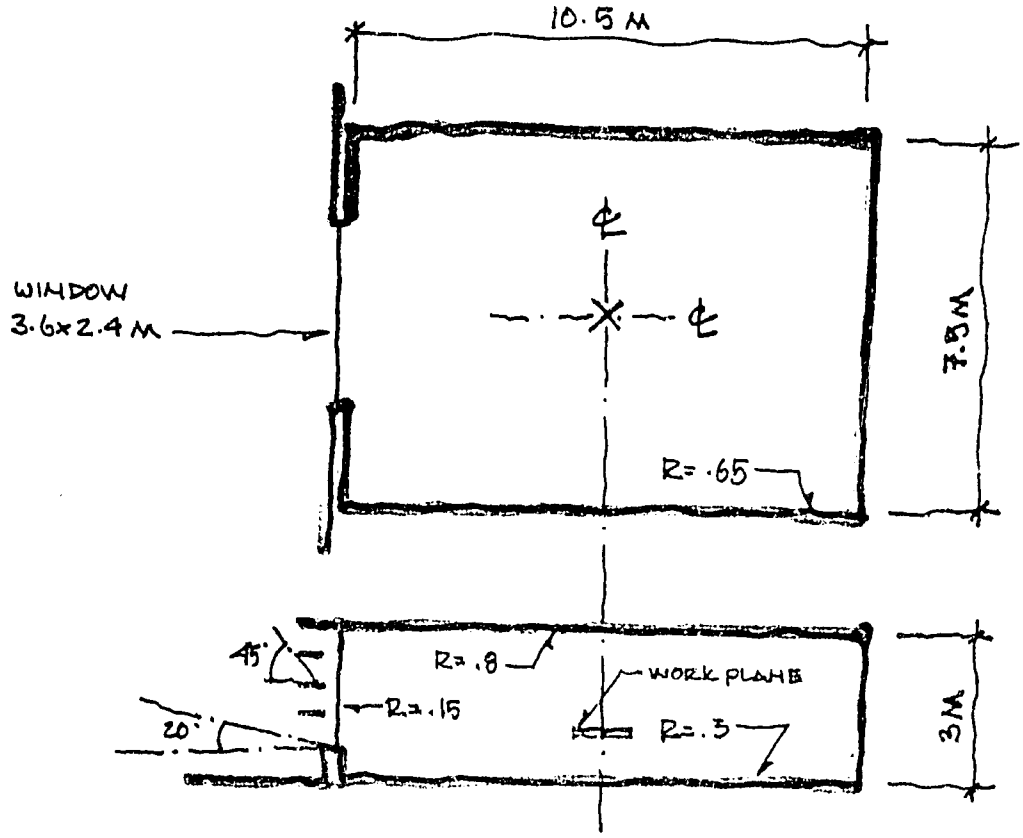
A SIMPLE ILLUMINATION NOMOGRAM



NOMOGRAM ASSUMES:
1. GROUND LUMINANCE = 3400 cd/m²
2. SKY LUMINANCE = 1000 cd/m²
3. SOLAR ALTITUDE = 90°

TASK: DETERMINE ILLUMINATION AT THE CENTER OF THE ROOM (5.25M FROM WINDOW) ON THE WORKING PLANE

1. CALCULATE SURFACE AREAS

FLOOR	78.75
CEILING	78.75
WALLS	99.35
WINDOWS	8.65
TOTAL	265.5

2. CALCULATE RATIO OF WINDOW (W) TO TOTAL SURFACE (A_t)

$$\frac{W}{A_t} = \frac{8.65}{265.5} = 0.0325$$

3. CALCULATE AVERAGE REFLECTANCE (INTERNAL)

$$r = \frac{78.75(0.3) + 78.75(0.3) + 99.35(.69) + 8.65(.15)}{265.5} = .574$$

4. TAKE NOMOGRAM, LOCATE VALUE OF W/A_t ON SCALE A & THE VALUE OF r ON SCALE B & CONNECT WITH A STRAIGHT EDGE. SELECT APPROPRIATE SCALE, IN THIS CASE D, AND READ THE ILLUMINATION VALUE. = 199 LUX

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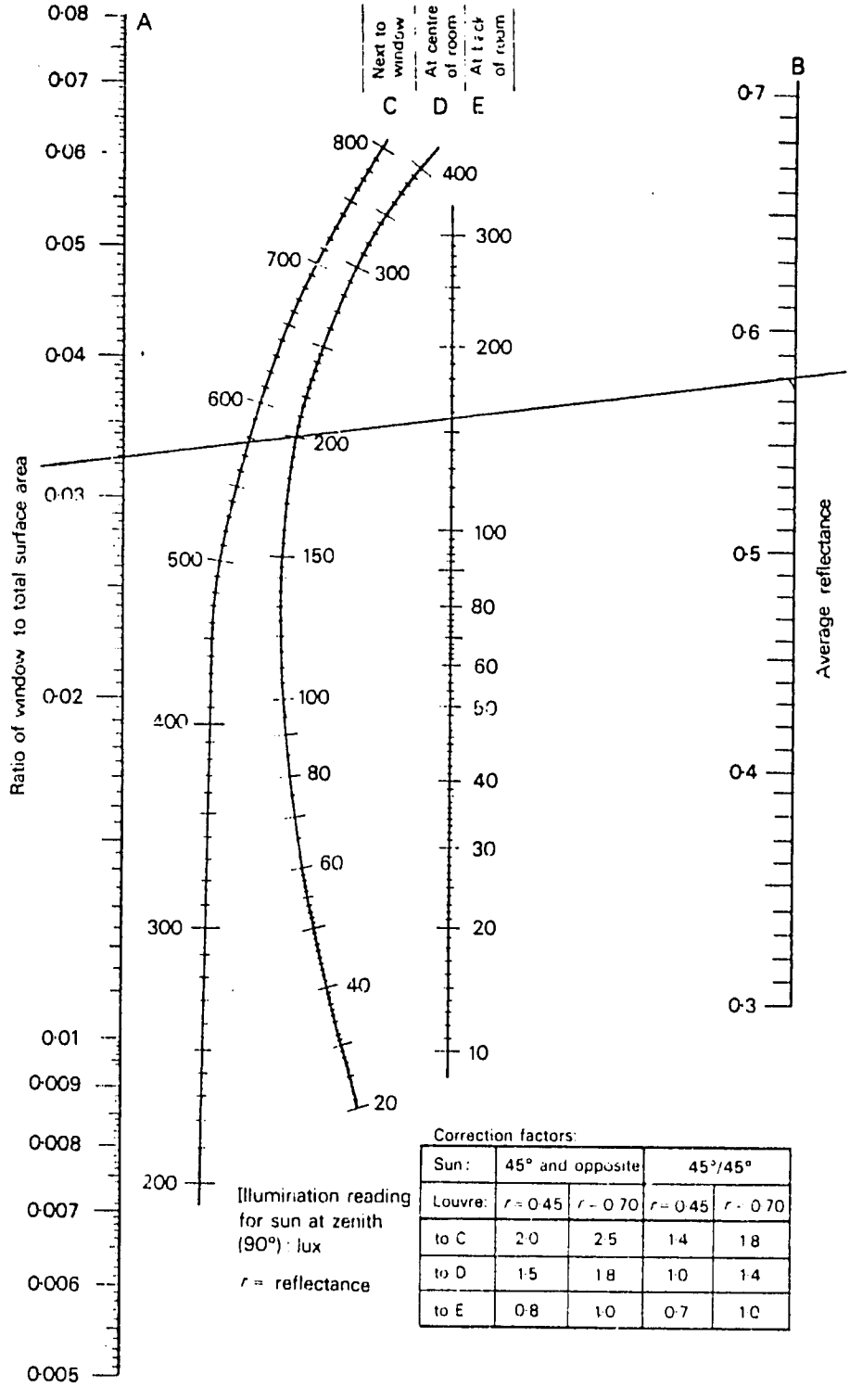
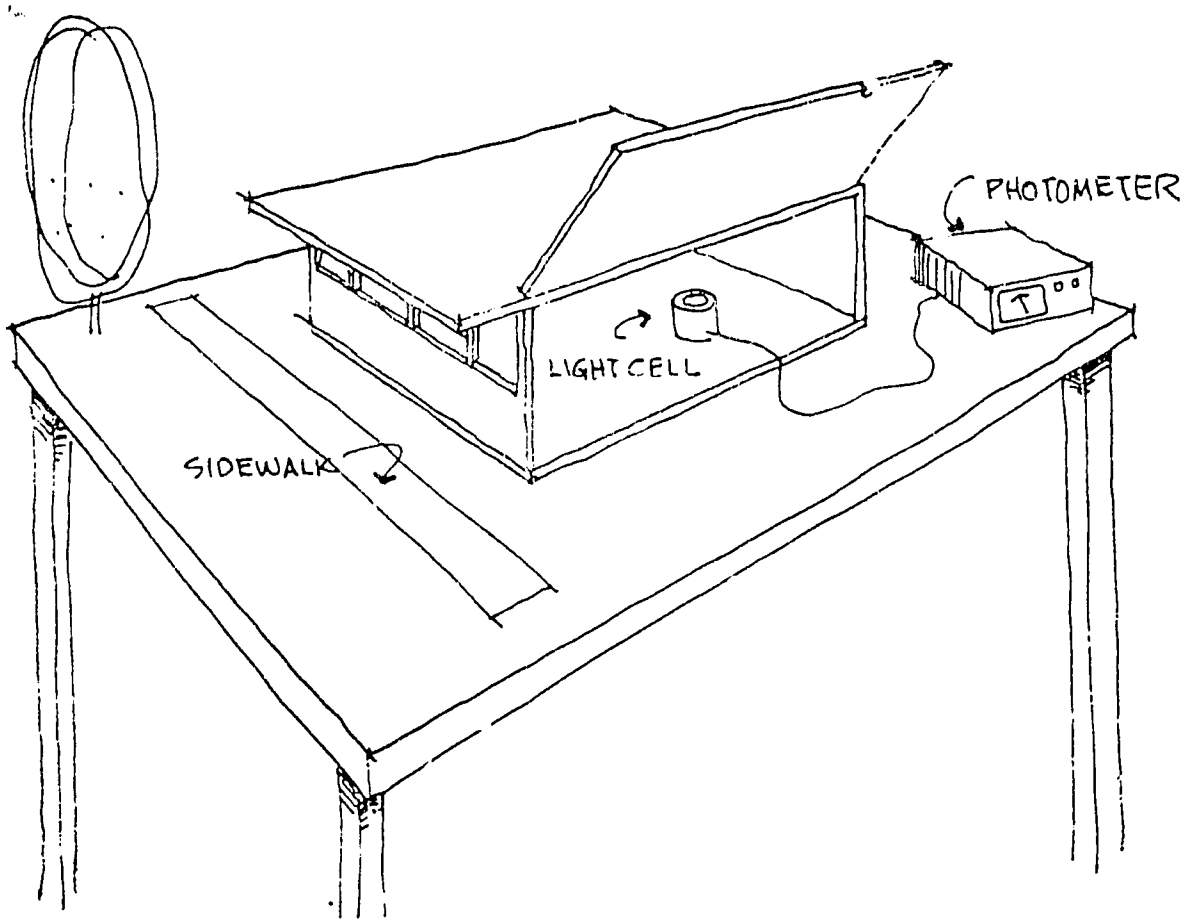


Correction factors:

Sun:	45° and opposite		45°/45°	
Louvre:	r = 0·45	r = 0·70	r = 0·45	r = 0·70
to C	2·0	2·5	1·4	1·8
to D	1·5	1·8	1·0	1·4
to E	0·8	1·0	0·7	1·0

(Source: Koenigsberger)



THE MODEL IS OPENED AND THE LIGHT CELL POSITIONED.

(Source: B. Evans)

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14. INTEGRATION OF ENERGY CONCERNS INTO THE DESIGN PROCESS

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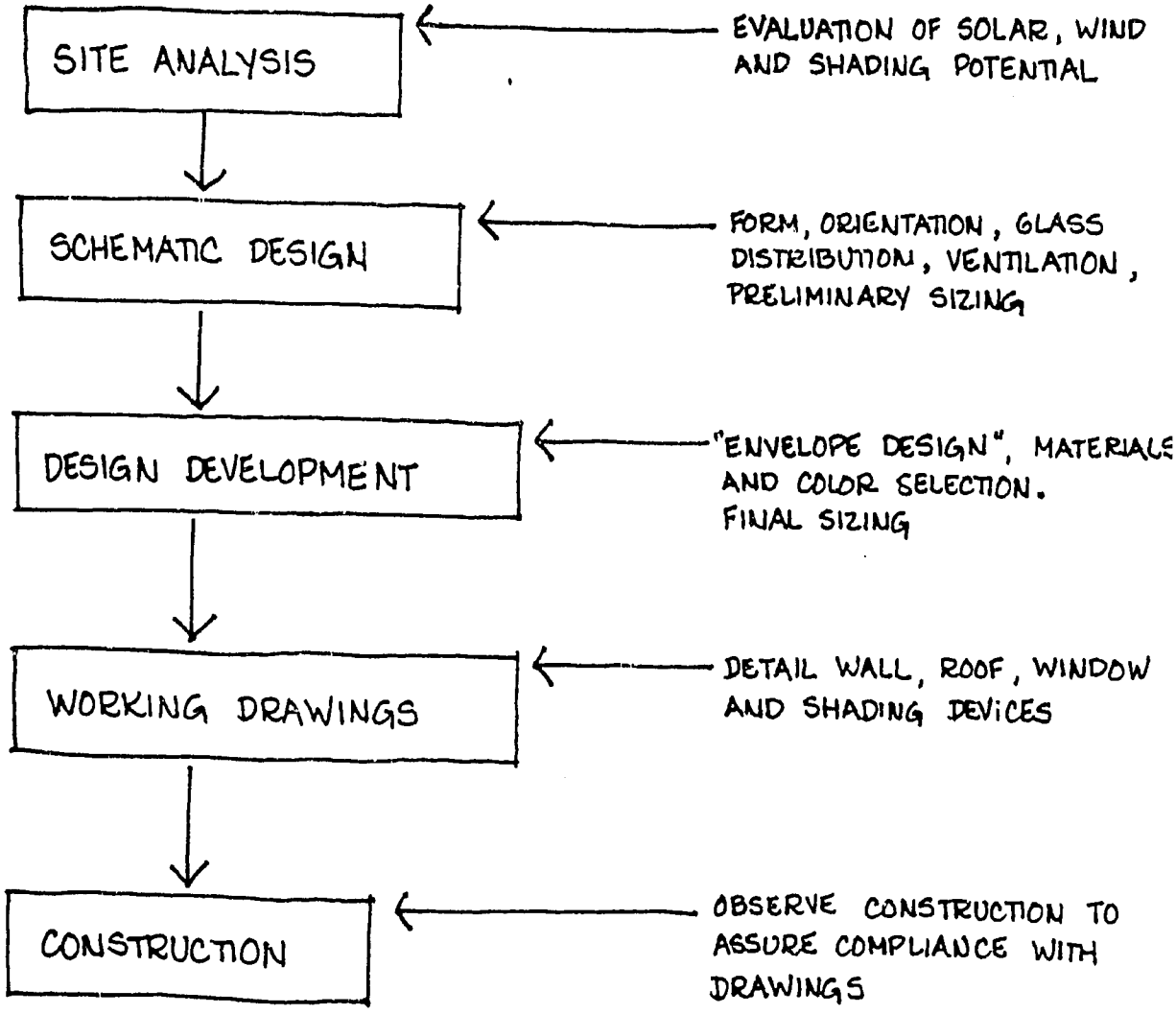
INTEGRATION OF ENERGY CONCERNS INTO THE DESIGN PROCESS

The purpose of this chapter is to outline when and where energy concerns enter into the design process. There are, as this workbook clearly suggests, a myriad of energy issues which have to be considered from the first evaluative steps of site planning to the fine tuning and detailing of the shading devices. It is critical that they be viewed as an integral part of the design process and considered carefully at each step. It does no good to execute a detailed energy site survey only to ignore its requirements in the schematic design. If this integration takes place, then energy will be woven into the fabric of the design along with function and aesthetics.

