ENERGY CONSERVATION IN BUILDINGS

PASSIVE SOLAR DESIGNS

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ABSTRACT

Consideration of the Steady-state model of the energy balance through buildings can suggest an optimal building form and fabric. However, when the dynamic energy balance in buildings is considered, such optimal forms and fabrics become far more difficult to define.

This thesis first reviews the current trends in energy consumption in the U.K. Algeria and world wide in order to accentuate the need for more energy efficient buildings.

Secondly, existing passive systems and technology are reviewed, and an argument made for a 'demonstration' cell for both educational and practical purposes.

Finally, such a demonstration cell is schematically designed and specified. The design and assessment method is described in some detail, and the methods of assessment critically appraised.

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INTRODUCTION

Consideration of the steady - state model of the ener.y balance through building fabric can suggest an optimal building form and fabric.

Indeed, pioneering work carried out by Page (1) in the mid-seventies, derived optimal residential densities and layouts from steady-state considerations. Typically, the 'worst-case' situations generally based upon the seasonal 'Degree-Days' totals were used in the energy requirement calculations.

However, when the dynamic energy balance in buildings is considered, such optimal forms and fabrics become far more difficult to define. Ideally, energy conscious energy efficient design should pay attention to the integration of the energy balance over the entire lifetime of the building under consideration. Nevertheless, even if this were possible there would still be disagreement over the units in which energy efficiency should be measured. For example, it is not clear which of energy cost at present, energy cost at some future time, (primary cost or cost at point of consumption), cost including for capital investment or simply cost in use, is of enduring relevance.

The dynamic annual view would have to account for the irregular variations in temperature and exposure to which the building is subjected, both over the seasonal and diurnal cycles. The inclusion of thermal capacity and insolation into the energy balance leads to the necessary considerations of what are considered to be 'representative' climatic conditions, an area still under contention after several decades of academic debate.

The results of the past decades experience of dynamic thermal modelling has promoted the gradual movement from fundamental finite difference models more pragmatic analysis which make use of correction coefficients which have been extracted from the comparison of computer simulations (using these finite difference programs) with the output from live monitoring of buildings in use.

Requirement for a Bench Test.

It is interesting to note that the Los Alamos Test Cube should have been adopted internationally as the bench-test with which to compare simulation/appraisal programs, by reference to the climatic and heat flux data monitored at and within the cube.

The 1 x 1 x 1 m cube bears no relation whatsoever to a building in use ! Moreover, many of the institutions which have developed the simulation/appraisal models are currently involved in 'validating' them by comparison of their output to monitored cells' results. It is presumably assumed that if the cells performance can be modelled, then so can that of a building; despite the difference of scale, complexity and use.

Clearly there is a requirement for a consciously designed bench test to be used as an international validating standard. Such a bench test would involve a commonly occuring building type (test-rig) of standard geometrical form. Besides being a representative building type, the test-rig should be designed to amplify the variations in the models, small alterations in the test-rig characteristics should produce a correspondingly larger swing in the energy flow through it. Hence, it would also be an excellent 'demonstrator' of solar phenomena, in addition to providing a highly responsive vehicle against which to test simulation models.

Both of the objectives would be aided by a building or cell, which amplifies the internal temperature swings: In the 'demonstrator' by making the environmental differences great enough to be experienced directly by humans without the need of monitors, since it requires quite a large variation to make the body respond, and in the latter case, by producing large fluctuations which would amplify errors in the simulation model.

Consideration of energy in relation to the built environment reveals that in Europe and the United States, for example, in excess of 50% of all delivered energy can be associated with buildings and for this some considerable portion (more than 60% in the U.K, for instance) is consumed to moderate spatial conditions (Chp 1).

The need for comfort will increase and needless to say that some measures must be taken. Hence, retrofit and innovatory design measures are concerned with the management and potential conservation of significant amounts of energy. By effective implementation of such measures some noticeable reduction in energy consumption can be made.

Improved design of new buildings can make a cheap and enducing contribution to energy conservation. Although this is not always possible to achieve in mass housing, it is perhaps the major area in which activities and building designers can make a contribution to curtailing the overall energy demand.

Another way to improve housing will perhaps be to put strict regulations to building designs. Although many researches have been undertaken during the past few years there still is a need for an architectural guideline based on all the monitoring experiments, simulation and validation models.

CHAPTER 1 -

CHAPTER 1

INTRODUCTION

1.0 Since the start of the Industrial Revolution, (in the early 18th century), man has too often ignored or neglected his intrinsic dependence upon radiation from the sun. During this period, in order to satisfy the growing demand for heat and power, we have rapidly dissipated the earth's finite but readily available, cheap fossil-fuel reserves. These reserves are themselves the product of the fossilisation of organic matter grown through the process of photosynthesis - ultimately dependent upon the sun. The rapid escalation of fossil-fuel costs since the OPEC action in November, 1973, as well as a growing realisation that fuel reserves have already been severely depleted, and that the continuity of such supplies may be easily disrupted by political action, have led to a resurgence of interest in alternative energy sources, particularly solar.

In the more recent past, particularly in an era of cheap fuel, the attitude of many designers has been one of ignoring the natural characteristics of the site. However, important exceptions to that way of thinking include the theorists Olgyay (2) and Givoni (3), who wrote classic works on climate and architecture.

1.1 World Energy Consumption

As shown in Figure1.1, (4), world energy consumption so far this century has been provided almost entirely from fossil-fuels. Today oil and natural gas provide over 60% of worlds energy consumption. Projecting forward to the next fifty years and beyond, world demand for energy seems likely to continue to grow, driven by the growing need for energy in the developing countries.

Figure1.2, (4), projects the growth of energy demand for the next sixty years. On the basis of an optimistic low-growth forecast, world energy demand is anticipated to virtually double during the period 2000 to 2050.

Energy consumption is related to the population of energy users, and the projected increase in world energy demand is thus a function of the expected increase in world population, which is expected to grow over the same period. Not only is there an anticipated absolute increase in energy demand, but it is likely that the distribution of that demand will also change.

At present, the developed countries, accounting for 15% of the world population consume in excess of 50% of the worlds energy. However, with the accelerating rate of development of the industrial infrastructure of the emergent nations, along with increasing comfort expectations of their residents, it is inevitable that the pattern of energy usage will shift in favour of these less well off nations.

In order to conserve energy, then the per capita consumption of todays major consumers must fall in order to permit a more equitable distribution.

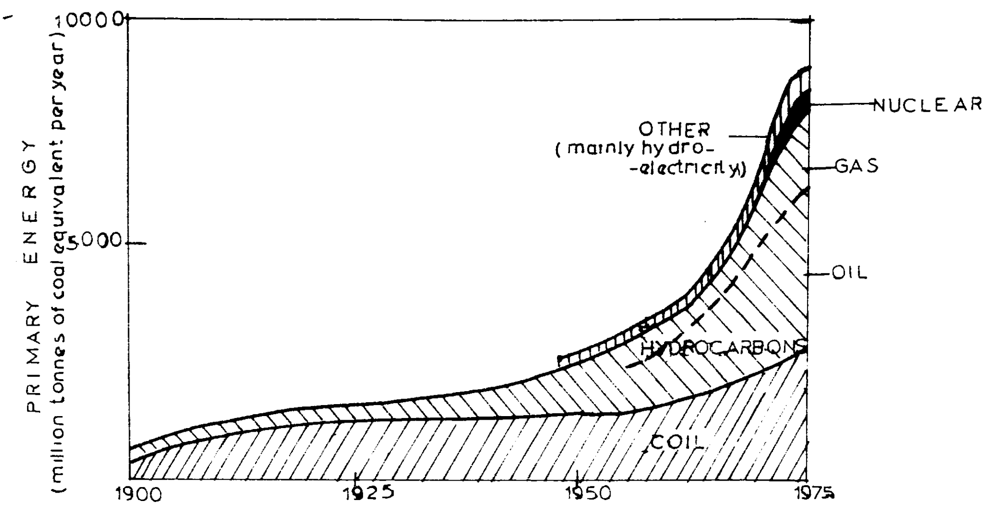


FIG.1.1 WORLD ENERGY SUPPLIES - THE 75. YEARS-1900-1975

FOSSIL FUELS HAVE SUPPLIED WELL OVER 90% OF THE WORLD'S ENERGY IN THIS PERIOD. INITIALLY THE SUPPLIES WERE LARGELY COAL. IN RECENT DECADES, CHEAP OIL AND GAS REPLACED COAL AS THE MAJOR SOURCE. TODAY THE WORLD IS DEPENDENT ON OIL AND GAS FOR OVER 60% OF THE ENERGY SUPPLY.

AS OIL AND GAS PEAK AND THEN DECLINE SUPPLIES OF COAL AND NUCLEAR ENERGY MUST EXPAND TO MEET THE WORLD'S NEED BUT THE CONTRIBUTION FROM THERMAL REACTORS IS LIMITED BY THE AVAILABILITY OF URANIUM.