On page 14-2 is a chart which divides the design process up into its constituent parts and indicates, in a general sense, what issues to consider when. This general outline is then developed in greater detail on the pages that follow.

ENERGY & THE DESIGN PROCESS



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The following is an outline suggesting some of the concerns about energy use and when they should be addressed in the design process.

A. SITE ANALYSIS

1. Determine true north. (Tool: Sundial or compass).
2. Locate solar extremes (Tool: First method).
3. Evaluate direct and indirect solar gains.
4. Evaluate shading potential of existing trees and other obstructions (Tool: Solar site survey including horizon profile if there are serious obstructions).
5. Evaluate wind speed and direction (Tool: Meteorological records and local inquiries and Beaufort scale).
6. Study topography to evaluate potential for ground contact cooling and possible modifications of wind patterns.
7. Record information on site plan drawing.

B. SITE SELECTION

1. Select a site based on the above data as well as the more traditional site data such as access, etc.

C. SCHEMATIC DESIGN

1. Orient building to reduce undesired direct and indirect solar gains and to introduce wind for natural cooling.
2. Consider compact square, east-west oriented rectangular and courtyard forms as appropriate.
3. Extend the plan into the "inside-outside" zone with verandahs and outdoor activity areas.
4. Use "extra" building elements such as a covered car park to provide west shading.
5. Provide a narrow building section to improve cross ventilation or a low-high building section to induce stack effect cooling.

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6. Open plan to increase cross ventilation.
7. Provide for easy air circulation between internal spaces across the path of the air flow.
8. Size preliminary ventilation openings.
9. Allocate glazing primarily to the north and south elevations and size preliminary openings for winter solar gain.
10. Estimate dimensions and form of north, east and west shading devices. Use existing vegetation for shading where possible and consider plantings where appropriate.
11. Develop preliminary rain water catchment and distribution system.

D. DESIGN DEVELOPMENT

1. Roof
   a. Material - heavy if possible, insulated if not.
   b. Color - light.
   c. Insulation - minimum 25mm fiberglass or greater.
   d. Venting - at gable ends if peaked roof, at eaves if a flat or shed roof, and at eaves and ridge if gabled with ceiling at underside of sloped rafters.
2. Wall design
   a. Material - heavy weight block or brick.
   b. Color - light except on north.
   c. Insulation - not recommended but if used consider either cavity walls or externally insulated wall.
   d. Internal walls and floors to be of heavy weight block and concrete respectively. Color light.
3. Ventilation
   a. Location of openings - if on north and south walls use windows. If on east or west walls consider operable vents with good weather seals.
   b. Review preliminary opening calculation and correct, based on free area evaluation of vent.
   c. If operable vents used, review seals against infiltration and rain.
   d. Resize internal wall vents in light of item b.

4. Glazing

   a. Consider double locking devices and weatherstripping to reduce infiltration.

5. Door

   a. Consider draft excluders.

6. Plantings

   a. Select trees, shrubs and vines and locate according to short, medium and long-term shading and wind channeling strategies.

7. Water

a. Develop system for external rain water collection and combine with internal grey water collection to irrigate shade plantings.

E. WORKING DRAWINGS

1. Exercise care in developing roof details. Provide adequate space for the insulation and the flow of air. Use netting at the eaves to exclude insects.
2. Develop window details to exclude drafts around the outside of the frame. Same for doors.
3. Develop details of shading devices. Light color and mass.
4. If employed at all, develop external wall insulation on a bracketing grid or, if wall insulation is used, consider how to insulate the edge of the floor slab.
5. Minimize the number of plumbing and electrical penetrations through the external walls. They are a source of infiltration. Detail them to block air flow.
6. Where possible, locate electrical outlets on internal walls to avoid penetrating the outside skin of the building.
7. If internal shades are used, they should be light colored and enclosed at the top by a valance.
8. In utility areas, use fluorescent lighting. It is more efficient and less costly to run.

F. CONSTRUCTION

1. Inspect the site layout before permitting the contractor to proceed, particularly with respect to orientation.
2. Inspect masonry closely to assure that it is dense enough to provide thermal mass.
3. Make sure that the insulation in the roof is not crushed and is spread evenly and thoroughly over top of the whole ceiling. The batts should butt up against each other.
4. Make sure that air is able to circulate over top of the insulation.
5. If cavity wall insulation is used, make sure that it is installed below the window sills.

15. RETROFITS AND ADDITIONS

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RETROFITS AND ADDITIONS

While most of the orientation of this workshop material has been toward design concepts which can be used in new construction, some of these same concepts have excellent applications in additions to or renovations of existing buildings.

The following page lists the most relevant concepts to consider when thinking about improving an existing home. The heating and cooling strategies in section 4 of this workbook are referenced for further information and the strategies expected to yield the highest benefit for their cost are highlighted.

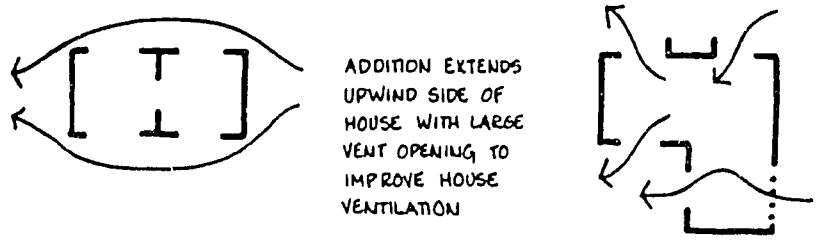
The other page in this section illustrates a number of concepts which can be considered to improve the energy design of a home when an addition to the home is being planned.

RECOMMENDED MEASURES FOR IMPROVEMENT OF EXISTING HOMES (RETROFITS)

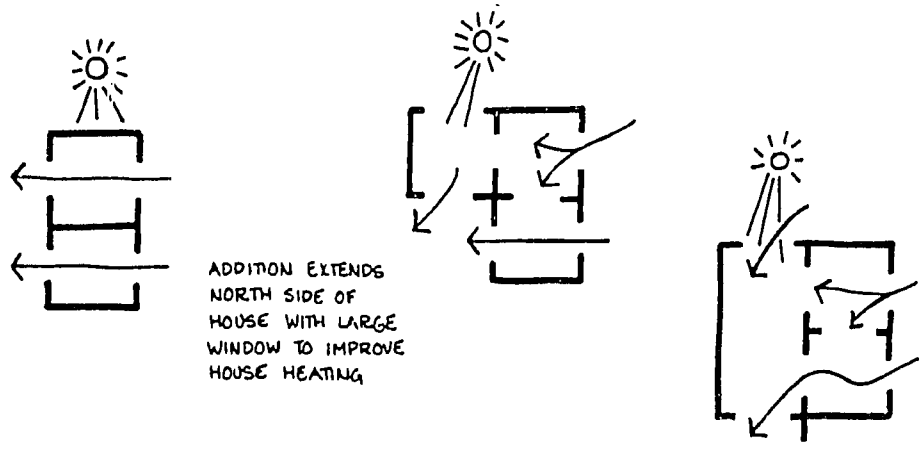
★ designates improvements which will usually yield the highest benefit for the labor and materials invested.

MEASURE	SEE COOLING STRATEGY #	SEE HEATING STRATEGY #
★ 1. Paint roof a color with low solar absorptivity and high emissivity.	1B, 6A	
2. Paint east, west and south walls a color with low solar absorptivity.	1B	
3. Paint north wall a color with high solar absorptivity.		3B
4. Reduce reflected radiation off ground by planting shrubs, grass or ground-cover plants nearby house walls.	1A	
★ 5. Plant vegetation or build shading devices to reduce solar gain through windows in summer.	1A	
6. Plant vegetation or build shading devices to shield roof and/or walls from solar radiation in summer.	1B	
★ 7. Add insulation to roof.	3A	1A
8. Use vegetation or build outside devices (such as wing walls) to direct wind in some windows and out others.	2A	
9. Add new ventilation openings if present size is inadequate.	2A, 2B	
★ 10. Use fans inside house to provide direct air movement on occupants.	2C	
11. Add fan to provide whole-house ventilation.	2C, 6B	3D
12. Seal up leaks to reduce infiltration.	5A	2A

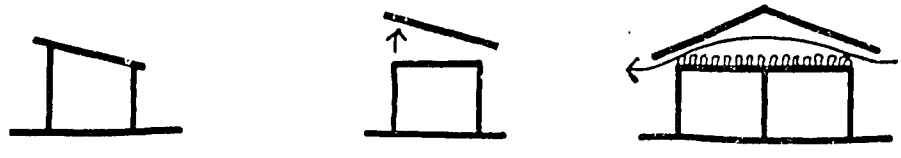
CONCEPTS FOR HOME ADDITIONS



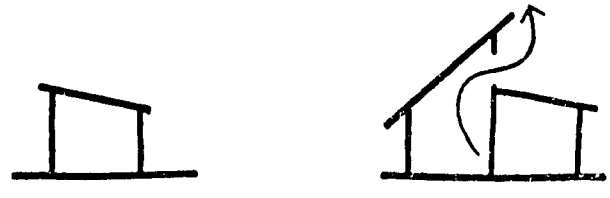
ADDITION EXTENDS UPWIND SIDE OF HOUSE WITH LARGE VENT OPENING TO IMPROVE HOUSE VENTILATION



ADDITION EXTENDS NORTH SIDE OF HOUSE WITH LARGE WINDOW TO IMPROVE HOUSE HEATING



ADDITION COMBINED WITH RAISING ROOF ON OLD SECTION TO ADD INSULATION AND IMPROVE VENTILATION ABOVE CEILING.



ADDITION ON SOUTH SIDE WITH NORTH-FACING GLASS AND HIGH VENT FOR STACK- AND WIND-DRIVEN VENTILATION

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16. RESOURCE BIBLIOGRAPHY

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APPENDICES

EFFICIENT WOOD STOVES AND BUILDING DESIGN

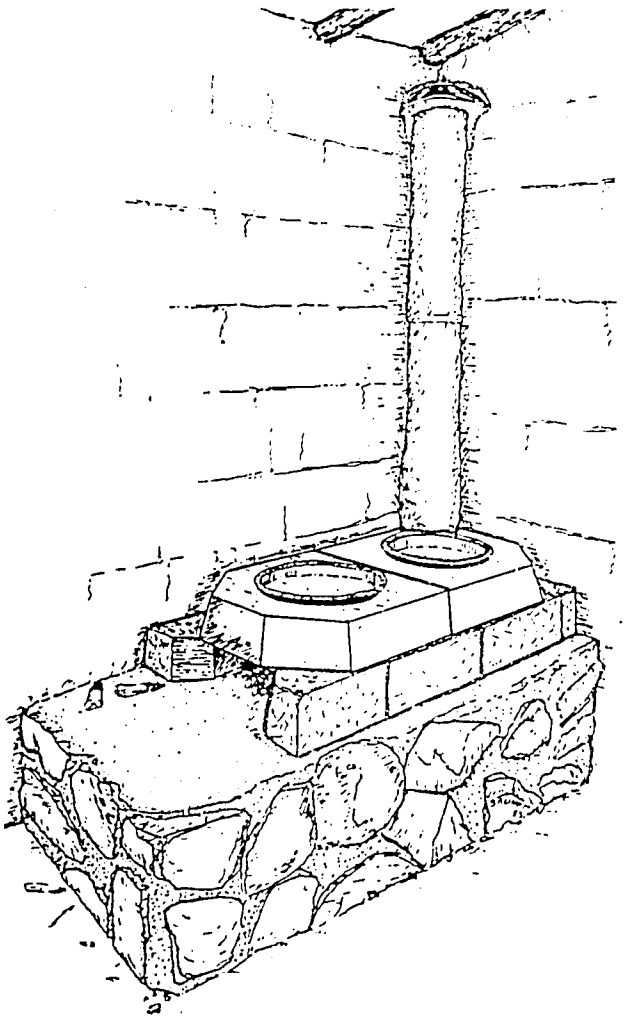
Some Information on Low Cost Wood Stoves

Types of Stoves

There are mudstoves and metal stoves, one hole and two hole stoves, with exitting chimneys, with freestanding chimneys and without chimneys.

Considerations:

- Mud stoves are stationary and need shelter, (a roof and wall against rain).
- Metal stoves are portable and will rust if left in the rain.



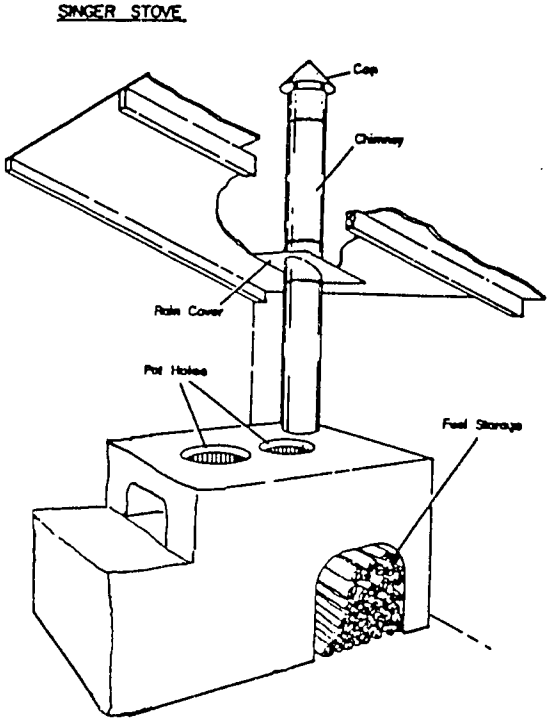
- One hole stoves vary in size from 30-50cm di
- Two hole stoves are roughly, 50cmX90-100cm.

- All stoves can be put on a platform 30-40cm in height, but then the platform should extend 20-30 cm beyond the firebox entrance to permit long firewood to be used.

- An exitting chimney will allow the stove shelter's interior walls to be relatively smoke free.

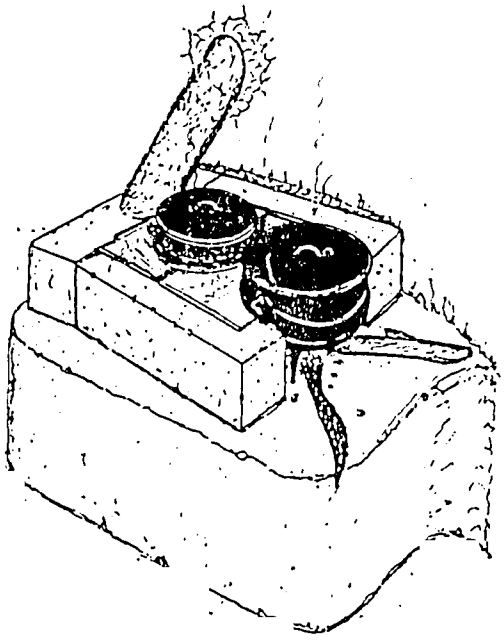
There are two types of exitting chimneys, metal and mud, and two types of sheltered exitting situations, wall and roof.

A roof exitting situation would:



- require a metal chimney,
- attention to rain and fireproofing details such as: -proximity to flammable material
  - -flashing
  - -rain capping
  - -sealants
  - -replacability, cleaning
- attention to avoiding excess draft by:
  - -maintaining as short a length of chimney as possible (max. 1m for a chimney interior dia. 10cm)
  - -and/or installing a chimney damper

A wall exitting situation



- does not require a metal chimney
- Actually a mud chimney is more compatible with a mudstove.
- Attention must be paid to planning a suitable size hole in a brick or concrete wall for a chimney 30 - 60cm long (max 1 meter)
- Installing a metal flap above the hole to deflect wind, smoke and rain.

Smoke will blacken the exterior wall depending on the wind orientation. Also smoke may come back into the shelter if the wind blows into the chimney.

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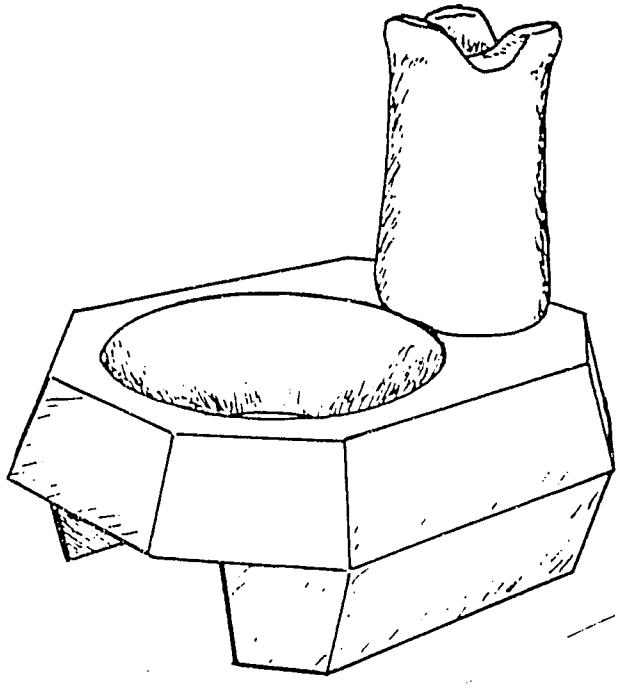
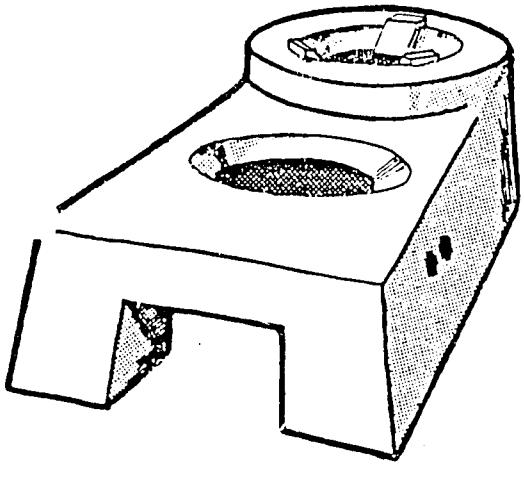
A free standing chimney will allow a shelter to be relative smoke free ie. the smoke should be abov shoulder height.
However, interior walls will be blacken
In a sheltered situation the smoke must exit naturally by providing adequate space between the wall and roof for ventilation.



short stack
clay pot stove
(small pot fits on top of chimney.)

Chimneyless stoves in a sheltered situation require even more attention to the natural venting of smoke for a clean cooking environment
Interior walls will be blackened.



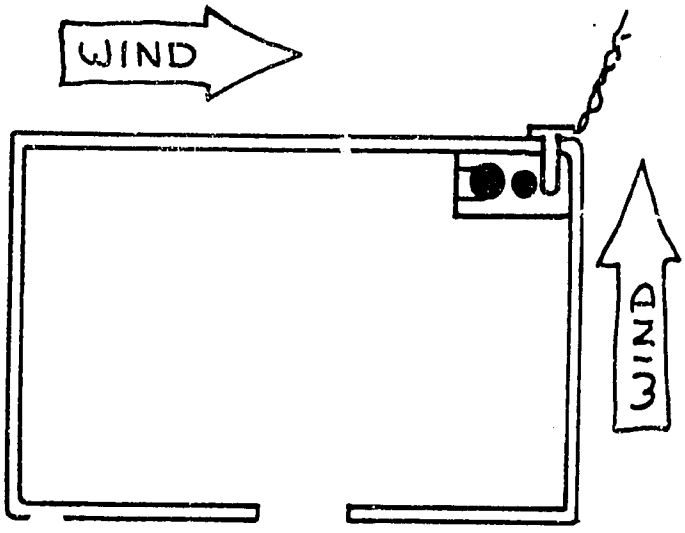
Locating the stove shelter

Considerations
- access to food, water and pots
- access to firewood and wood splitting area
- where the smoke will go to
- where the heat will go,
  - in the summer
  - in the winter
- lighting requirements
- safety
- security

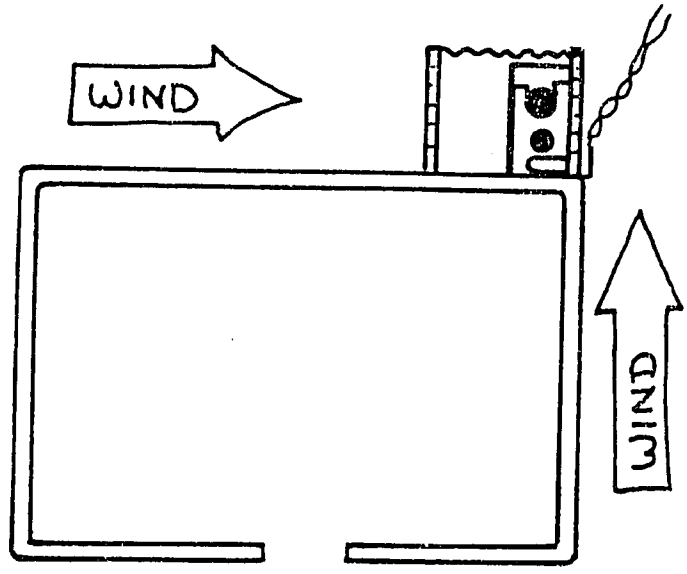
Locating the stove in a shelter, in an open enclosure

Most important consideration - Orientation

- In general the chimney should be down wind. In practice, two dominant winds may be at cross purposes, so the stove must be oriented so as to not have predominant winds striking the stove at an angle greater than 60-90 degrees from the firebox entrance. A strong wind should not be allowed to enter the firebox directly.



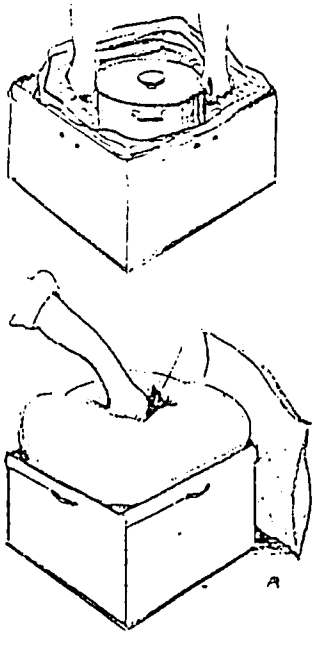
INSIDE LOCATION



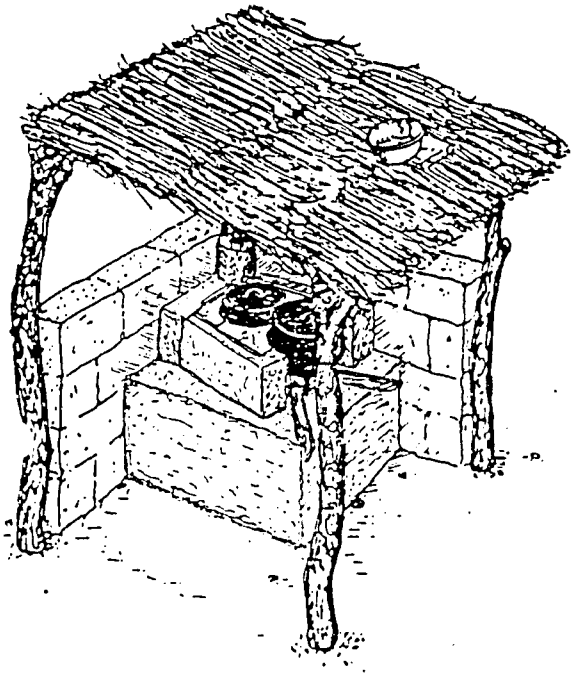
OUTSIDE LOCATION

Other considerations - access to pots, water and food
- room on the stove to cross firewood
- firewood storage
- other activities to be carried out in
- the room or outside (food preparation, brewing, eating, etc.)
- lighting requirements
- safety

Consider locating a wonder box (insulated box 50x50x50cm)
- retained heat cooker



Cooking in the open Considerations	- Shade for the summer, open for the winter - Natural wind barriers - Stove platform and seating - See locating the stove shelter.
Some notes on Open fires	-Efficiency increases when wind barriers and fire shields are provided. -Efficiency increases when tending is easy, comfortable and constant.



CONSERVATION DURING THE 1983 GABORONE WATER CRISIS AND BEYOND

BY: Carl P. Zietlow, PH.D
Botswana Renewable Energy Technology Project

INTRODUCTION

Botswana is a country with an arrid anf semi-arrid climate. There are frequent periods of droughts lasting two or three years. During normal conditions, there is a limited water supply for both human and animal consumption. During drought years, the normal marginal situation is exacerbated. At the end of the 1983 rainy season, the country is in its third year of below normal annual rainfall. The Gaborone water supply consists of surface water runoff stored behind a dam near the city. The low point of the dam at the beginning of March, 1983, is causing general alarm. This is a paper to explain various home use water conservation devices which could be implemented to extend the existing low water supply. The conservation devises can be used in houses, apartments, hotels, restaurants, and offices. The paper will also give policy and implementation recommendations.

Water problems and solutions can be related to various sub-systems of the water supply system:

1. Source
2. Storage
3. Purification
4. Distribution
5. Consumption
6. Capital Expenditure

Conservation relates to the fifth sub-system mentioned above, consumption. With any scarce resource, conservation is a valuable approach because it can be the most immediate response, most cost effective, and most readily available addition to the resource supply. Conservation also might be the most controllable.

From various studies in the United States, water is consumed for various uses in the proportions given below (see diagram. Appendix A).

2416

40%	Flush toilets or
35%	Bath, showers, and bathroom sinks
12	Laundry
10	Kitchen
3	Outside
100%	Total

As such information is not available for Gaborone, below each of these water household uses will be analyzed on a per unit bases. Conservation methods and devises will be mentioned in the following order: reducing the number of flushes and the amount of water used in flush toilets; reducing water used in showers, sinks, and yard watering; and a few miscelaneous suggestions. Recommendations are given at the end of each section and summarized at the end of this paper.

HOUSEHOLD WATER SYSTEM

FLUSH TOILETS

Water can be saved by reducing the amount of water flushed down. This can be accomplished by reducing the number of fluses or the amount of water used in each flush. A combination of both approaches could easily reduce water used in each Gaborone toilet by more than 50%. Below is a list of potential technologies including some advantages and disadvantages.

Reducing The Number of Flushes

The average person might flush a toilet between five and sevan times per day. If people were to flush for each defacation and only after two, or three, or even four urinations, this number could be cut in half. Advantages: immediate potential savings, a better option than not having water, disadvantages: change in behavior is necessary, some aesthetic adjustment necessary, after more than three urinations there might be some odor, more rapid discoloration causes more frequent cleaning.

A second method is waterless or composting toilets. There are commercial models available, particularly from Sweden, which can be used inside bathrooms. There are also designs for solar assisted composting toilets. Both eliminate odors. Advantages: eliminate all water for waste, perhaps most appropriate long run solution for human waste disposal in extremely arrid climates.

Disadvantages: commercial inside models cost ore than P1,000, solar assisted models would require an out-building or major remodeling and attachment to the house, require a change in perception of how to handle human waste in urban environment.

Reducing Amount of Water Used in Each Flush

Water used in each flush can be reduced by lowering the capacity of the toilet tank. This can be accomplished by displacing water with a solid object or by replacing the tank or entire toilet. The toilet works with a combination of amount of water and head or pressure of the water. Displacing some of the water in the tank reduces the amount of water while having little affect on the cleasing pressure.

BRICKS OR STONES: may be placed inside the tank which displace water thus reducing the amount of water needed to fill the tank. Many people think this is as immediate solution.

Advantages: low cost, easy to do, materials immediately available.

Disadvantages: the sharp edges of a heavy object could crack or brake the cermac tank if dropped, bricks tend to deteriorate it wet which can harm valves and seals in the tank.

PLASTIC BOTTLES FILLED WITH SAND OR STONES can accomplish the same results without the same dangers.

Advantages: low cost, easy to do, materials available.

Disadvantages: bottles can get in way of operating mechanisms, less water is displaced than with tank dams mentioned below.

COMMERCIAL DAMS can be placed into the tank which trap water behind them which means the water stays in the tank and does not need to be replaced with each flush (see 'Little John' diagram included Appendix B). The author brought a Little John plastic model with him and placed it in the toilet in his house. He estimates the capacity of the tank to be 13.5 L and the dams to block 4.5 L, or a 33% reduction in water used per flush. The toilet continues to clear all defacation flushes. The flow could be reduced even more and still clear with each flush, but the location of the mechanisms in the tank prevent a more efficient placement. Such models are available in plstic for $2.00/pair in lots of 1000 or in metal for $2.50 per pair in lots for 1000 FOB Washington DC.

24/8

Advantages: efficient retrofit of existing tanks, simple to install.

Disadvantages: plastic dams break on occasion, might slip and dislodge, consequently require occasional inspection and occasional replacement, potential shipping delays.

TANKS can be replaced with a lower capacity tank.

Advantages: a continuous fixed reduction, integrated tank mechanism.

Disadvantages: might not work on all existing bowls, cost installation costs.

COMPLETE TOILETS are available from some countries which us as little as five litres per flush.

Advantages: a continuous fixed reduction, integrated total mechanism.

Disadvantages: might not work on existing traps in plumbing system, cost, installation costs.

RECOMMENDATION FOR TOILETS

1. Initiate an immediate educational program through the newspapers and radio to encourage people to save three to four utinations before flushing and flush only solids after single use.

2. Purchase a quantity of toilet dams and install in all government owned and controlled housing. Offer dams either at cost or free to other people. Inorder to insure immediate delivery find someome coming from the states who is willing to bring them as excess bagage. If that is not possible, find a US citizen willing to make a short trip back before Easter to take advantage of the current Pan Am half fare plan.

3. Immediate educational campaign for people to try plastic bottles with sand or stones inside as stop-gap until toilet dams arrive.

SHOWERS

Water can be saved during showering by reducing the the amount of water used. This can be accomplished by people turning water off during soaping or by reducing the flow from the shower head. Turning the water on for getting wet, off for soaping up, and back on for ringing off seems only practicle in the summer when one takes an all cold shower or has a cut off in the shower without changing the water temperature. Most shower heads seem to be rather large and both need and use a high liter/minute flow. Most current shower heads are estimated to use 5.7 gal./min. (20-30 l/min). It is possible to purchase shower heads which give an adequate shower with 2 gal/min use (8 l/min). Consequently, the technologies available and mentioned could reduce water used per Gaborone, by more than 50%.