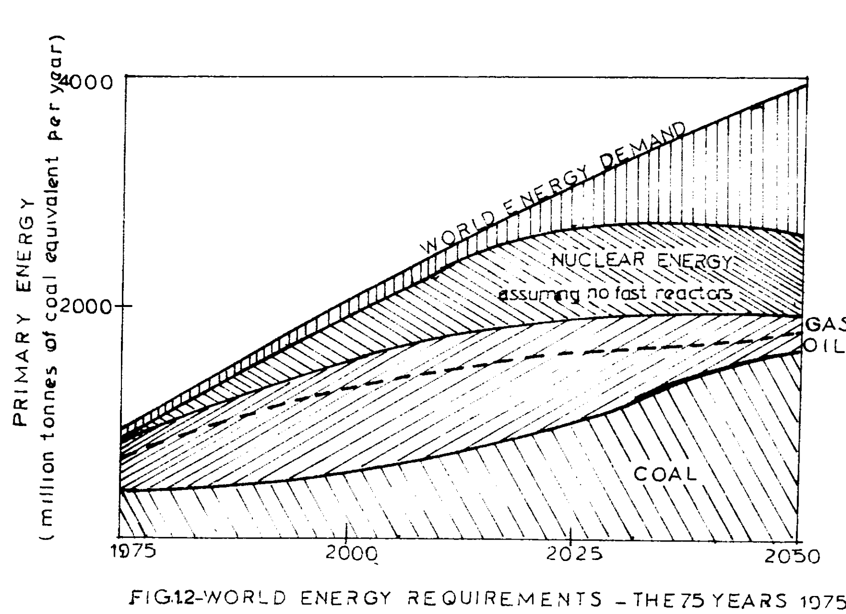


FIG.1.2-WORLD ENERGY REQUIREMENTS - THE 75 YEARS 1975-2050

1 2 Energy Consumption in the UK.

The advent of the Industrial Revolution was made possible through the extravagant exploitation of fossil-fuels, and the UK energy consumption has risen dramatically ever since.

In the past decade or two, the UK's coal based economy has been modified by the advent of the North Sea oil exploitation. The benefits accruing from the North Sea reserves are expected to reach their maximum in the mid 1980's, and they are at best, a short term palliative. Nevertheless, the UK still has several hundred years reserves of coal, at current rates of energy consumption.

1.2.1 UK Experience

In the period since 1945, the pattern of energy supply in the UK has changed profoundly. In the late 1940's, coal and oil were almost the only primary fuels. Approximately 90% of all primary energy was derived from coal, the balance from oil. By the early 1960's, the gas industry had diminished it's reliance upon town-gas, (coal-gas), and was vigorously exploiting natural gas resources, whilst there were also great plans for the rapid development and introduction of nuclear powered electricity generation to provide a small but growning nuclear component in the overall supply. By the mid 1970's, the UK had a "four fuel" economy - incorporating natrual gas, oil, coal, and an electricity contribution from, both nuclear and hydro-electric sources. These developments are illustrated in Tables1.1 to1.4 below, (5)

TABLE 1.1 - UK CONSUMPTION OF PRIMARY FUELS (MTCE)

	1950	1960	1970	1978	1980	1983
Coal (1)	204.3	198.6	156.9	119.9	120.8	111.5
Oil (2)	22.9	68.1	150.0	139.3	121.4	106.1
Natural Gas (3)	-	0.1	17.9	65.1	71.1	74.8
Nuclear (4)	-	0.9	9.5	13.4	13.4	18.1
Hydro (5)	0.9	1.7	2.3	2.1	2.0	2.4
Total	228.1	269.4	336.6	339.8	328.7	312.9

(1) Including other solid fuels
(2) Excluding petroleum for non energy use and marine bunkers
(3) Includes non-energy use of natural gas
(4) Electricity supplied ie excluding own use
(5) Excluding pumped storage

TABLE 1.2 - UK SECTORIAL ENERGY CONSUMPTION BY FINAL USERS

million therms

	1979	1980	1981	1982	1983
Domestic	16,501	15,816	15,750	15,569	15,494
Industry	23,170	19,130	18,142	17,436	16,943
Transport	14,037	14,109	13,168	13,909	14,319
Public Administration	3,792	3,546	3,504	3,441	3,447
Agriculture	732	594	557	558	555
Miscellaneous	3,463	3,342	3,350	3,366	3,421
Total supplied to final consumers	61,695	56,537	54,921	54,279	54,179

TABLE 1.3 - UK CONSUMPTION OF PRIMARY FUELS

MTCE

	1979	1980	1981	1982	1983
Coal	129.6	120.8	118.2	110.7	111.5
Petroleum	139.0	121.4	110.9	111.1	106.1
Natural Gas	71.1	71.1	72.1	71.7	74.8
Nuclear Electricity	13.8	13.4	13.7	16.0	18.1
Hydro	2.2	2.0	2.3	2.4	2.4
Total	355.7	328.7	317.2	311.9	312.9

The Table below shows in percentage shares, the breakdown of energy consumption by final users on a heat supplied basis in 1983.

TABLE 1.4

By Consuming Sector

	Solid Fuel	Petroleum	Gas	Electricity
All final users	14	41	31	14
Industry	23	28	34	15
Transport	-	99	-	1
Domestic	19	6	57	18
Other	8	34	30	27

By Type of Fuel

	Industry	Transport	Domestic	Other
All fuels	31	26	29	14
Solid fuels	53	-	39	8
Petroleum	21	63	4	11
Gas	34	-	52	13
Electricity	34	1	38	27

The generation living between the end of the post-world-war II reconstruction through the mid-seventies enjoyed the most rapid economic growth in UK history. Correspondingly, energy consumption rose between 1950 and 1978 by 48%, (see Tables 1.1 to 1.4). Figures 1.3 and 1.4 show the evolving development of the four fuel economy from 1963 to 1983.

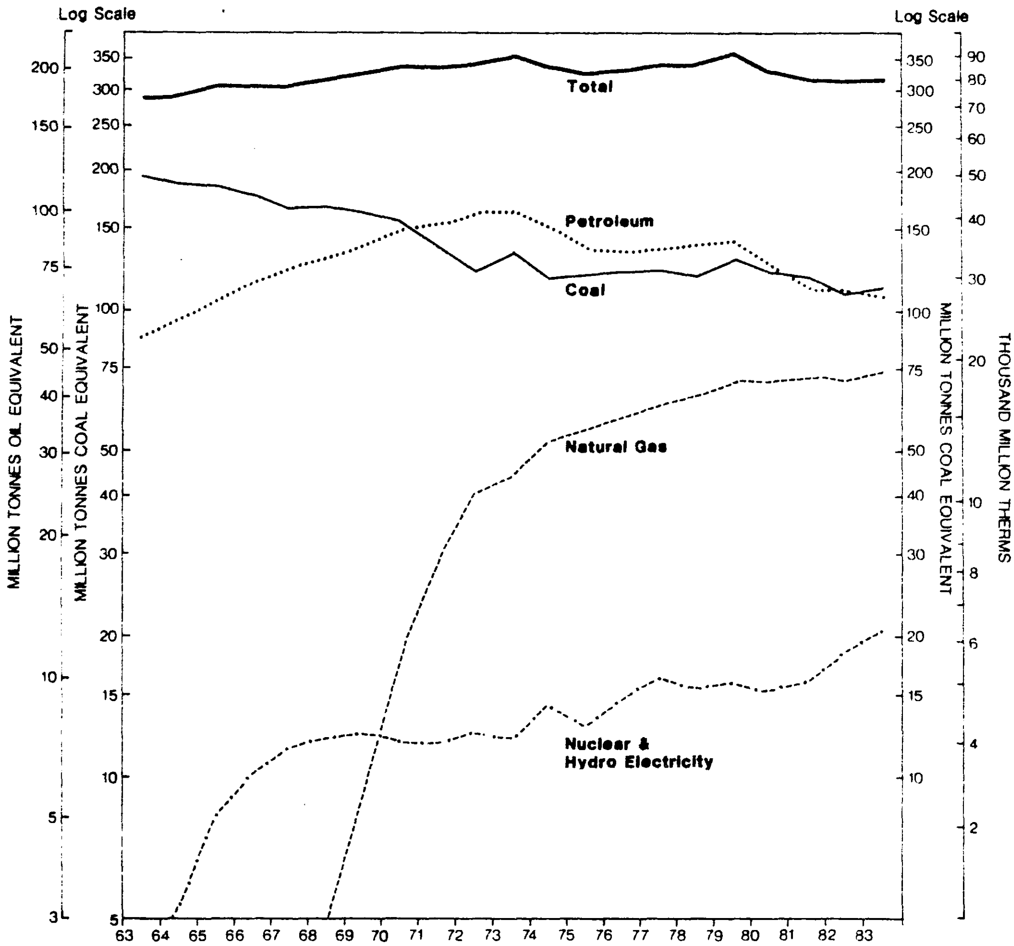
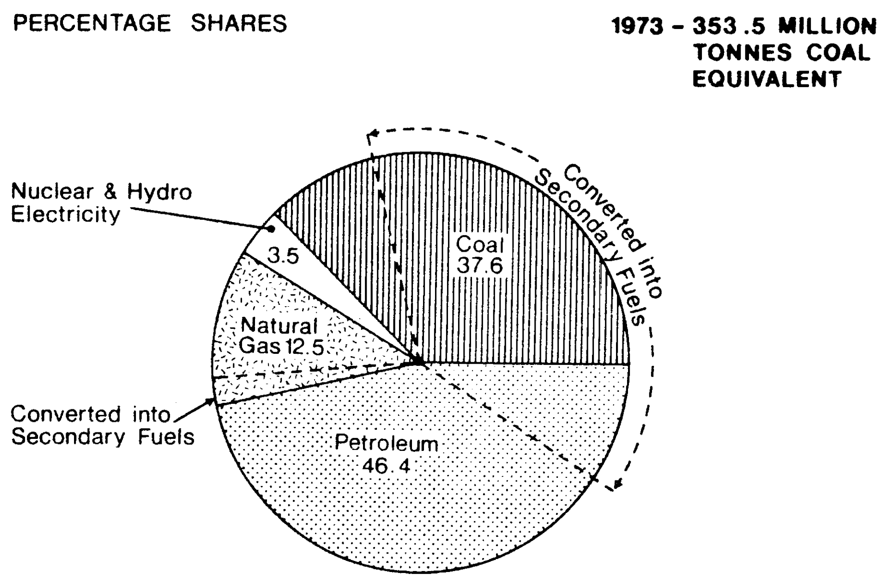