FLOW RESTRICTORS are a washer insert with a small hole which reduces the flow down to something like $2\frac{1}{2}$ gallons/min. They cost less than one US dollar.

Advantages: easy to install, cheap.

Disadvantages: sometimes do not provide adequate shower with existing shower head.

EXTERNAL FLOW CONTROL VALVE can be placed between the end of the pipe and existing shower head so one can cut off flow while soaping without changing temperature of water. This devise could reduce shower water by as much as one half when used by a conscientious person and costs about $4.00.

Advantages: easy to install.

Disadvantages: require change in behavior while showering.

FLOW RESTRICTING AERATING SHOWERHEADS are available which give very acceptable showers while using 2-2.5 gal./min. (8-10 l/min) or a reduction of more than half of most existing shower heads in Gaborone. These shower heads are available in the states for $2.90 each in lots of 1000. (See Appendix C).

Advantages: very pleasant shower, integrated unit which works well.

Disadvantages: require shower head replacement, some people might need some adjustment to accept the lighter shower.

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FLOW RESTRICTING AERATING SHOWERHEAD WITH SHUT OFF are available for $4.15 each in lots of 1000. (See Appendix C). These units combine the advantages of the 2 gal/min shower head with shut-off while soaping. Such shower heads are used on board ships.

SHOWER RECOMMENDATIONS

1. Immediate educational campaign to shut off showers while soaping up.

2. Purchase quantity of flow restricting shut-off shower heads and install in all government controlled showers and offer at cost to other people. Follow similar arrangements as suggested for toilet dams.

KITCHEN AND BATHROOM SINKS

There are low flow aerators and flow restrictors available for sink faucets which are threaded. However, there seem to be very few threaded faucets in Gaborone for use of this technology. Some water could be saved by running water in the sink for washing rather than washing with the water running down the drain. Dishes could be washed rinsed in dishpans or bowls rather than under running water. When brushing teeth, turn water off when brushing and only for rinsing tooth brush.

LAWN AND GARDEN WATERING

In most locations, this use of water could be eliminated by passing the grey water (all water used in the house not in the toilet) first through a sand filter and then onto the lawn, garden, or trees through a soaker type system. Each house would need to make simple sand traps outside of the house where the grey water exits. The water from the sinks and laundries exits higher on the wall and could provide some head for sending the water to the extremeties of the yard. The shower and tub grey water exits closer to the ground and could be used closer to the house. (see simple diagrams Appendix D). The sand in the filter would need to changed occasionally.

MISCELANEOUS

Water is lost through leaks. A one drip/second leak from a faucet amounts to gal./day. Savings could be achieved through a vigorous maintenance campaign.

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2. As has been know and practiced for some time, cisterns at houses can increase supply available. All houses could be equiped with cisterns again for use for bathing and washing.

3. Wash laundry only in full loads. Front loading machines us one-third to one-half the water required for the same sized top loading machine.

SUMMARY OF RECOMMENDATIONS FOR IMMEDIATE SITUATION

1. An immediate educational campaign for
   a) Less toilet flushes
   b) Plastic bottles in toilet tank
   c) Turning off shower when soaping
   d) Repairing all leaks
   e) Careful use of water in sink basins and for teeth brushing.

2. Buy and install toilet dams and low-flow shut-off shower heads.

SOME LONG RANGE RECOMMENDATIONS

1. Require on all new construction and on all government buildings
   a) Low-flow shut-off shower heads
   b) Minimum flow flush toilets
   c) Low-flow faucets
   d) Grey water system for yard watering

2. A thorough investigation of the use of commercial and solar assisted composting no water toilets.

3. An investigation of the economics and contribution of cisterns at individual houses.

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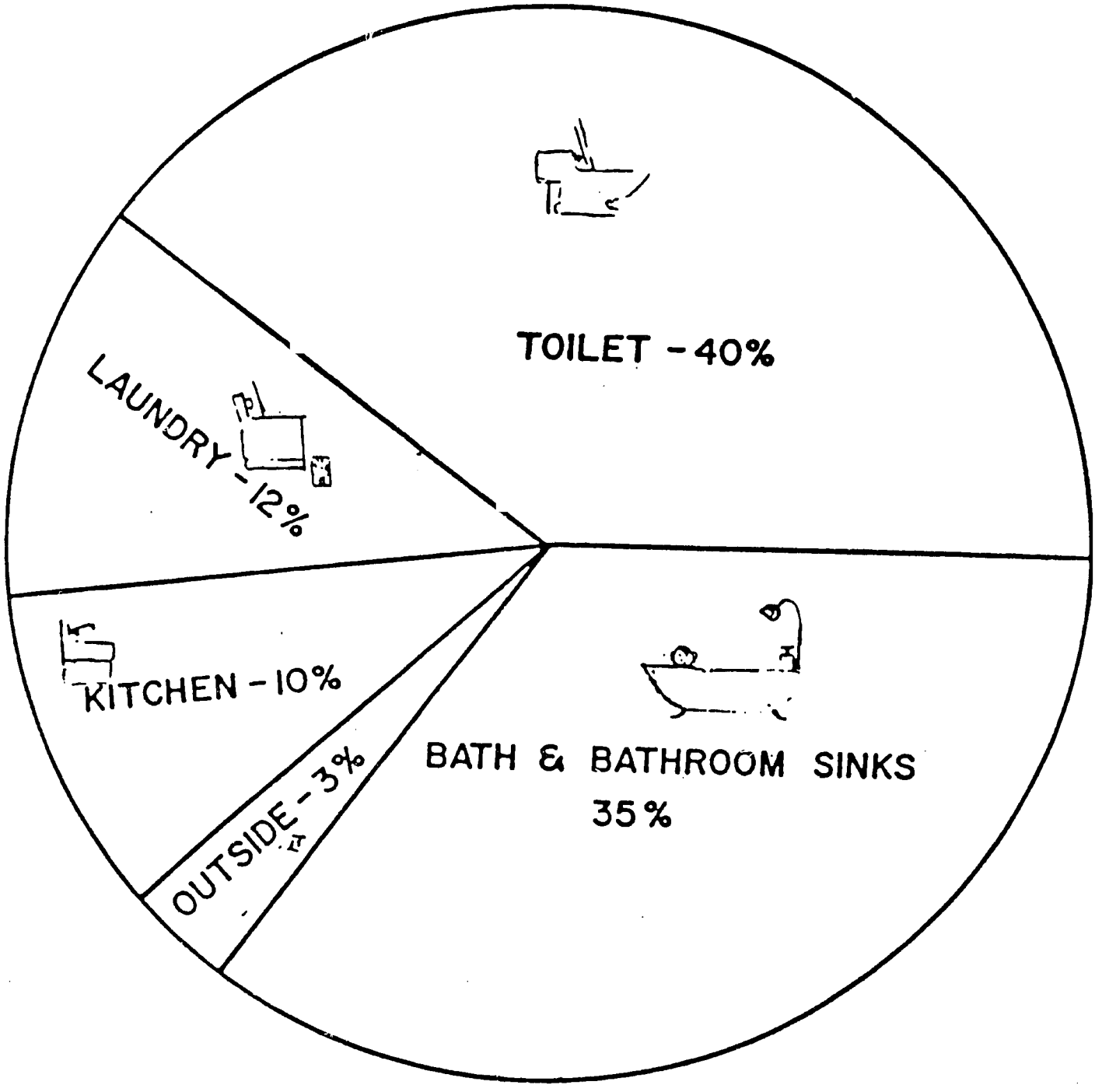
HOUSEHOLD WATER USES

United States Averages



WATER CONSERVATION TIPS

1) THE TOILET IS THE NUMBER ONE USER OF WATER, DON'T USE IT AS A WASTE BASKET FOR FOR REFUSE; THIS WASTES BOTH WATER AND MONEY.

2) WHEN REPLACING AN OLD TOILET OR INSTALLING A NEW ONE, CONSIDER PURCHASING A NEW CONSERVATIVE TANK TOILET. THESE TOILETS SAVE BOTH WATER AND MONEY.

3) IF YOU'RE IN THE MARKET FOR A NEW WASHER, CONSIDER PURCHASING A FRONT LOADING MACHINE. WIDELY USED IN EUROPE AND NOW READILY AVAILABELE IN AMERICA, THESE MACHINES SAVE WATER, DETERGENT AND ENERGY.

4) CHECK PERIODICALLY FOR POSSIBLE LEAKS IN FAUCETS, SHOWERS, AND TOILETS. FOR EXAMPLE A LEAKING TOILET CAN USE UP TO 4500 EXTRA GALLONS OF WATER PER MONTH. THIS IS A PHENOMENAL WASTE OF WATER AND ENERGY.

5) SHOWERING TAXES BOTH WATER AND ENERGY. TURNING OFF THE SHOWER WHILE SOAPING UP IS A SIMPLE CHANGE THAT CAN TRANSLATE INTO INSTANT SAVINGS.

6) WHEN WASHING DISHES BY HAND, USE A BASIN FOR SOAPY WATER AND ANOTHER FO. RINSING DISHES. CONTINUOUS RUNNING WATER IS NOT NEEDED TO GET DISHES CLEAN AND SANITARY.

7) IF YOU OWN AN AUTOMATIC DISHWASHER, ONLY USE IT WHEN IT IS COMPLETELY FULL. THIS WILL SAVE LARGE AMOUNTS OF WATER AND ENERGY.

8) FOR A COLD DRINK OF WATER, KEEP A LARGE BOTTLE OF TAP WATER IN THE REFRIGERATOR INSTEAD OF RUNNING THE FAUCET

9) CONSIDER WRAPPING HOT WATER PIPES WITH INSULLATION MATERIAL. THIS KEEPS THE HEAT IN LONGER THEREBY CAUSING ONE TO USE LESS WATER AND CORRESPONDING ENERGY.

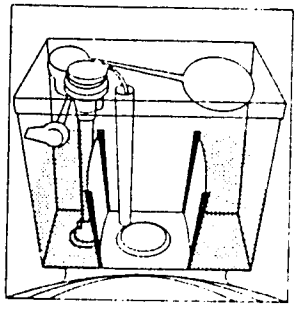
10) CLEANING FRUITS AND VEGATABLES WITH ABRUSH AND RINSING THEM IN A SMALL TUB IS ANOTHER WATER SAVING PRACTICE.

THIS IS A SMPLE OF SOME POSSIBLE WATER SAVING TIPS TO BE INCLUDED IN THE MAILOUT

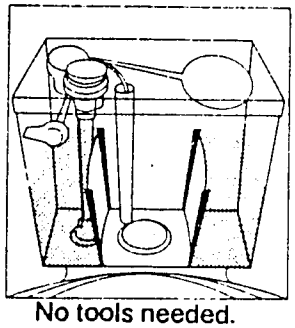
Little John Ad Clip Sheet

Metropolitan Watersaving Co., Ir
5130 MacArthur Blvd., NW
Washington, DC 20016
(202) 363-1980

Save Money. Save Water. Little John the Watersaver. Save up to 20% on your water bill with Little John.



SAVE MONEY. SAVE WATER.
WITH LITTLE JOHN THE WATERSAVER.



Now you can save up to 20% on your water bill with a simple, inexpensive device called Little John.

Insert Little John in your toilet tank and begin immediately to save water and money.

No tools needed. Guaranteed. Pays for itself in a few months.

LITTLE JOHN
THE WATERSAVER.

dealer logo

SAVE MONEY. SAVE WATER.
WITH LITTLE JOHN THE WATERSAVER.

LITTLE JOHN
THE WATERSAVER.

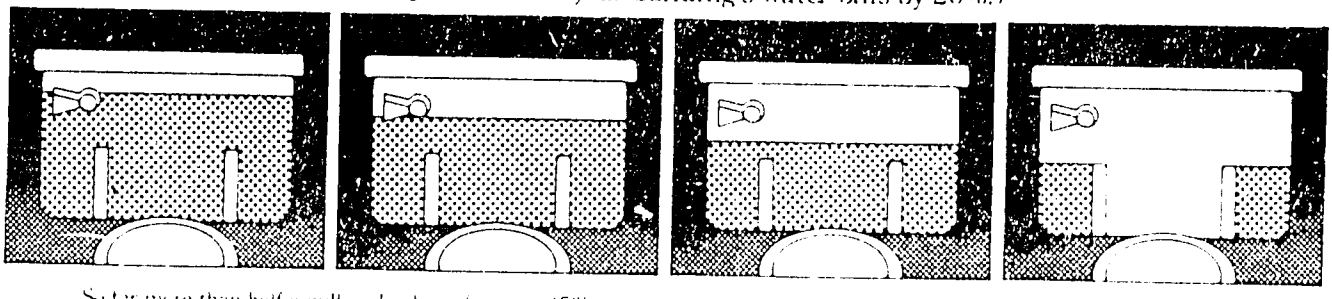
SAVE MONEY
SAVE WATER

Little John will save you up to 20% on your water bill. Easy to install in your toilet tank. No tools needed. Guaranteed. Pays for itself in a few months.

dealer logo

HOW TO BE FLUSHED WITH SUCCESS

(Little John can cut your building's water bills by 20%.)



So far more than half a million Little Johns have been installed in apartment and office buildings across the country. It makes quite a success story, for which we are reasonably flushed with pride.

But it wouldn't mean a thing if the owners and managers weren't absolutely delighted to save up to 20% on their water bills.

Some facts and figures.

"After a thorough evaluation, we purchased over 1,000 Little Johns for our apartment complex in Houston."
Foy Midkiff, Lincoln Property Co., Inc., Houston, Texas

"We are extremely pleased with our savings in water and money. After installing Little Johns, we saved enough water the first year to fill our swimming pool 12 times—over 700,000 gallons."
Brant Callaway, Investment Property Management, Birmingham, Alabama

"We reduced our water bill 23% after putting Little Johns in our 526 units."
Jack Davenport, Monumental Properties, Inc., Baltimore, Maryland

"I am delighted to announce the results of our tests. We saved 20.9% on our water bill at Kessler Gardens. This amounts to $1,200 per year. I got my original investment back in less than 5 months. And what's more important, we have experienced no resident complaints. I am putting Little Johns in the rest of my units, and I strongly urge you to do the same today."
Al Mordoh, Apartment Owner and Committee Chairman, Apartment Association of Indiana, Inc., Indianapolis, Indiana

THE LITTLE JOHN SAVINGS PLAN

The conventional flush toilet is the biggest single waster of water. It accounts for over 45% of the water used—that's more than the clothes washer, the shower or the dish washer.

In today's modern buildings a toilet is flushed on the average of once an hour every hour of the day. Each flush uses 5 to 7 gallons of water.

But most toilets need only 3 to 3.5 gallons of water to work properly. This is where Little John comes to the fore front. Little John cuts your building's water consumption by about 20%—and that means 20% off your water bill.

THE LITTLE JOHN FLUSH

Little John is a simple plastic device that fits snugly around the drain in the toilet tank and prevents half the water from going down the drain.

The toilet works the same, cleans the same. It just uses less water—the water it doesn't need.

In conventional toilets, the drain valve opens as the tank is flushed. All the water in the tank (5 to 7 gallons) goes down the drain.

When Little John is installed, the water stops at the halfway mark. The toilet is flushed. Half the water is saved.

What's more, your plumbing fixtures do less work because you're using less water. There's less wear and tear on the pipes and septic tanks last longer. Maintenance costs are reduced.

This means quite simply two things. Little John saves water. Little John saves money. About 20% of your monthly bill.

THE LITTLE JOHN ADVANTAGE

Little John requires no tools to install.

Little John is inexpensive—pays for itself in a matter of a couple of months.

Little John is durable, strong, corrosion free. There are no moving parts. It fits in almost all standard, vertical tanks.

Little John is guaranteed. It will start to save you up to 20% on your water bill as soon as it's installed.

Little John is a tested, proven product. It has withstood the test of time for over 5 years.

If you'd like to see for yourself, we'll send you a free Little John. Call us collect at (202) 363-1980 or send the coupon.

LITTLE JOHN™ THE WATERSAVER

Metropolitan Watersaving Co., Inc., 5130 MacArthur Blvd., N.W., Suite 106, Washington, D.C. 20016

☐ Yes, I'm interested. Send me more information on how Little John can save me money and water.

☐ Yes, I'm interested. Send me a free Little John so I can see how it works.

Name _____ Title _____

Company Name _____

Address _____

City _____ State _____ Zip _____

Phone _____ Approx. No. Units _____

VISIT US AT BOOTH #6611 IN LAS VEGAS AT THE APARTMENT BUILDER DEVELOPER CONFERENCE & EXPOSITION

GENERAL SERVICES ADMINISTRATION
FEDERAL SUPPLY SERVICE
AUTHORIZED FEDERAL SUPPLY SCHEDULE PRICE LIST

New Item Introductory Schedule: Class 4510
Contract #GS00S64294
Period: 1/23/78 to 1/22/79

INFORMATION FOR ORDERING ACTIVITIES

Special Item No. NIS G4436

Maximum Order Limitation: $20,000.00

Minimum Order: $50.00

Delivery Area: All Contiguous States & D.C.

Production Point: West Hartford, Hartford County, CT

NET PRICE: **LV-1-TP** **$2.38 each**
LV-2-TP **$4.11 each**

Prompt Payment Discount: 2% 20 days

Time of Delivery: 30 days

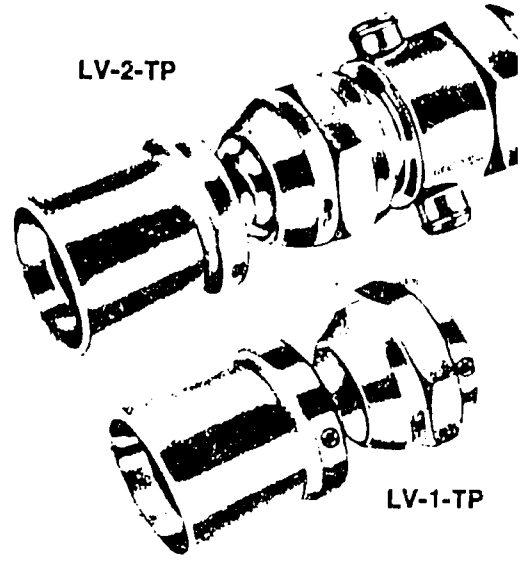
FOB Points: CONUS Destination or
CONUS Transshipment Point

Ordering and Payment Address:

Vanderburgh Enterprises
Box 138
Southport, CT 06490

WARRANTY: All necessary adjustments of equipment procured hereunder not occasioned by accident or misuse through fault, or negligence by the U.S. Government shall be made by the Contractor at his own expense, including transportation costs, if any, during the 90 day period after acceptance by the U.S. Government. All equipment procured hereunder is guaranteed for a period of (1) one year from date of acceptance. During the Guarantee period all broken or defective parts not caused by accident or misuse through fault or negligence by the U.S. Government will be replaced, and all necessary equipment adjustments occasioned by such defective parts will be made at the Contractor's expense, including labor, parts and transportation cost, if any.
We are a small business.

SAVE WATER
SAVE ENERGY
SAVE $$$$



LOVO

(low volume)
"OXYGENATING"
Shower Heads

ONE OF THE BEST WAYS TO SLASH ENERGY COSTS IN HOT WATER HEATING!

VANDERBURGH ENTERPRISES, INC.

BOX 138 • SOUTHPORT, CT 06490 • 203/227-4813
Cable: VANDERBURGH

SPECIFICATIONS

MATERIAL: Premium quality chrome-plated brass. Meets all Federal Government specifications.

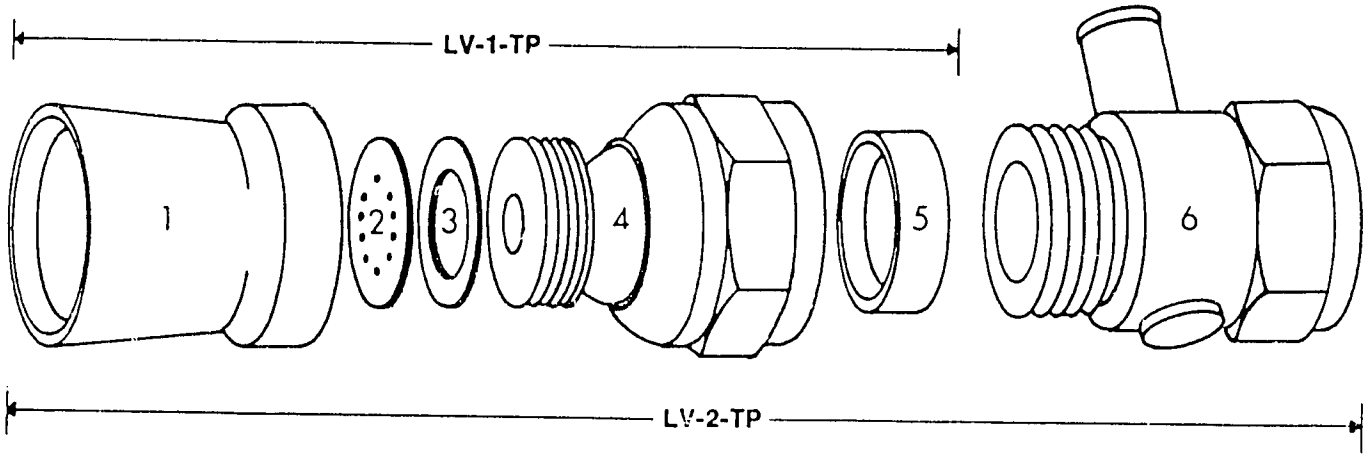
MODELS: Two. LV-1-TP — Tamper Proof Shower Head
LV-2-TP — Tamper Proof Shower Head with added Throttle Valve

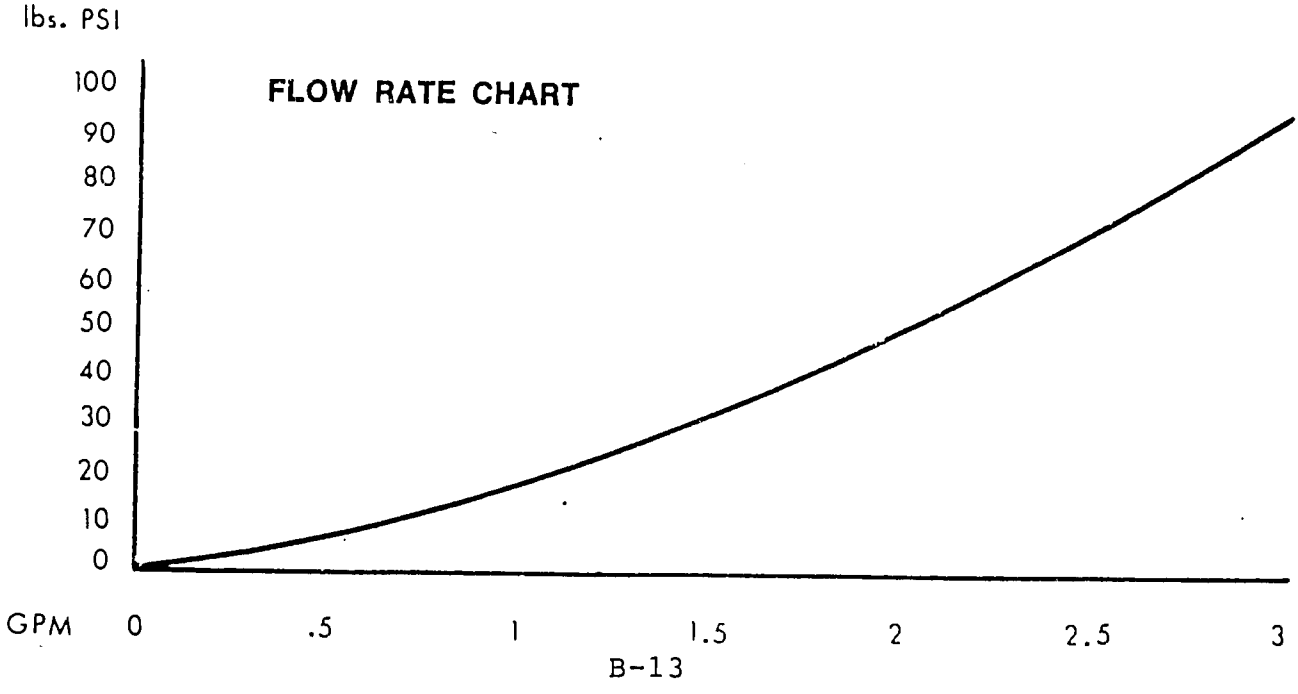
NO MOVING PARTS • NO PLASTICS • NON-CORROSIVE MATERIALS

Compact design gives stimulating, massage-like shower at 2 gallons per minute flow rate as opposed to 6 to 10 gallons per minute flow rate of ordinary shower heads. No sacrifice of shower effectiveness regarding satisfaction and cleansing action to bather. Adapters available for all non-standard shower arm connections.

PARTS IDENTIFICATION

1. Nozzle
2. Shower Disc (10 hole plate)
3. Disc Washer
4. Ball Joint Coupling
5. Ball Joint Washer
6. Throttle Valve





VANDERBURGH
ENTERPRISES, INC.
BOX 138 · SOUTHPORT, CONNECTICUT 06490
Cable VANDERBURGH
Telephone 203/227 4813

SPECIAL LOVO USER SURVEY RESULT BULLETIN

In January 1978 a key survey was taken of 1,000 users of the new (introduced in April 1977) LOVO "Oxygenating" Shower Head. These users were primarily home owners with families and were well spread across the U.S.A.. Institutions were not contacted for reasons that are apparant by the nature of the questions. Prices paid were much higher than are quoted to quantity users since these units were sold to the retail level consumer.

It is clear that a 2 gallon per minute (GPM) flow rate in a shower head will save water and energy (even when compared to 3 GPM), yet, most all forms of flow restriction are unsatisfactory when they cut flow down below 3½ GPM in a head designed to flow at 6 to 8 GPM (as do most all shower heads in use today).

Our claim is that LOVO not only flows at 2 GPM (with line pressure of 45 pounds per square inch - that's about average) but that it provides the bather with a forceful, cleansing, stimulating shower bath. Simple flow restriction can not do this. LOVO is designed for a low controlled flow (U.S. Patent Pending); therefore, these questior focused on user enjoyment of the actual shower quality.

452 responses were received out of the 1,000 people polled. Below are the results in actual count as well as percentage (%) of the total received:

1) How does the force of the LOVO compare with that of your old shower head?

Stronger	Weaker	About the same
252 (56%)	80 (18%)	120 (26%)

2) How about cleansing qualities of LOVO?

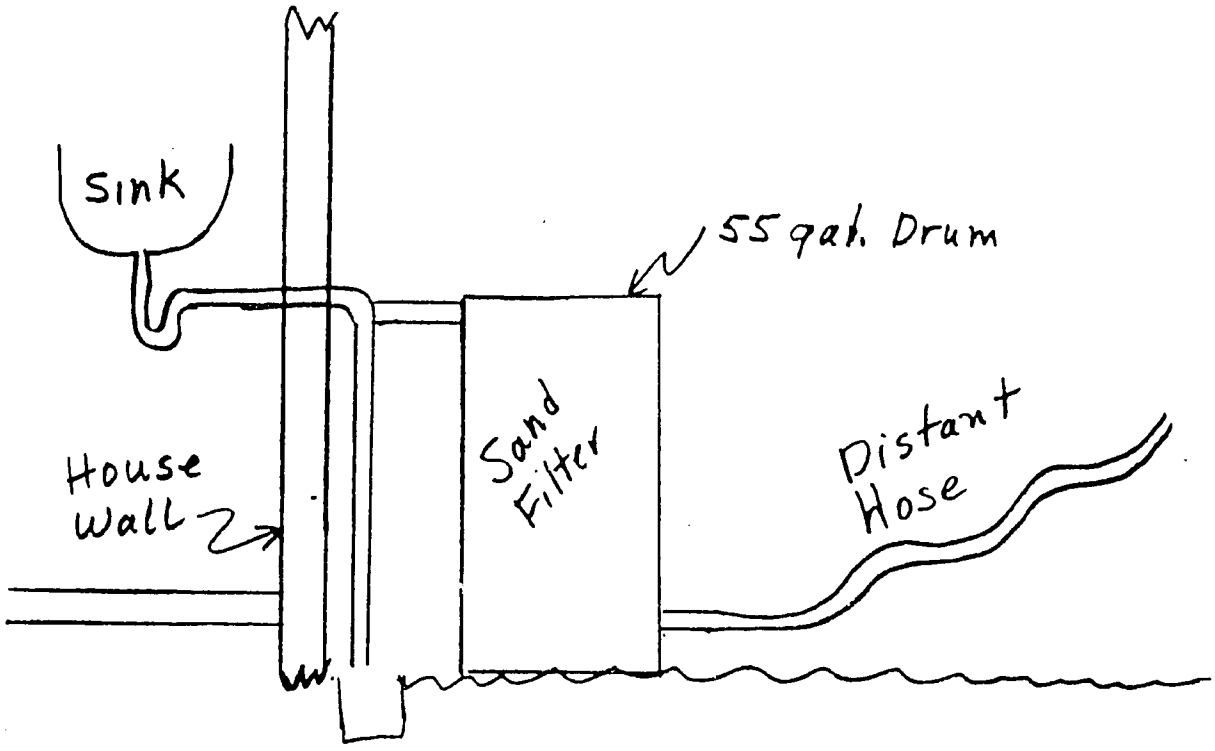
Better	Not as good	About the same
207 (46%)	28 (6%)	213 (48%)

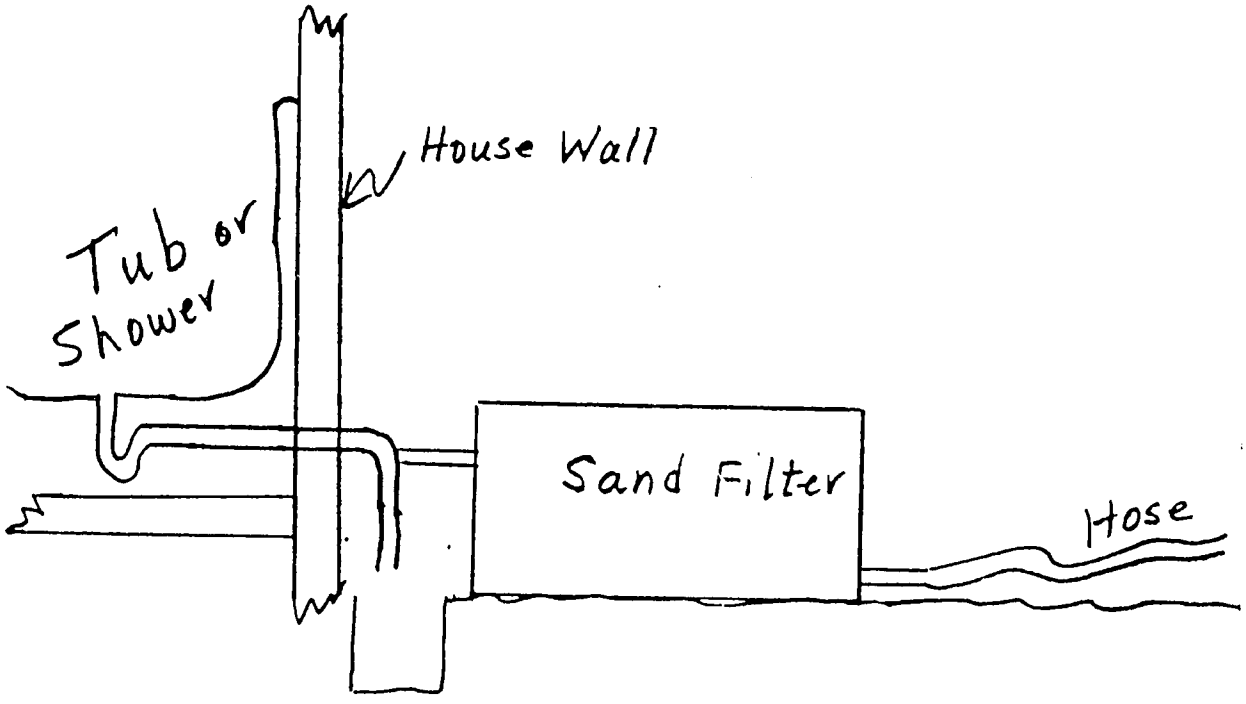
3) Do you find showers with LOVO as enjoyable and stimulating as they were with your old shower head?