FIG.13 INLAND CONSUMPTION OF PRIMARY FUELS AND EQUIVALENTS FOR ENERGY USE.



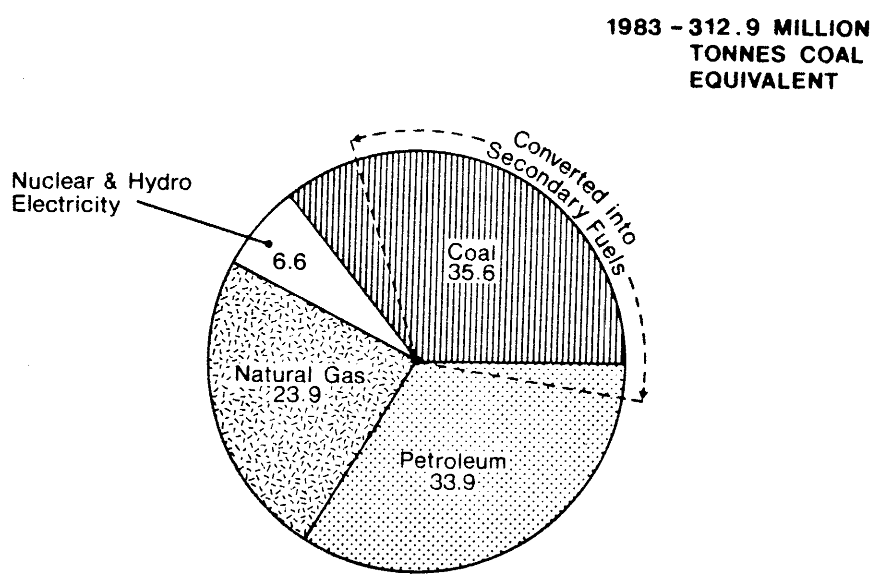


FIG.1.4 - INLAND CONSUMPTION OF PRIMARY FUELS AND EQUIVALENTS 1973-1983 -

1.2.2 Energy Usage

Of the energy used a significant amount, (greater than 25%), is consumed inside buildings, and much of this is required as space heating. Building users and householders use 29% of the country's primary energy for providing a comfortable environment within, (6). This figure allows for a 40% loss due to the inefficiency and distribution loss in converting and transporting the primary to secondary energy.

1.2.3 Potential Energy Savings

Of the secondary energy delivered to domestic end users, over half is used for space and water heating. Consequently, thermal insulation and draught prevention are obvious and familiar measures for reducing energy requirements; however, there are several less apparent benefits:-

Due to the 'free heat' gains from equipment such as artificial lighting, mechanical and electrical machinery, furnaces, ovens and cookers, energy given off by industrial and domestic processes, in addition to that given off by the metabolic processes of the occupants, etc., the overall energy demand can be reduced by trapping these sources by increased insulation. This important point is illustrated in Figure 1.5; using data of a typical UK house, (7) Whilst insulation reduces the heat loss through the building fabric from 100 to 60 units, due to the free heat gains the demand is reduced to 43% of the original requirement.

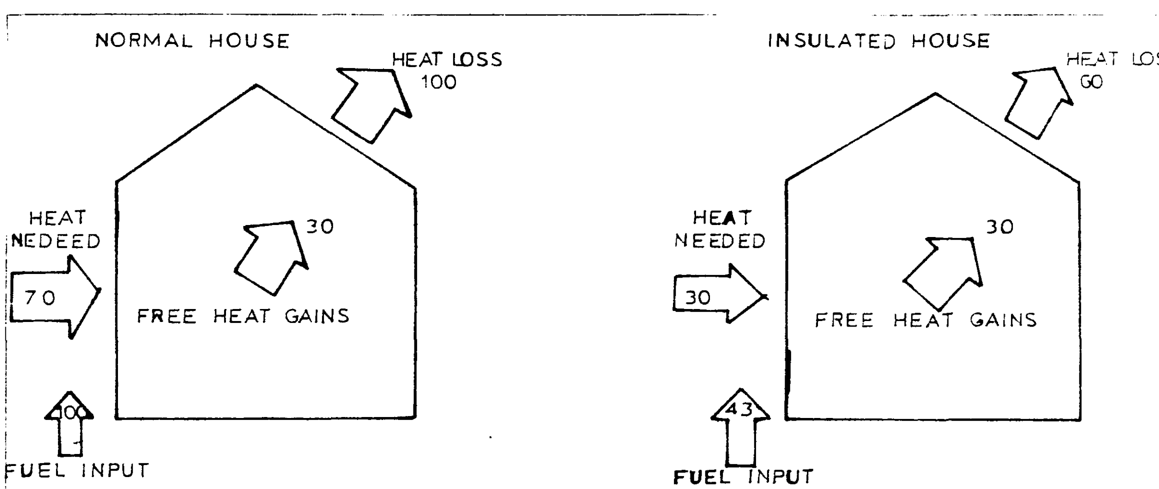


FIG1.5 EFFECT OF FREE HEAT GAINS ENERGY USE IN BUILDINGS_

A further benefit is the smaller heating equipment needed as a result, and can be more effectively sited within the building so that a larger proportion of their heat losses, (from their casings, and lost through the extract system), now add to the free heat gains.

1.3 Solar Contribution

Solar energy is perhaps the most attractive alternative energy source available. Until relatively recently it had been thought that the relatively high latitudes of the UK, (Lat 50 to Lat 59), was an insurmountable handicap.

There are several factors which must be considered prior to any solar application in the UK. First, the maximum intensity of the incident solar radiation is no more than 1kw/m2. Averaged over the whole year the intensity is far less; approximately 105w/m2, a value which is far less than half of that of the best insolated areas in the world. Secondly, in any application where continuous operation is essential, some form of energy storage must be provided, as the level of solar radiation is usually far too low for direct and instantaneous usage outside the 4 hours on each side of the solar noon. Thirdly, only a part of the radiation consists of direct sunlight, and this means that focussing devices would not be very effective. Finally there is the very considerable variation between summer and winter conditions.

The most immediate application of solar energy are for water and space heating. The key to successful schemes is linked to that of their storage systems, and this would currently seem to be their weakest link.

1.4 Conservation

Many reports have been published on energy conservation which point to the considerable scope for reducing energy demand in the ways outlined above. Many conservation techniques, such as insulation and heat recovery systems, are cost-effective at present fuel prices, and will become increasingly so as fossil-fuel prices rise, (8), (9), (10),

A major factor inhibiting the introduction of such measures is the initial capital investment required - a long term investment - which is often difficult to justify when compared with expenditure promising more immediate benefits.

There would appear to be four major areas with which conservation can be achieved:

1.4.1 Thermal Insulation of Buildings

It has been Government policy to promote the insultation of building fabric since 1978 by the introduction of more stringent standards in the Building Regulations, and by the funding of Insulation Grants in order to improve existing building stock. It is estimated that these measures could save one third of space heating energy.

1.4.2 Heat Recovery and Control Systems

Heat can be recovered and recycled from both waste water and extracted ventilation circuits, by means of simple heat exchangers or other simple devices. These devices tend to be more appropriate to larger buildings than individual houses. In some circumstances, district heating systems have been sponsored by Local Government authorities in order to best make use of waste heat from their larger buildings.

1.4.3 Control Systems

Improved control of space heating systems can yield significant savings. 'Tighter' control of systems has been the result of the availability of cheap micro-computers, and robust monitoring devices, eliminating the time delay inherent in mechanical thermostats and their equivalent. These control systems can make positive use of the thermal capacity of the building itself. Temperature 'hunting' of only + 1 deg.C in a heating system can entail an excess energy demand of 10%.

1.4.4 Building Design

Improved design of new buildings, which make optimum use of incidental energy gains, and maximum use of the beneficial aspects of the local micro-climate can make a cheap and enduring contribution to energy conservation. Although this is not always possible to achieve in mass housing, it is perhaps the major area in which architects and building designers can make a contribution to curtailing the overall energy demand.