More enjoyable	Less enjoyable	About the same
285 (65%)	53 (12%)	109 (24%)

The key information above demonstrates that 87% of shower bathers felt that a LOVO shower was better than or equal to their old shower in quality of shower, even though it was putting out only a fraction of the water. It appears it is possible to please most of the people most of the time.

Simple Grey Water Filter System





APPENDICES

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APPROPRIATE TECHNOLOGY IN BOTSWANA

AT

TITLE: RAINWATER CATCHMENT POSSIBILITIES FOR BOTSWANA

J. E. GOULD

NOVEMBER 1983

BOTSWANA TECHNOLOGY CENTRE

INTRODUCTION

Rainwater collection has many advanteages over other water sources;

- it is a renewable resource
- it is available at the point of consumption
- it is clean (provided contamination can be avoided)
- it is potable.

There are two basic types of rainwater catchment systems; these are

1) Roof Catchment Systems - where a roof, normally of corrugated iron or some other imperious material is used for the collection of rainwater which is geneally fed via gutters into an above ground storage container.

2) Ground Catchment Systems - where a natural or treated ground surface is used as a catchment apron to collect rainwater, which normally stored in a sub-surface container.

In this paper, various systems which can be used for different functions will be introduced, and advice will be given on how to make the most efficient use of the catchment areas and resources available through the construction of technically and economically appropriate storage tanks.

SUMMARY

The purpose of this paper is to try to make the reader aware of the huge potential offered rainwater catchment as a supplementary water source in many parts of Botswana.

A simple method for calculating the most appropriate storage volume required is introduced for roof catchments, as well as a table for determining the gutter size required. The advantages and disadvantages of different types of tanks, corrugated iron, ferrocement jars, brick/cement and sub-surface tanks are summarized and the cost of different options compared.

Different types of ground catchments are also discussed and various materials that can be used for excavated tanks mentioned. The water quality of both ground and roof catchment systems is discussed, and various approaches to insure high quality water are suggested.

Finaly, a price list of various types of catchment tanks available in Botswana is included.

TECHNICAL DISCRIPTION

Rainfall Distribution

Botswana is a semi-arid country, but rain does fall in adequate quantities and generally with sufficient regularity to make rainwater catchment a worthwhile enterprise in most areas, even from relatively small catchment areas. Map 1, shows the mean annual rainfall distribution in Botswana. Apart from the central Kalahari and extreme east and south-west, most of Botswana has mean annual rainfall totals of more than 400 mm. Not surprisingly these are also the areas where the vast majority of the population resides.

Using the accompanying rainfall map it is easy to estimate the mean annual rainfall in your area. Locate your position on the map, and by seeing which isohyets (lines of equal rainfall) you lie between, you can interpolate (approximate) the rainfall value for your locality. It should be remembered that these are mean values, and there will be considerable variation from year to year.

RAINWATER CATCHMENT

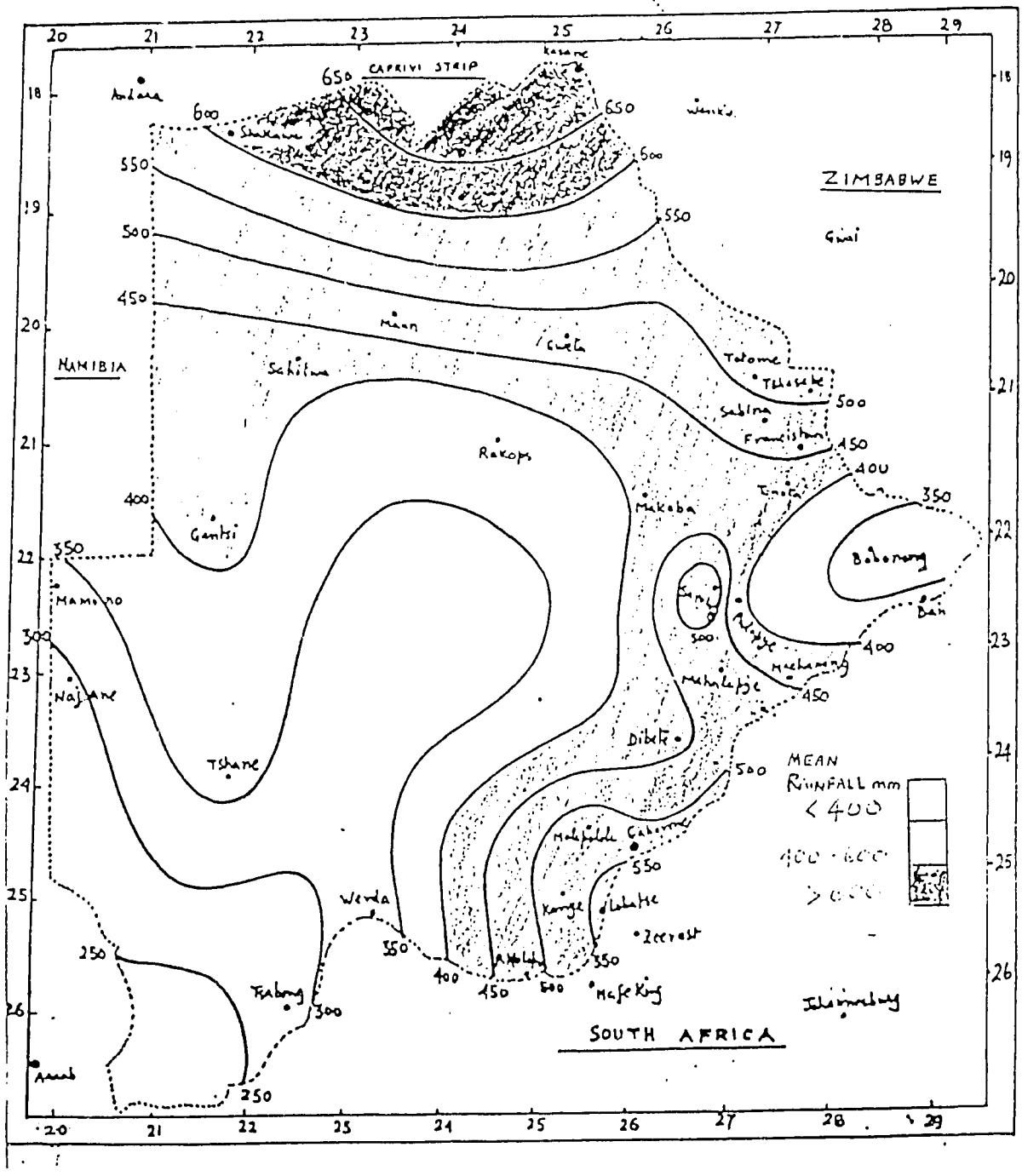
Rainwater catchment is already widely practised throughout Botswana. However, the amount of rain that it is possible to collect and store is often under-estimated. A simple example of the rainwater catchment potential of a small roof illustrates this point well.

In this calculation a runoff coefficient of 0.9 is included, to take into account losses due to leaking gutters, and rainfall events too small to produce significant runoff. Nevertheless, even when these losses have been taken into account, 19 440ℓ of potentially useful runoff are provided in an average year by a roof of only 6m x 8m (48 m^2 in area). If all this could be collected and stored a supply of 53ℓ/day could be maintained throughout the whole year. This is equivalent to about 3 buckets/day which is more than an average rural family in Botswana nomarlly uses for domestic purposes.

MAP 1. BOTSWANA

MEAN ANNUAL RAINFALL (mm)

(SKETCH-MAP)



In order to collect and store all of this rainwater an extremely large storage capacity would be required, espcially if carryover from wetter years was required to provide a supply in drier periods. In fact for Botswana where rainfall is both seasonal and highly erratic, the storage capacities required to collect ans supply all the rainwater running off the roof would have to be almost equal in volume to that of the total annual runoff.

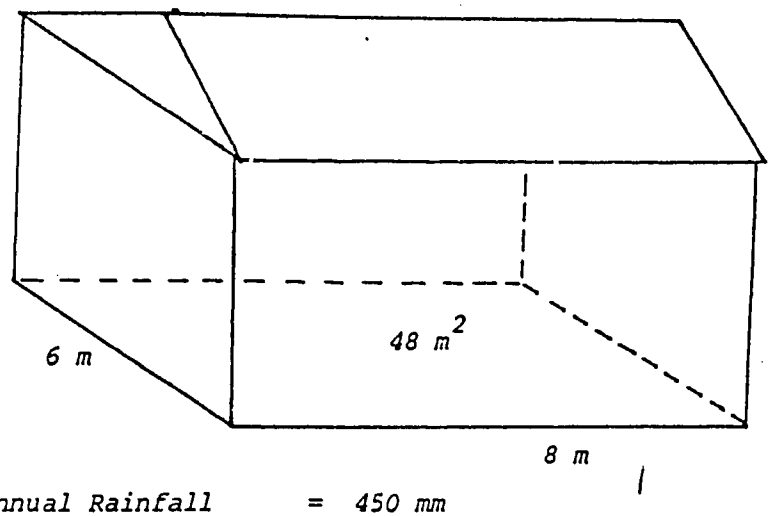
Clearly, storage capacities of such volumes are both unrealistic and uneconomic in all but the most extreme situations. However, in Botswana where water is highly valued and precious resource, the challange is how to collect, store and supply as much rainwater as possible and as cheaply and efficiently as possible.

With the assistance of a computer model which analyses past rainfall data, the Botswana Technology Centre has derived a simple method for approximating the most efficient storage volume for a given catchment area. An example is given on the following page.

A more detailed explanation of the rainwater catchment storage/demand computer model is given in appendix 1.

Example 1.

Typical Roof Catchment Potential in Eastern Botswana.



Mean Annual Rainfall = *450 mm*

Runoff Coefficient = *0.9*

Roof Area = *48* m^2

Rainwater Catchment Potential = *Mean Annual Rainfall* x *Runoff Coefficient* x *Plan Area of Roof*

0.45 m x *0.9* x *48*

= *19.44* m^3 *(19,440L/year)*

Water Quality

In non-industrial countries like Botswana, the chemical quality of rainwater is more or less guaranteed, due to the absence of toxic aerosols in most of the atmosphere. Once the rain comes in contact with a surface, contamination is possible. There is little evidence that the chemical quality of stored rainwater is not at an acceptable level. Fears that rain collected in ALDEP tanks from clay and dung smeared threshing floors would have unacceptably high nitrate levels have also been disproved.

Although purity of water is normally considered to be a positive atribute the extreme chemical purity of rainwater can in fact be a hazard in itself. If rainwater is drunk exclusively over long periods of times, minerals which are normally disolved by water from the earth, and inturn extracted from the water by the body, are found to be lacking. As a result health may deteriorate due to deficiencies in these minerals. Occasional access to other water sources or a nutritious diet should, however, make up for such dificiencies.

Roof Catchment

Not all roofing materials are suitable for rainwater catchment. In Botswana the vast majority of roofs consist either of thatch or corrugated galvanized iron. Although the possibilities of collecting rainwater from thatched roofs in Botswana has been suggested, a detailed questionaire survey of four villages has shown that the vast majority of people consider water running of thatched roofs to be unclean. This is because it is generally discoulered. Although a few people do collect this water for washing and building there seems little point in developing this technology when other alternatives such as ground catchment exist.

Corrugated iron roofs normally form relatively clean catchment surface. However, where trees over-hang a roof leaves and bird droppings may form serious sources of contamination. Even where roofs are in the open, it may be beneficial to allow the first rain at the end of the dry season to wash away bird dropping, dead insects and other debris on the roof and in the gutters. Such roof washing can be facilitated by having a detachable downpipe. Although a number of ingenuous devices exist for separating the first and lightest runoff from the main runoff of a storm which is allowed to flow into the tank, it is not felt that these are appropriate

for generalized use in Botswana at the present time and simple sedimentation traps and filtration devices may prove to be more useful.

RAINWATER TANKS

Calculation of the appropriate storage volume for a given catchment area.

1. Calculate the catchment area in square metres.
   For a rectangular roof, or ground catchment apron, this will simply be length x width.

2. Decide whether you are in an area with (i) more than 600 mm (ii) 400-600 mm (iii) less than 400 mm of mean annual rainfalll.
   Use map 1 to help you.

3. Using Table 1, choose the storage coefficient appropriate to your area and multiply it by the catchment area.
   This will give you the most appropriate storage volume in cubic metres (or thousands of litres).

Table 1

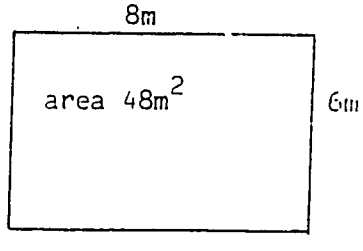
Rainfall (mm)	< 400	400-600	> 600
Storage coef.	0.15	0.2	0.25

4. Having calculated the appropriate storage volume, a reliable approximation of the annual water supply which can be provided with 95% reliability can be obtained by multiplying the storage volume by $1^1/2$.

Example

For roof catchment in example 1)

i) Roof area = 6m x 8m = $48m^2$



ii)

Mean annual rainfall approximately 450mm.

this is between 400-600mm therefore Storage coefficient = 0.2

iii)

Roof area x Storage coef. = Storage volume

$48m^2$ x 0.2 = $9.6m^3$

270

iv)

Mean annual Supply at 95 percent reliability

$= 9.6m^3 \times 1.5 = 14.4m^3$ (14400 Lts.)

Mean daily supply at 95 percent reliability

$= \frac{14400 \text{ litres}}{365} = \underline{39 \text{ litres per day}}$*

* i.e. almost 40 litres of water can be supplied every day from this roof with 95% reliability.

Gutters

Gutters can be made of a variety of materials both natural and man-made. Commercially produced galvanized guttering is very expensive, around P3 per metre. For a short gutter an old piece of currugated iron sheeting can be cut and bent and hung under the eaves to provide. This method, is in fact, used quite extensively.

For larger buildings, where a serious attempt to collect and store rainwater efficiently is required, more orthodox commercial guttering is the most appropriate. The problem here, however, is to decide what size the design on the other are to be overcome.

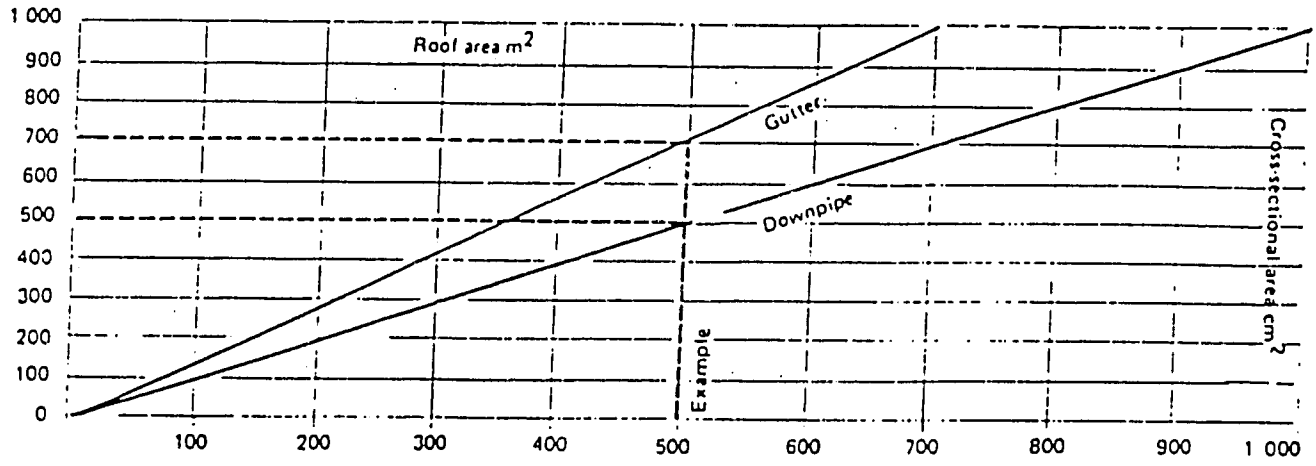
For detailed information on this see The Building Research Establishment Digest 188 and 189, or contact the Botswana Technology Centre. A rough guide, however, is given by Table 2. The values suggested are for horizontal gutters. For sloping gutters the values would be smaller. If the gutters are built too small they will overflow during high intensity storms.

The design dimenstions suggested here are based on rainfall intensities of 150mm/hr which are both unusual and shortlived in Botswana.

In order to determine the gutter size required measure the maximum roof area being drained through a single downpipe and see where it fits in relation to the values given in the table. If the area is too large to be drained by the available guttering increase the number of downpipes.

Table 2

Determination of Sizes of Gutters and Downpipes
The chart is calculated on the assumption that 1 cm^2 of downpipe is sufficient for 1 m^2 of roof area, and 7 cm^2 of gutter is sufficient for 5 m^2 of roof area.
(SBR Chapter 12 page 42).



Example of use of chart
To determine the size of gutter and downpipe required for a roof area of 500 m^2, the 500 m^2 -line on the horizontal base should be followed up until it intersects the diagonal downpipe-line and the diagonal gutter-line. The corresponding horizontal readings on the vertical left-hand-line are the cross-section areas required.

Roof area	500 m^2
Gutter required	700 cm^2
Downpipe required	500 cm^2
Recommended downpipe	4 x 125 mm dia. circular downpipe

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If designing small buildings with rainwater colelction in mind, it is useful to REMEMBER three facts.

(1) It is cheaper to construct guttering for a small building where the roof only slopes in one direction.

(2) If a single slope roof is built with the slope facing the prevailing wind, rainwater yields may be significantly increased.

(3) Over hanging trees will result in more pollution from bird droppings, and leaves will invariably block the gutters.

In urban Botswana, where most gardens have tall trees for shade, the problem of leaves blocking the gutters is so serious in some cases, that it may put into question the whole viability of using roof catchment system there.

Table 2 Results from bacteriological analysis of 10 roof tanks in Botswana.

		Total coliforms*	Faecal coliforms*	Faecal Streptococci*	Other information
Roof Tanks	1	0	0	0	From covered corrugated iron tank in Tutume.
	2	0	0	0	" " Nata
	3	0	0	0	" " Francistown
	4	0	0	0	" " "
	5	0	0	46	" " Tlokweng
	6	0	0	44	Details known
	7	0	0	75	" "
	8	0	0	90	" "
	9	1	0	1	" "
	10	28	6	62	Tank not covered

* Per 100ml calculated from analysis of 5 and 50mℓ samples

The above figures illustrate the generally high quality of properly stored rain water. For a comparison the table below gives World Health Organisation requirements and the limits considered acceptable to the Botswana Department of Water Affairs.

	Total Coliforms	Faecal Coliforms	Faecal Steptococci
W.H.O. Limits	10	0	0
Botswana accepted limits	100	10	10

If there is any reason for concern as to the quaity of the water in a tank, then periodic chlorination is probably the most economic solution. Approximately 2 mg of chlorine per litre of water will require only 1/2 hr contact to be effective, and application approximately every 3 months will be adequate in the majority of cases.

It should, however, be noted that if the tank if properly covered and openings protected against insects and vermin this treatment should not be necessary.

GROUND CATCHMENT

Water Quality

The situation for ground water catchment tanks is somewhat different as can be seen from the table. For ALDEP tanks, at least, where threshing floors are normally used as catchment aprons, and water is extracted from the tanks using a tin or bucket, the quality of the water does not reach the standards required for consumption. This is in spite of the fact that a simple small excavated sediment trap and crude filter is generally built by the inlet to the tank.

Although, poor water quality may make rainwater a less attractive source, there are normally ways and means of overcoming these problems. Boiling, filtration and chlorination are three methods which are commonly used. In most of Botswana, however, the factors which will determine whether a water source is used or not, are more likely to be related to taste, colour and odour rather than necessarily directly to quality.

		Total Coliform	Faecal Coliform	Faecal Streptococci	Other Information
ALDEP Subsurface Rain Catchment Tanks	1	TNTC	600	-	TNTC=too numerous to count
	2	TNTC	1000	-	
	3	TNTC	400	-	
	4	6	300	-	
	5	6	15	29	1 year old rain sampled direct tank.
	6a	2	6	124	
	b	TNTC	14	TNTC	Samples collected using extraction tin.

Ground Catchment Systems

Simple ground rainwater catchment systems have been used in Botswana for centuries. These consist of small hand dug haffirs fenced with thorn bushes which are still used extensively for watering livestock and providing domestic water in the rainy season. The first attempt to develop this technology a step further was made in 1969, when the Inter-

mediate Technology Group in London, sponsored a one year pilot project in the construction of low cost plastic lined excavated rainwater tanks at 12 primary schools in the Palapye area. Teachers were trained centrally and sent back to their shcools with all the necessary mateials provided to construct the tanks with the help of the pupils. The tanks were built next to the school gardens to provide water in the dry season. Although seven tanks were constructed, because the pilot project only ran for a year and there was no follow up, only two tanks were still successfully operational after three years. There was a little replication of the technology in other areas, but today 15 years after the start of the project there are only a couple of tanks still working, one in Morwa and one in Tamasane.

The Headmistress of one of the Primary Schools in Morwa, who had one of these tanks built at her home has, as recently as 1981, had a ground catchment tank built for the school garden. The tank which, unlike those built in 1969, uses no plastic but only bricks and cement, has a capacity of 50 cubic metres and costs P400, which was raised out of school funds. As yet, there is no cover for the tank but 80% shade netting would seem a suitable material for the cover.

Tanks of this type could be built at school garden throughout Botswana to provide useful water for irrigation during the dry season.

Butyl Rubber and PVC cement lined tanks

Experiments with other types of ground catchment tanks have been conducted in Botswana. At Morwa Brigade a number of PVC/wire mesh/cement lined tanks were built in the mid 1970's. These were used successfully for a while, mainly for irrigation purposes, but the cement began to flake away from the PVC sheeting after some years and by 1983 all were in a poor state of repair and most were not functioning at all.

At Serowe Forestry Brigade a 600m^3 excavated tank was lined with butyl rubber sheeting in 1977, but no cover was provided. The tank was used successfully to provide irrigation water for a small horticultural project for a few years. Rainwater was collected off a cleared hillside and diverted to the tank by retaining walls. The horticultural project ended in the late 1970's and the tank was no longer used. It still held water, albeit dirty, in July 1983, proving that the technology is technically sound.

Opportunities for using large excavated tanks for providing water for irrigation are widespread in Botswana, but this branch of rainwater catchment and storage has long been ignored.

ALDEP Rainwater Tanks

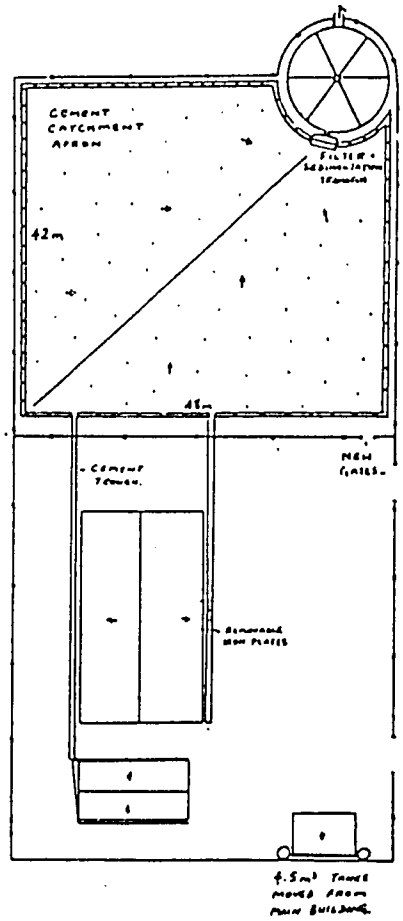
This is the most imported and widespread innovation in the field of ground catchment tanks to have occurred in Africa in recent years. The Arable Lands Development Programme (ALDEP) tanks were developed at the Integrated Farming Pilot Project at Pelotshetlha. The original concept of using a traditional threshing floor as a catchment apron came from a farmer in Mochudi. After more than a year of experimentation with different tank designs, two final designs were chosen. One for areas of consolidated soils and one for areas of unconsolidated soils. These designs are shown in the following diagrams.

There are now over 300 of these tanks in Botswana, and most are of the plastered variety. The Ministry of Agriculture has been responsible for the construction of most of these and over 200 more are planned for 1983-84. Although the specifications for the tanks are $8m^3$ for the brick and $10m^3$ for the chicken wire and cement type, a survey of 30 tanks showed an average size of $14m^3$. The cost of the tanks is P450, providing a hole is dug by the farmer and transport is provided by the Ministry of Agriculture.

Rainwater Harvesters

At the present time there are no rainwater harvesters in Botswana, although this technology has been used in many other parts of the world. A proposal has, however, been submitted by the Botswana Technology Centre for the construction of two rainwater harvester at Nata. The following diagrams show a plan of these and it can be seen that basically all they consist of is a cemented catchment apron and an excavated tank.

ONE POSSIBLE DESIGN FOR A RAINWATER HARVESTER AT THE BOTSWANA AGRICULTURAL MARKETING BOARD SITE IN NATA.



TANK VOLUME = 400 m³

MEAN ANNUAL SUPPLY AT 95% RELIABILITY = 991 m³

PROVIDING A DRINKING WATER SUPPLY FOR 1050 PERSONS

CATCHMENT AREA = 2700 m²

METRES 0 10 20

SCALE 1 : 500

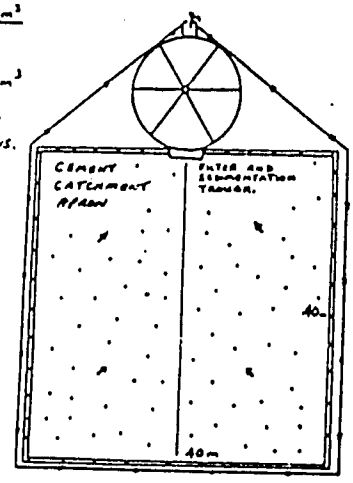
ONE POSSIBLE DESIGN FOR A SECOND SMALL RAINWATER HARVESTER IN NATA

TANK VOLUME = 400 m³

MEAN ANNUAL SUPPLY AT 95% RELIABILITY = 574 m³

COULD SUPPLY DRINKING WATER TO 684 PERSONS.

CATCHMENT AREA = 1750 m²



METRES 0 10 20

SCALE 1 : 500

Choosing the appropriate type of tank

Once the appropriate storage volume has been calculated it is necessary to decide how best to provide this. Several types of surface and sub-surface tanks may be considered to do the job. Each has its own advantages and disadvantages and these are summarized in Table 2. Clearly where ground catchments are involved sub-surface tanks are the only option. This requires some means of extracting the water. As pumps are too expensive in the case of the small sub-surface tanks, tins or buckets are geneally lowered into the tanks directly, resulting very often in contamination of the supply. For this reason and for the convenience of a tap supply, surface tanks, although more expensive, are preferable for roof catchment systems.

Corrugated iron, brick/cement and the sub-surface ALDEP rainwater catchment tanks have all been used in Botswana for some time. A pamphlet entitled "How to build an ALDEP Rainwater Tank" gives details of the construction method for those tanks and is available form the Government Printers, or the Ministry of Agriculture.

Ferrocement tanks and cement jars are both relatively new technologies in Botswana, although both have used extensively elsewhere in Africa. In Kenya UNICEF has successfully promoted extensive use of cement jars for rainwater storage, whilst in Zimbabwe a large number of Ferrocement tanks have been built over a number of years by the Hlekweni Friends Rural Training Centre, near Bulawayo. In both cases the technologies have proved successful.

Cement Jars and Ferro Cement Tanks

i) Cement jars are normally constructed by first making a tough cloth or hessian bag as a mould. This is placed on a prepared concrete slab built on a foundation of crushed rocks. The bag is then filled with grass leaves or any other suitable filler. A circular former is placed on the top of the bag to provide a mould for the top opening. The bag is then plastered with a 1:2 sand: cement mix, and left to set for 24 hours, the bag and its contents can then be removed and reused. The tank should, however, remain under a damp cloth or plastic and out of sunlight for up to two weeks to cure. This technique can be used for jars up to 3000ℓ in capacity.

(ii) Ferrocement Jars

For cement jars of capacities above 3000ℓ, chicken wire needs to be wrapped around the cloth bag mould before the plastering is done, and barbed or fencing wire should also be used as reinforcement. Once the plaster has set and the bag removed, the inside of the jar should also be plastered. Tanks of this design have been built in their hundreds in Kenya, with volumes of 5-10m^3. Once completed the tanks should be partially filled withwater, covered with a polythene sheet and left for a month to cure.