1.5 Algerian Energy Consumption

1.5.1 Topography and Climate of Algeria

1.5.1(i) Algeria has the tenth largest area in the world, but may be divided into two areas, belonging to distinct morphological regions:

1) The northern region (325,000 km2) lying between the

Mediterranean Sea to the north, and the Sahara Atlas mountains to the south in which over 90% of the population live. It has a Mediterranean climate on its northern seaboard, and an Alpine climate further south.

2) The Sahara region to the south is a sparsely populated desert region of immense area. Figure 1.6 (11)

The topography of northern Algeria is dominated by the parallel ranges of the Atlas mountains running west to east; the Tell Atlas mountain range to the north, sloping down to the sea, separated by a high plateau from the Sahara Atlas mountain range to the south, which descends on its southern slope to the Sahara desert. In reality, there is a great complexity in the detail and relief, and it gives the country an appearance of separated compartments - good for both west-east, and north-south communication.

South of the Atlas mountains, the northern half of the Sahara is occupied by the great Ergs, (Great Western Erg and the Great Eastern Erg); large ranges of shifting dunes, and by basin plains carpeted by the debris brought down by erosion in the northern mountains.

In Southern Saharan Algeria the principal feature is the crystalline Ahaggar range of volcanic peaks above 300m in altitude. It is surrounded by a sandstone plateau, the Tassili, whose steep bluffs dominate vast pebble strewn plains like Tanezzouft, the driest location of the Sahara. Figure 1.6 (11)

The contrasts in Algeria's climate is even more marked than that of it's topography. The area of northern Algeria enjoys a Mediterranean climate, which becomes increasingly dominated by the effects of the Sahara as one progresses further south.

Summer is characterised by high temperature and dryness; winters are mild and humid, maximum rainfall occuring at the beginning of the spring and decreasing from north to south. Thus from west to east, and from north to south, because of the amount of annual rainfall, one may distiguish the profile of two climatic zones parallel to the coast:

1) The Tell: This is the region between the sea and the northern limit of the High Plains, which has a rainfall of over 400mm annually which permits agriculture without the need of artificial irregation. The major proportion of the population is concentrated in this coastal plain.

2) The High Plains: This area has a rainfall of between 200 - 400mm annually, and is a transitional area between the Mediterranean and desert areas, the latter becoming increasingly dominant in the High Plains of Western Algeria which are drier than those of Eastern Algeria. In the High Plains region, inadequate water and semi-aridity makes farming very precarious. The scarcity of rain, coupled with it's unpredictability from year to year, leads to semi-nomadic or itinerant livestock grazing in place of farming, except in the east which is higher and better watered - generally more favourable.Fig1.7

1.5.1(ii) Temperatures

The continent has immense areas over which the diurnal temperature

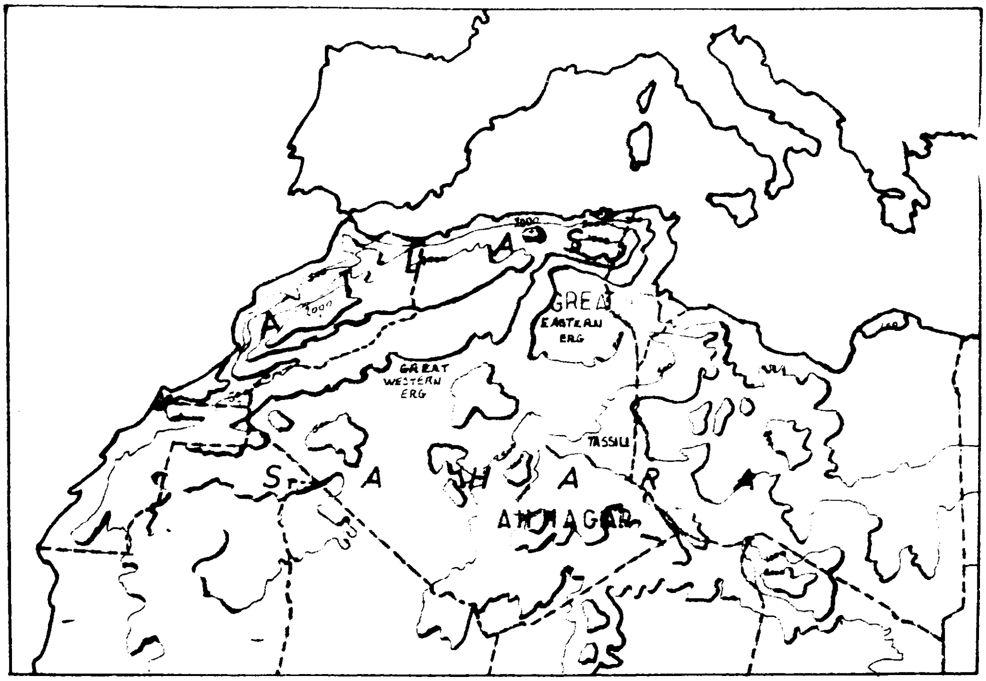
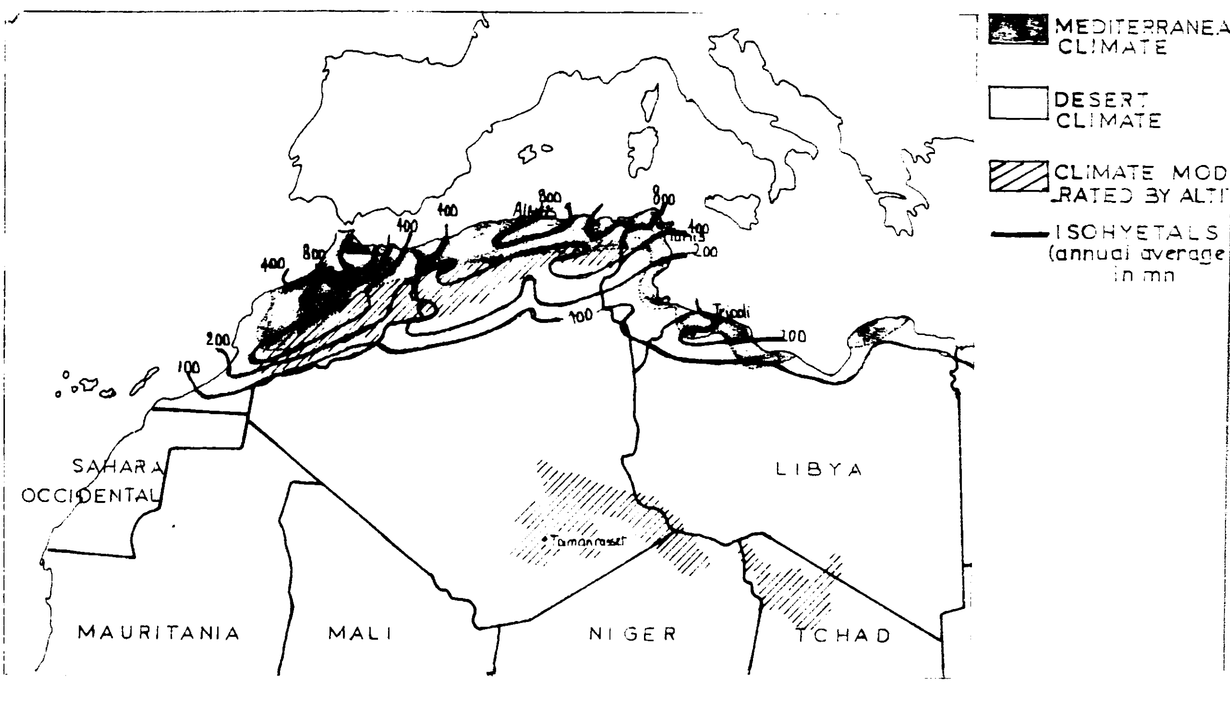


FIG1.6 TOPOGRAPHIE OF ALGERIA

FIG1.7 MAJOR CLIMATIC ZONES



range is very large. In fact, most of the continent has a diurnal temperature in excess of the seasonal difference, reinforcing the saw that "night is the winter of the tropics". The large diurnal fluctuation can lead to a daily freeze-thaw cycle in some of the highland areas.

To define the practically important range of temperature over the continent, two measures are necessary; first, is the maximum mean monthly temperature, (H), and secondly the minimum mean monthly temperature, (L). High values of H, (greater than 32 deg.C), are found over much of the continent with some 30% of the landmass experiencing temperatures in excess of 38 deg.C, with a maximum H of 47 deg.C in southwest Algeria. The increase of H with distance from the sea, (the Continental Effect), is very marked, and the only exceptions being in the plateau and highland areas of the east, and in the northwest, where the Atlas mountains of Morroco effectively shields a small area from maritime and oceanic influences.

Values of L reflect the effects of latitude and longtitude than that of continentality. Small areas have values of less than 5 deg.C and only in Algeria and Morroco, at altitudes in excess of 1000m, the L value will fall below 0 deg.C.