(iii) Ferrocement Tanks

Large cylindrical ferro-cement tanks can be made using corrugated iron formwork moulds, which can be bolted together and dismantled for re-use. The formwork should be erected on a thick slab oc concrete laid on an excavated foundation of sand and gravel. The outside of the formwork should then be covered with chicken wire, and galvanised iron wire should be wrapped around each corrugation to act as reinforcement. Two layers of mortar in a mix of 1 part cement to 3 parts sand should then be plastered on the floor of the tank. A thick cement slurry should then be painted on the inside of the tank in order to seal it. A small quantity of water should be left to stand in the bottomof the tank and it should be covered and allowed to cure for seven days. (See diagram, page)

To date, tanks of 10 and 20m^3 capacity have been built in Botswana. Tanks of over 100m^3 have been constructed elsewhere and it is claimed that tanks as large as 450m^3 couold be built.

For a more thorough discussion of ferrocement water tanks including construction details see Ferrocement Water Tanks, S.B. Watt (1978) I.T. Pulbication, 9 King Street, LONDON, U.K. This is also available at the Botswana Technology Centre.

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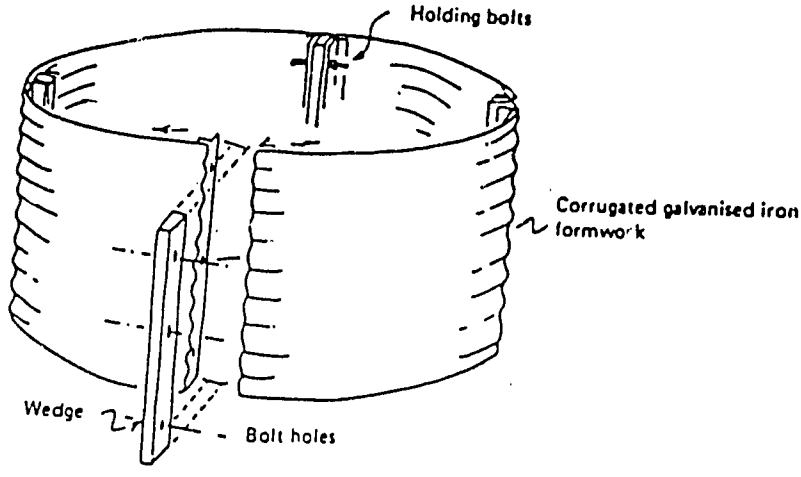
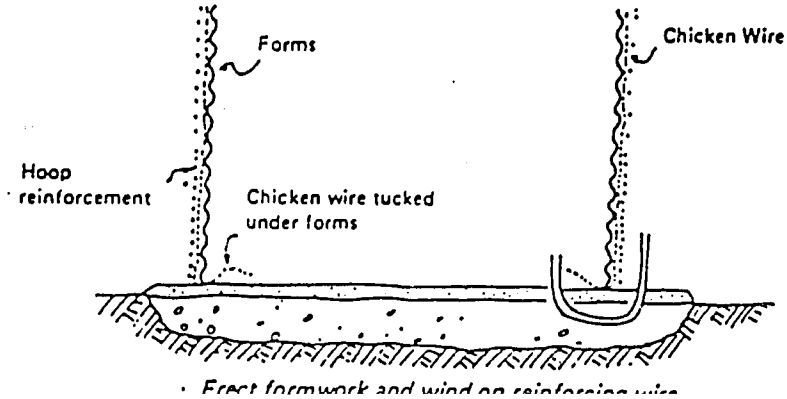
ADVANTAGES AND DISADVANTAGES OF DIFFERENT TYPES OF RAINWATER CATCHMENT TANKS.

Type of Tank	Advantages	Disadvantages	Estimated Life Expectancy	Approximate Cost Per m^3
Corrugated	1) Readily available 2) Ready to install 3) Low Labour costs	1) Short life expectancy 2) Rusts easily 3) Needs to be transported to site 4) Not made in Botswana 5) Max. size $9m^3$	2-10 + years	P40-55
Ferrocemnt	1) Long life expectancy 2) Can be built much larger than corrugated tanks 3) Use local labour and materials	1) Require special moulds for construction 2) Require trained builders 3) Danger of cracking if allowed to dry out	15-25 years	P40.50
Cement jars	1) Small but cheap 2) Require only a cheap easily made portable cloth mould for construction 3) Long life expectancy	1) Max. size $3m^3$ 2) Require trained builder	15-20 years	P30
Brick and Cement	1) Can be built any size 2) Can be built above or below ground 3) Long life expectancy	1) Most expensive alternative	20 + years	P60-100
ALDEP Sub-surface tanks	1) Cheaper than equivalent surface tank	1) Some means of extracting water needed	15-20 years	P50
Brick/Cement Plastered Chicken wire	1) Cheaper than most surface tanks	1) Danger of cracking if allowed to dry out	10-15 years	P30.45

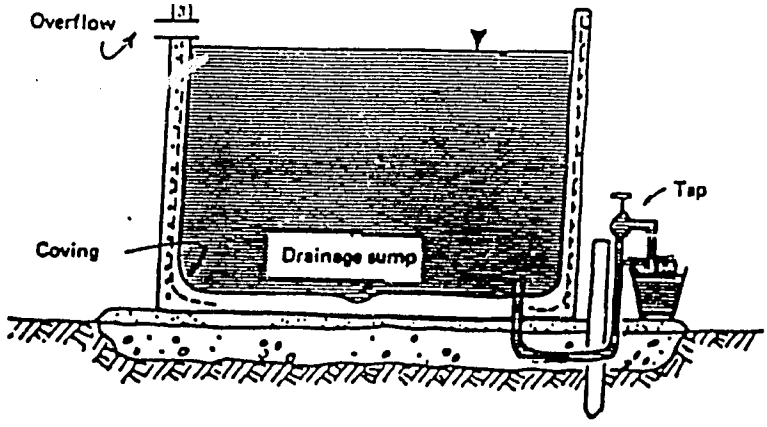
DIAGRAMS SHOWING THE STAGES OF CONSTRUCTION OF FERROCEMENT RAINWATER CATCHMENT TANKS



Assembling the formwork



Erect formwork and wind on reinforcing wire



The completed tank

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ECONOMICS

The biggest cost incurred by those having rainwater catchment systems is the relatively large initial capital outlay. Once operational the running costs are negligible, and the tank starts to help repay the initial outlay through the savings in water collections and purchases which are made. A 200ℓ oil drum is included, this is not recommended except for very small buildings where the household cannot afford anything larger. The prices quoted are those one can expect to pay in Gaborone, or Francistown at the time of writing (November 1983).

Price List of Catchment Tanks Available on the market.

TANK TYPE	VOLUME (m^3)	Cost	
Old oil drum	0.2	P6	
Galvanized Drum	0.2	P33-60	
Corrugated Iron Tank	2.25	P137-160	
	4.5	P200-210	
	9	P400-500	
Ferrocement	22	P100	
Plastered (ALDEP)	10	P450	Self help excavation
Brick (ALDEP)	8	P450	85% Grant available to eligible farmers
Brick/Cement	50	P5000	
Surface Tank	400	P30,000	

Galvanized guttering cost P2.77/m

It is hoped that cement jars may soon be commercially available. For enquiries about these and ferro-cement tanks, contact the Botswana Technology Centre.

SOCIO-CULTURAL ASPECTS

One of the biggest advantages of rainwater collection over alternative supplies is the general preference which people have for drinking and washing with rainwater rather than other water. The majority of people say that they prefer the taste of rainwater to groundwater, which is occassionally slightly saline.

There is, however, some doubt in people's minds about the quality of water collected from ground surface although generally it is considered to be acceptable. Rainwater from thatched roofs is in most cases regarded as being of low quality and of little use.

LIST OF BOOKS AVAILABLE ON RAINWATER CATCHMENT IN THE BOTSWANA TECHNOLOGY CENTRE

Ferro cement Tanks	- S.B. Watt 1978 I.T. Publications, LONDON
Rainwater Catchment and Water supply	- E. Nissen-Petersen 1982 Hodder and Stonghton
How to build a water catchment tank	- M. Whiteside 1982 Government Printers, GABORONE
The introduction of Rainwater Catchment Tanks and Micro irrigation to Botswana	- I.T.D.G. 1969 I.T. Publications, 9 King Street, LONDON
Waterlines (Contains relevant articles on the subject)	- 1982 I.T. Publications, LONDON

ADDRESSES AND CONTACT PERSONS

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Appendix 1

RAINWATER CATCHMENT

COMPUTER MODEL OUTPUT

Adapted from
work by B. LATHAM

University of
OTTAWA.

STORAGE/DEMAND CURVES
FOR FRANCISTOWN, BOTSWANA
BASED ON MONTHLY RAINFALL DATA
FROM 1922 - 1979

Appendix 1

SUMMARY OF THE RAINWATER CATCHMENT STORAGE/DEMAND COMPUTER MODEL

The computer model is designed to use past rainfall data as a guide to how much rainwater could be collected, stored and supplied in the future by tanks of different capacities from catchment areas of different sizes. The model provides a particularly useful tool for rainwater catchment systems design in a country like Botswana where the rainfall is both unpredictable and erratic. Using the model, a reliable estimate of the storage volume required to give sufficient carryover capacity from wetter years to drier ones, at different levels of reliability, can be obtained.

How to use the model

By feeding in mean monthly rainfall total over a period at least equal to the expected life of the tank, storage/demand curves can be derived. These provide a means of predicting the storage capacity required (as a fraction of roof runoff) at different levels of reliability. The storage/demand curves are produced by the computer as a discrete set of data and have to be plotted. The accompanying curves have been plotted based on Francistown data.

The applicaiton of these curves is best illustrated by an example.

Roof Area = $100m^2$

Mean Annual Rainfall = 467mm

Runoff Coefficient = 0.9 = $\frac{\text{water running into tank}}{\text{water falling on rof}}$

Water demand for family = 487ℓ/week

(1) Calculate Average Annual inflow (AAI) to tank

$$AAI = \text{Roof Area} \times \text{Runoff Coeff.} \times \text{Rainfall}$$

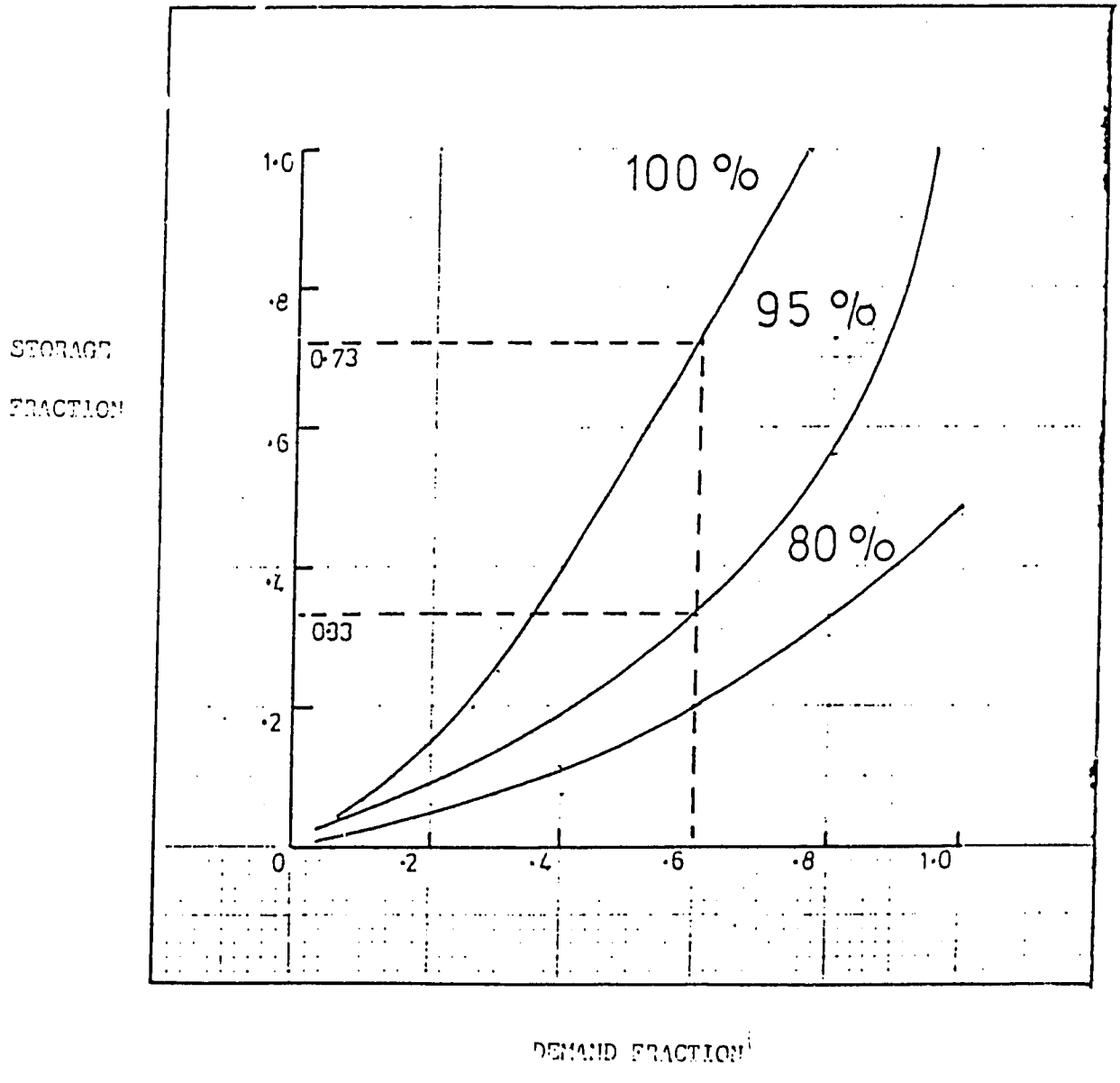
$$= 100 \times 0.9 \times \frac{467}{1000}$$

$$= 42.0m^3/\text{year}$$

(4) Each set of curves is based on a particular set of data from one place over a specified period. Application of the results to other places has to be conducted with caution - as the rainfall regimes may vary markedly.

STORAGE/DEMAND CURVES
FOR FRANCISTOWN, BOTSWANA
BASED ON MONTHLY RAINFALL DATA

FROM 1922 - 1979



(2) Calculated Annual Demand

Annual Demand = 487ℓ x 52 weeks

= $25.2m^3$/year

N.B. Demand <u>must</u> be less than AAI supply.

(3) Calculate Demand Fraction = $\frac{\text{Annual Demand}}{\text{AAI}}$

$$\frac{25.2}{42.0} = 0.60$$

(4) From graph read off storage fraction for demand fraction of 0.6 for

a) 100% Reliability

b) 95% Reliability

Storage fraction required

a) for 100% reliable supply = 0.73

Storage fraction requred

b) for 95% reliable supply = 0.33

(5) Calculate Storage Requred = Storage Fraction X AAI

a) for 100% Reliable supply = 0.73 x $42.0m^3$ = $30.6m^3$

b) for reliable supply = 0.33 x $42.0m^3$ = $13.9m^3$

This example clearly illustrates that the tank capacity required to satisfy a given demand, deminish very substantially if one is willing to accept a 95% (rather than 100%) level of reliability for the supply. In effect this means that if the rate of withdrawal remains constant the tank will be dry for 5% of the time. The amount of time the tank is dry can, however, be considerably reduced if rationing schedules are administered in time of drought.

It should be remembered

1) The curves only work so long as the supply (Average Annual Inflow) to the tanks is greater than the demand.

(2) The curves are based on historical rainfall data and cannot take into account possible future climatic changes.

(3) The storage is an estimate only.

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(4) Each set of curves is based on a particular set of data from one place over a specified period. Application of the results to other places has to be conducted with caution - as the rainfall regimes may vary markedly.

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