1.5.2 Pattern of Energy Consumption

The pattern of energy consumption in Algeria has changed drastically over the past two decades, as well as in overall annual energy demand. The total consumption was four times greater in 1977, (6 mtoe - million tonnes oil equivalent), than in 1965, (1.5 mtoe).

Algerian policy has given priority to the development of the industrial sector, and consideration of conservation and alternative energy sources has only recently been raised as a real issue. A result of this policy has been the increase in energy usage by the industrial sector by a factor of 6 over the same period, (1965 to 1977). These stastistics are presented in Tables 1.5 to 1.10 below, (12)

It is interesting to observe the evolutation of energy consumption, (Table 1.6). By 1976, energy derived through the combustion of charcoal, which accounted for 19% of the total in 1965, is now absent. Instead, that consumption of natural gas rose from 8% in 1965 to 15% in 1977. Similarly, consumption of LPG, (Liquid Petroleum Gas), has doubled during the same period.

From the late 1970's, Algeria's fuel economy has been based upon oil, natural gas and electricity, (generated presumably by the combustion of the previous two fuels).

TABLE 1.5 - ENERGY CONSUMPTION (1965-1977) OF ALGERIA

Year / Sector	1965	1969	1972	1973	1974	1975	1976	1977
Industry and Building	263 (17)	618 (17)	983 (27)	961 (24)	1023 (25)	1226 (25)	1412 (26)	1619 (27)
Transport	593 (39)	717 (27)	1177 (32)	1384 (35)	1555 (37)	1830 (38)	1842 (34)	1991 (33)
Household and Others	661 (44)	1259 (49)	1468 (41)	1608 (41)	1715 (39)	1758 (37)	2144 (40)	2408 (40)
Total	1517 (100)	2594 (100)	3628 (100)	3953 (100)	4323 (100)	4814 (100)	5398 (100)	6018 (100)

T.O.E.: Tonne of oil equivalent

TABLE 1.6 - EVOLUTION OF THE STRUCTURAL CONSUMPTION OF ENERGY RESOURCES OF ALGERIA (1965-1977)

Year / Sector	1965	1969	1972	1973	1974	1975	1976	1977
Charcoal	19	13	7	7	5	4	0	0
Coke	0	3	4	3	3	3	2	2
Oil (crude)	0	0	0	0	1	1	1	1
Refined Products	49	49	55	55	56	56	56	56
Natural Gas	8	10	9	8	10	10	13	15
LPG & others	5	7	8	7	7	7	10	9
Electricity	19	19	17	16	18	18	18	17
Total	100	100	100	100	100	100	100	100

TABLES - ALGERIA PRODUCTION AND CONSUMPTION OF ENERGY (1977 - 1990) (million tonne)

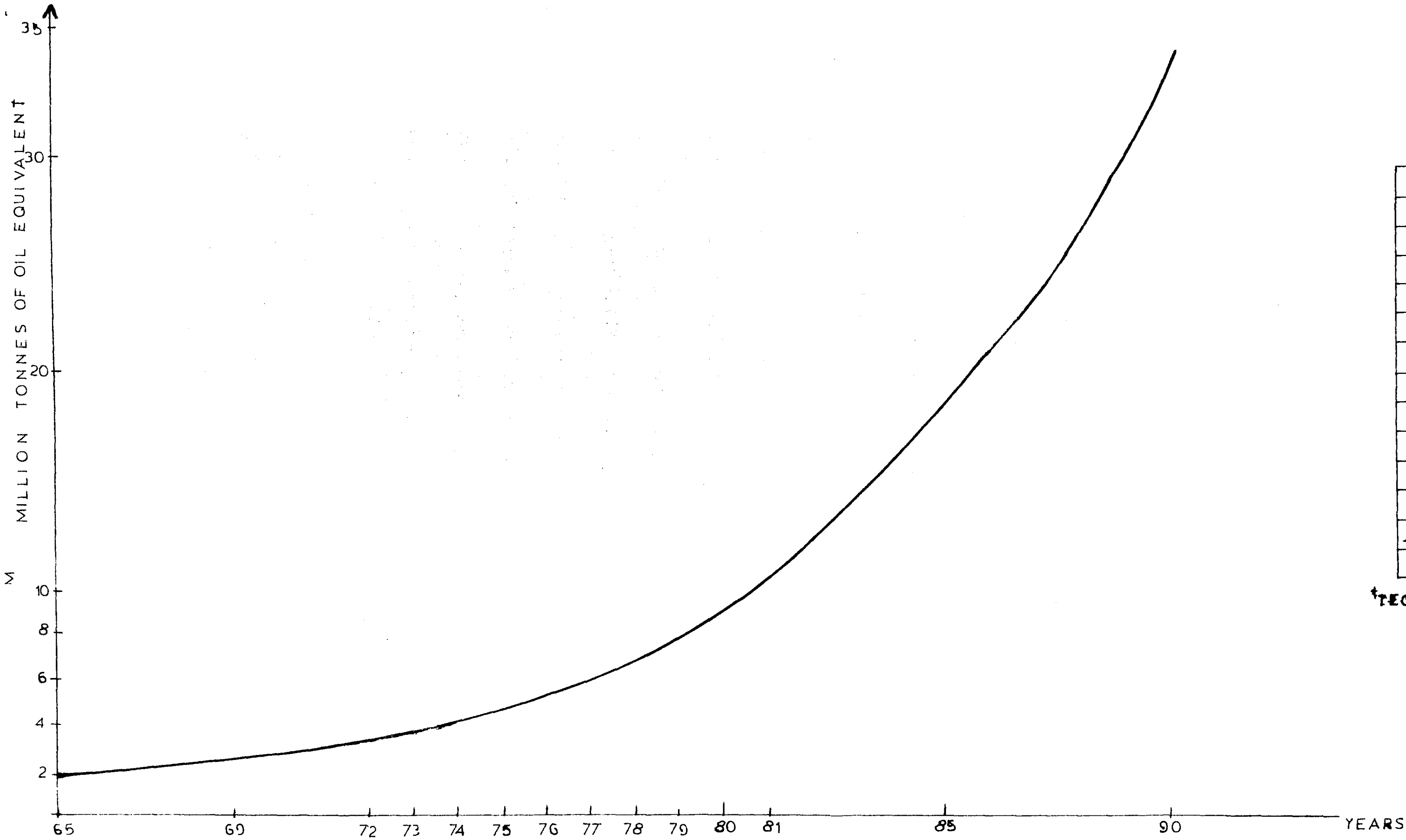
	1977	1978	1979	1980	1985	1990
1.7 Primary Resources						
Oil	51.10	54.60	53.80	54.90	53.50	40.80
Condensate	1.78	3.52	10.00	15.20	21.20	17.30
L.P.G. (deposit)	0.25	0.66	2.60	4.50	8.40	7.90
Natural Gas +	7.48	14.94	23.85	28.60	96.20	105.40
Electricity	0.08	0.08	0.08	0.08	0.08	0.08
Total*	60.69	73.80	90.33	83.28	181.38	171.48
1.8 Secondary Resources						
Refined Products	4.084	4.815	5.74	11.54	27.51	27.41
L.P.G. (refineries)	0.270	0.580	1.10	1.30	4.20	4.20
Electricity$^{\alpha}$	1.432	1.647	1.92	2.20	4.93	8.47
Total*	5.786	7.042	8.72	15.04	36.64	40.08
1.9 Total Energy Consumption						
Refined Products	3.53	4.03	4.24	4.50	8.44	11.39
L.P.G.	0.47	0.63	0.73	0.88	0.99	1.70
Natural Gas	0.85	1.23	1.63	2.12	6.68	14.36
Electricity	1.26	1.46	1.71	1.96	4.40	7.60
Total*	6.11	7.35	8.31	9.40	20.51	35.05
1.10 Importations						
Butane	0.136	0.175	-	-	-	-
Crude Oil	0.126	0.325	0.440	0.655	1.000	1.000
Total*	0.262	0.500	0.440	0.655	1.000	1.000

* million tonnes of oil equivalent
\+ Natural Gas consumed by the conversion factories excluded (1 million tonnes = 9450 therm units)
α Electricity : 1GW = 320 tonnes of oil equivalent
Sources : OAPEC - Bulletin, Juillet 1979
Tables taken from 'Le Secteur Des Hydrocarbures' A. Mekkideche
Office Des Reblications Universitaires, 1981

1.5.3 Future Consumption

The projected Algerian energy demand, (see Tables1.7 to1.10), indicates a doubling of demand, from some 10 mtoe in 1980 to 20 mtoe in 1985, and to 35 mtoe in 1990. Of this, natural gas is predicted to contribute 2.12 mtoe in 1980, rising to over 14 mtoe in 1990. It is apparent from Figure1.8 overpage, that the energy demand is rising exponentially, and indeed, Algeria is facing the same problems as confront the western industrial societies. Perhaps the observed demand might be mitigated by diversifying industrial expansion to include agriculture and tourism etc. in the development plans.

FIG18 ENERGY CONSUMPTION IN ALGERIA 1965-1990-



TEC*	YEAR
1.52	65
2.59	69
3.63	72
3.96	73
4.52	74
4.81	75
5.40	76
6.11	77
7.35	78
8.31	79
9.46	80
20.56	85
35.05	90

*TEC: TOTAL ENERGY CONSUMPTION

1.6 Summary

This brief overview of the relief and climate of Algeria shows that the renewable energy from the sun is not eronneous. Some parts of the country will benefit from it. The use of solar energy in domestic buildings, and public sector is still in it's infancy in Algeria. Some studies were undertaken by the C.R.A.U., (Centre de Recherches en Architecture et Urbanisme) in order to design a prototype village in South Algeria, (13)

1.7 Implications of World Energy Demand

1.7.1 There are several implications which may be drawn from Figures 1 and 2; as the world moves from an era which was fueled by cheap fossil-fuels, then in order to meet the growing energy demand certain technologies will become of key importance:

1) Improved utilisation and energy conservation which will reduce the overall energy demand.

2) New coal production and energy conversion technologies, which will make marginal reserves increasingly viable, and improve the efficiency of conversion into energy, thus making less fuel go further. This also presupposes that coal exploitation will be made less ecologically damaging; and

3) Nuclear powered electricity generation, which will attenuate the demand for fossil-fuels. Again, this presupposes that the ecological problems of long-lived fission products can be overcome, and that the future political climate will support these technologies' development.

For the longer term, technologies are needed to give the world greater independence from fossil-fuel based economies. These might include:

4) Fast breeder reactors, which can produce more plutonium fuel as an end product than that burnt.

5) Technologies for exploiting essentially inexhaustible energy resources, such as the power of the sun, wind, waves and tides.

6) Fussion reactors, which burn hydrogen, (the most plentiful substance in the universe), and produce less ecologically harmful end products than fission reactors. However, developments are still at a very early stage, and working reactors are not anticipated until the next century.

1.8 Energy Targeting

Due to the fact that both energy income and capital are finite, it is evident that the historical pattern of expotential growth of consumption cannot be sustained. Ultimately, the fossil-fuel reserves might become of greater value as chemical feed stock than as primary fuel, and mankind will necessarily have to live off of energy income.

With these long-term constraints in mind, it will be necessary to plan future energy policy by setting, and adhering to, reasonable targets for energy consumption.

Such targets must be based upon an estimate of the likely contribution which can be harvested from the energy income, having due regard not only to economic and environmental factors, but also to the amount of energy required to provide the hardware and facilities to do so; to the policy on the rate at which the remaining fuel reserves, (both fossil and nuclear), can responsibly be consumed; and to the estimate of the minimum energy requirement which will suffice to sustain the population at an acceptable level of comfort. Herein lie further difficulties of setting limits to such subjective qualities, such as nutrition, health, shelter, comfort, employment, education, mobility, leisure, culture, independence, safety and privacy.

Reaching concensus on an energy target will be a very different proposition than the current practice of making demand predictions based upon past trends, and will be very difficult to implement. The current attitude that well-being is proportional to energy consumption must be displaced. Certain steps, such as encouraging energy conservation in homes, offices and factories can be stimulated by financial incentives, and the resulting benefits would be apparent very rapidly. Conservation measures include more tenuous activities; over-packaging, unnecessary advertising, private transport ownership all lead to energy consumption.

The energy target must also make an allowance for the predicted contributions made by the energy income technologies, and their effective reduction on the energy capital requirement.

1.9 Summary

1.9.1 Throughout history architecture has incorporated a wide range of design solutions. Man has always sought to erect shelters that fulfill basic needs relating to survival.

These shelters provided an internal environment favourable to his physiological and psychological requirements.

The notion of buildings as shelters, ie. structures which intervene by acting as barriers and responsibe filters between the natural environment and the range of internal environments required for the pursuit of human activities, show us that climatic conditions used to be the most significant parameter considered, since the collection of fuel and the generation of energy was both painstaking and time-consuming.

1.9.2 In an alternative approach to the formulation of an energy policy, it must be recognised first of all that the earth's energy "capital" of fuel reserves is finite: secondly, that the earth's energy "income", also finite, is far greater than world energy demand, but is dispersed and of low grade. It is also inexhaustible and non-polluting. As an indication of the ratio of supply to demand, the current energy requirement of the UK is equal to the amount of solar energy incident upon 625 square miles of land surface.

1.9.3 There are two major impediments to the more widespread harnessing of solar energy: firstly, that the sun shines on any one point on the earth only intermittently, and secondly, the solar intensity received upon the earth's surface is variable, and relatively small in comparison to the solar intensity at the outer edge of the atmosphere. To overcome the first problem, some form of energy storage system is needed, and to overcome the second, dispersed energy needs to be concentrated perhaps by the use of large well designed surface area collectors.

1.10 Conclusion

The approach in this study is to provide the reader with a framework for consideration of strategies for the use of energy in buildings. A quantitative review of the information produced in the last few years has been carried out in order to identify some of the basic characteristics of energy when used for space-heating. It is noted that different research groups work independently of each other, and often with different aims. The result has been the publication of a large number of research papers, data lists and evaluations which have been summarised herein: this was done in order to embrace as many facets of the field as possible. However, these facets range widely; and consequently it has been necessary to concentrate upon those facets which appeared to be most significant. The information and references provided by this study will allow the reader to pursue points of particular interest in depth.

CHAPTER 2

CHAPTER 2

2.1 Introduction

Since solar gains are present in every exposed building, all buildings are passively solar heated to some extent. It is when solar energy contributes substantially to the heating requirements of a building that it is termed a 'solar building'.

The Egyptians were the first known civilisation to produce sun-dried bricks. Walls, twenty to thirty centimeters thick, constructed from these bricks could achieve a thermal time-lag of six to ten hours.

The Greeks were worshippers of the sun, and this devotion is exemplified in their architecture. Their public places, agora, were squares situated so that they would receive the sun's natural warmth. Private residences were arranged to so that each had a prominent southern exposure.

The Romans were located at much the same latitude as the Greeks, and were equally fascinated by the sun. Vitruvius, in his "Ten Books of Architecture" presented many energy conserving ideas relating to the siting, orientation and climatic response. The need for climatically responsive architecture is reflected in his statement:

> "One style of house seems appropriate to build in Egypt, another in Spain, a different in Rome and so on with lands and countries of other characteristics..."

The observations of Vitruvius have remained valid, though often ignored, throughout history.

Taking account of climate, particularly the sun, in the design of buildings is not a new idea, but it has only been in an era of cheap fuel that we have been able to ignore the benefits of designing with climate. Throughout the world, modern buildings resemble one another and seemingly ignore the sun when, for instance, all four facades are given the same fenestration treatments. It is not just design techniques which have changed, it also the advent of new building materials. In the Third World, particularly the Arab countries, traditional architectural styles and traditional building materials such as brick, abode, mud, plaster and grass thatch, all of which can be most effective in trapping and storing solar energy, have been replaced by western styles of building using concrete, glass and steel. The one exception to this new way of building is the mud brick used by Hasen Fathy in arches and vaults in his traditional Arabic architecture, (14).

During the last decades the increase in world energy demand has been dramatic, (as indicated in Chapter 1), and is particularly reflected in the growing demand for oil. An important part of the primary energy used in buildings, the bulk is used to provide low grade heat for space and water heating.

Proposals for reducing energy demand, such as conservation are aimed at reducing demand: on the supply side alternative energy sources may ultimately have a more enduring effect.

Indeed there are technical limitations to the contribution that these new sources can make. For instance, for solar energy the most obvious is the availability of solar radiation which varies widely over the world. Further technical limitations relate to the building itself, freedom from overshadowing, orientation and so on.

Passive systems that do not require high temperature thermal processes to function, are probably our most readily available and even our best longterm solution to many of todays energy problems.

Historically the main emphasis of research has been in the area of active space heating, although there is a gradual shift towards passive solar technology.

'Passive solar house' design is a popular term which has been used since 1975 to describe houses heated by the sun without the use of mechanical equipment.

Passive solar space heating has emerged as a promising option in recent years. The techniques employ the building fabric itself to collect, store and distribute solar energy. This is done by natural means: conduction, convection and radiation, whereas in active systems the processes are forced by technical means. In order to succeed in the implementation of passive processes in our buildings, we must re-evaluate all of our systems and draw from history, nature and technology at many different levels.

The first step towards this goal is to ascertain what forms of energy are being wasted. We need to know how much heat energy is required to do a job, and then use our knowledge to do that job in the most efficient and practical manner. Once the task has been singled out and objectively reviewed, we can proceed with creating the mechanisms for implementation.

Today the state-of-the-art passive systems are evolving rapidly. We are now aware that many tasks formerly requiring the combustion of fuels can be accomplished by much lower temperature means. Many researchers are exploring avenues of solving both short and long term problems through passive techniques. The simple reminder that enough usable solar energy falls on the surface of the earth to provide all of our energy requirements for as long as the sun shines, is enough to stimulate this long overdue research and development.

The term 'passive' is also used to describe certain natural cooling processes that allow heat to dissipate from buildings to the surrounding environment.

In both cases of heating and cooling, human comfort is the primary goal, although comfort cannot be objectively defined. It is a subjective quality, personal to individuals, varying with age, sex, state of health, clothing, environmental conditions and personal preference. Therefore comfort can only be related to levels of 'optimum' acceptability which have been statistically established by response tests for all types of subjects under varying environmental conditions of temperature and humidity (3)(15).

Passive designs attempt to manage natural heat flow through a building by the shape, composition, orientation, permeability and manupulation of the elements of construction. Whether a solar design is 'passive' or 'active', it's success is not necessarily related to the efficiency of the design, the ratio of 'energy in' as against the 'energy out', or the purity of the solar system, but rather the important questions of design quality is the energy return for investment of effectiveness. The issue is not whether solar energy will work technologically, but rather when and where it will become of real value economically. All over the world there is a wide range of climates, and detailed analysis is needed of the typical patterns of solar energy supply and energy demand in different areas before the true economic potential can be predicted.

2.2 The Basic Approach to Passive Solar Heating Systems

In every passive solar heating system three basic elements are necessary:

a) a solar collector,
b) a thermal mass for heat storage and absorption, and
c) a distribution system to and from storage.

Passive solar systems may be classified into three types, illustrated in Figure 2.1, "Passive Design Strategies", below.

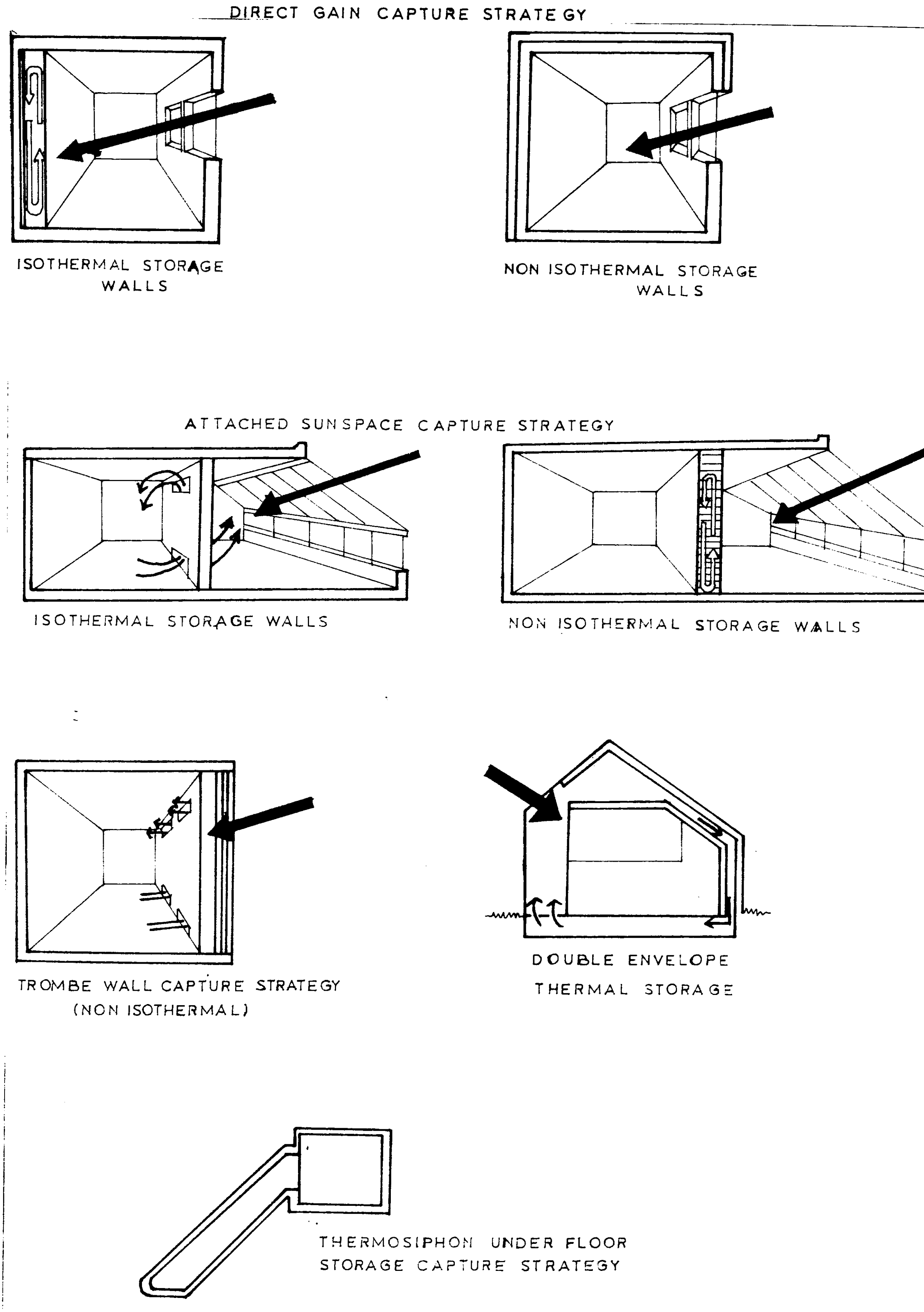


FIG. 2.1–PASSIVE DESIGN STRATEGIES–

These types are:-

2.2.1 Direct Gain Systems

This is one of the simplest implementations of passive heating. The important principal in this concept is that the heated space is a combined 'live-in' solar collector, storage and distribution system.

Typically, a direct gain system has a thermally massive structure for heat storage, and an expanse of south facing glazing. The thermal mass warms during periods of insolation by virtue of the greenhouse effect, and releases this heat back into the space when the space temperature drops below that of the thermal mass, due to the drop in external temperatures.

2.2.2 Indirect Gain Systems

Indirect systems separate the collector and heat store from the living space although they are still in physical contact.

Using natural convection, heat is circulated through the living space by pre-heating ventilating air entering the building through the collector.

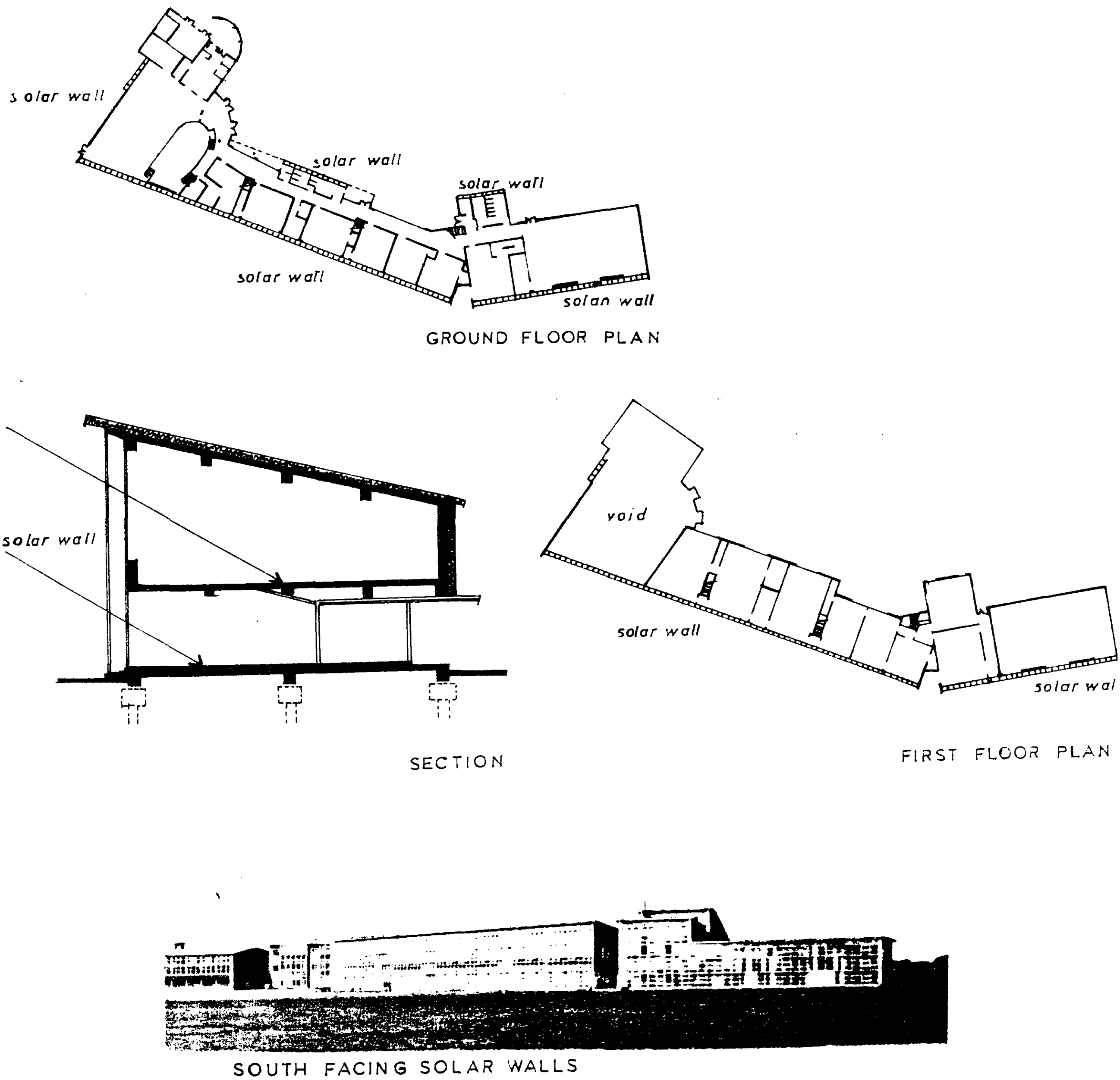
2.2.3 Isolated Gain Systems

Here the separation of living space and collector is complete.

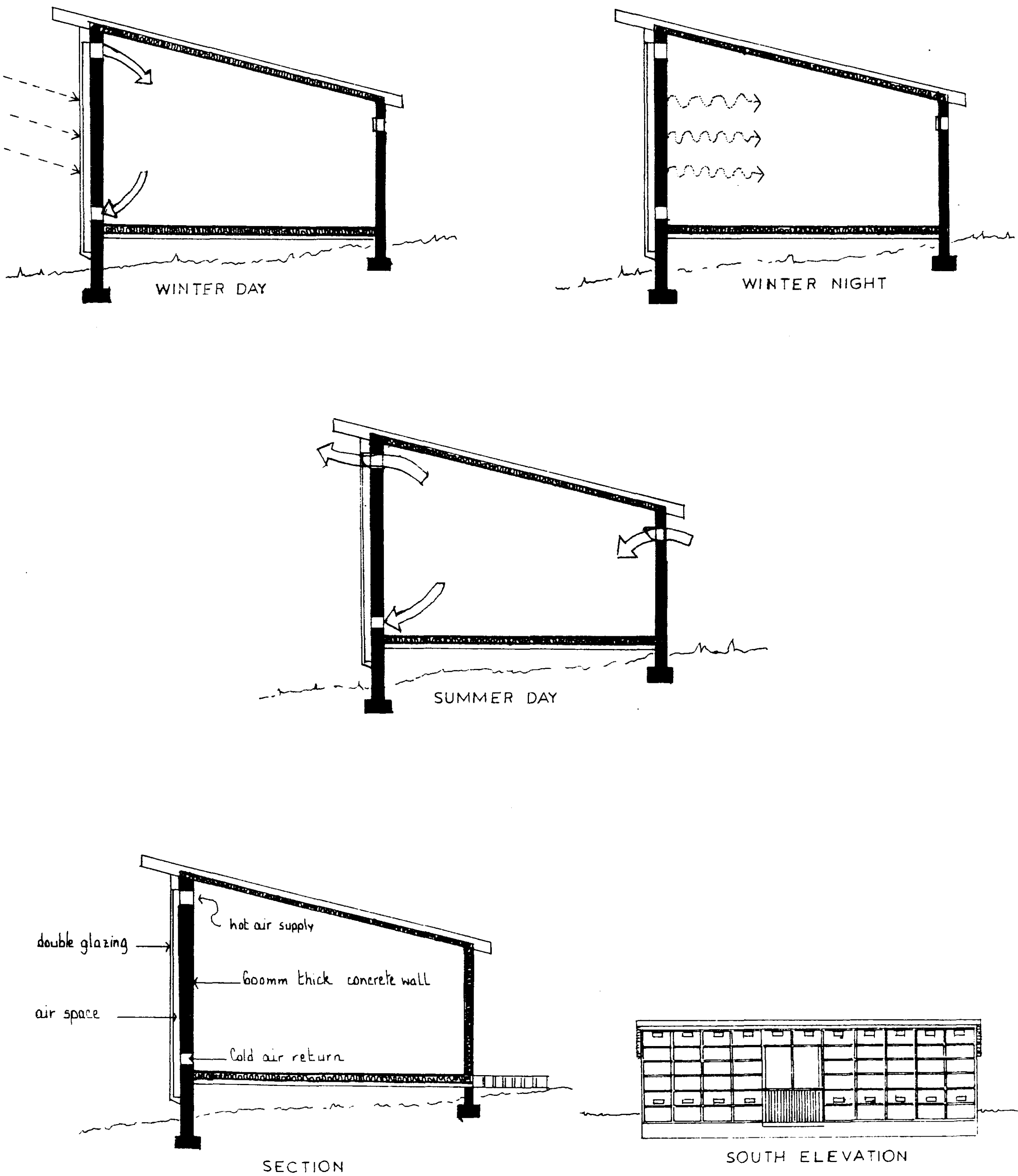
Again, radiant solare energy is collected by the greenhouse effect, and stored by a large thermal mass such as water or dense masonary. The heat is distributed when required by circulating air or water through a circuit linking heat exchangers in both the store and living spaces. Ideally the circulation is achieved by utilising natural convection currents set up within the system, but frequently mechanical aids are needed. Natural convection currents inherently involve a greater control time-lag than experienced with forced circulation.

An example of a direct gain system is St. George's School in Wallasey, Merseyside, built in the early 1960's, and the first solar heated building in the UK. It is a south glazed box, with a thermally massive concrete shell. This is illustrated schematically in Figure 3.2 below.

Fig. 2.2 Diagram of St. George's School.

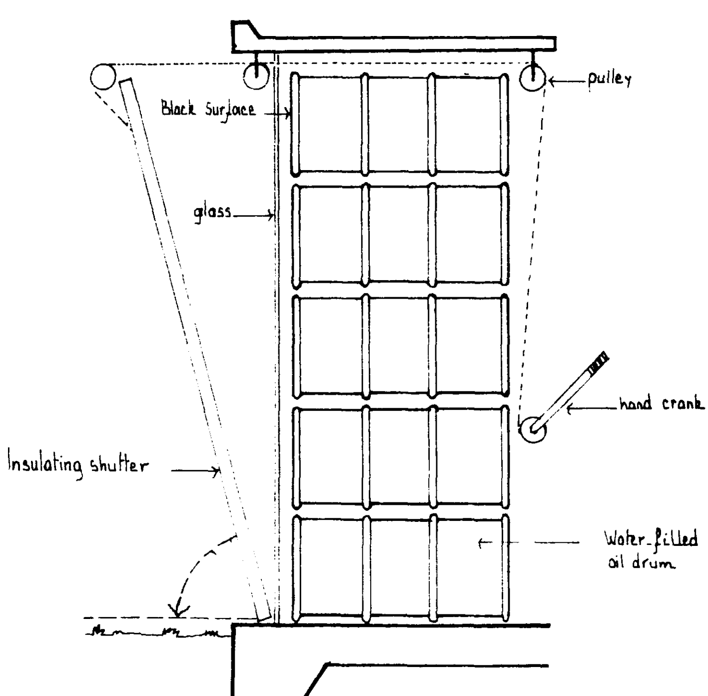


There are several variants of indirect systems, including storage walls, roof ponds and sun-spaces. The best example of mass walls, is the Trombe wall system as illustrated in Figure 2.3, which was used in the Trombe house, Odiello, France in the mid 1960's.



An example of a mass wall, but using the thermal capacity of water rather than masonary, is the Steve Baer residence in Corrals, New Mexico, USA, illustrated in Figure 2.4.

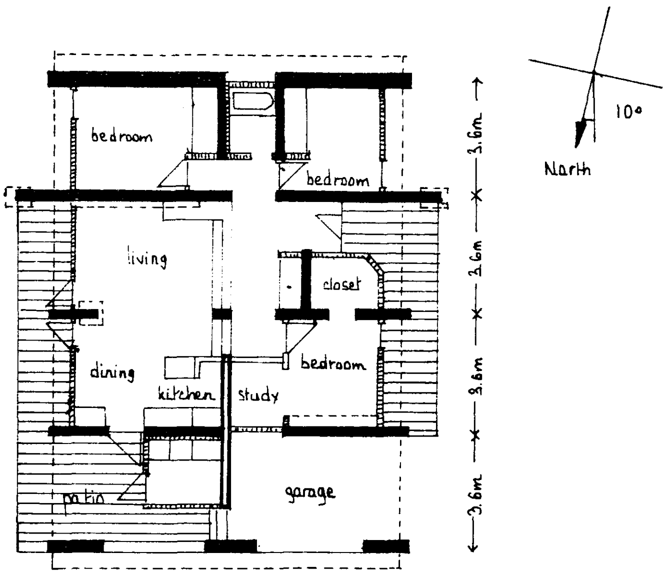
Fig. 2.4



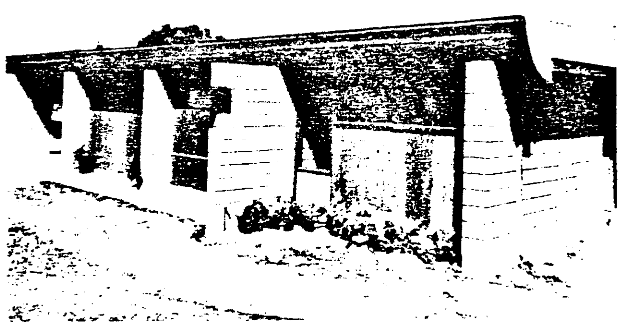
SECTION THROUGH COLLECTION WALL

One of the earliest examples of a roof pond may be seen in an experimental building in Atascaolero, California, USA, as illustrated in Figure 2 .5.

Fig. 2.5

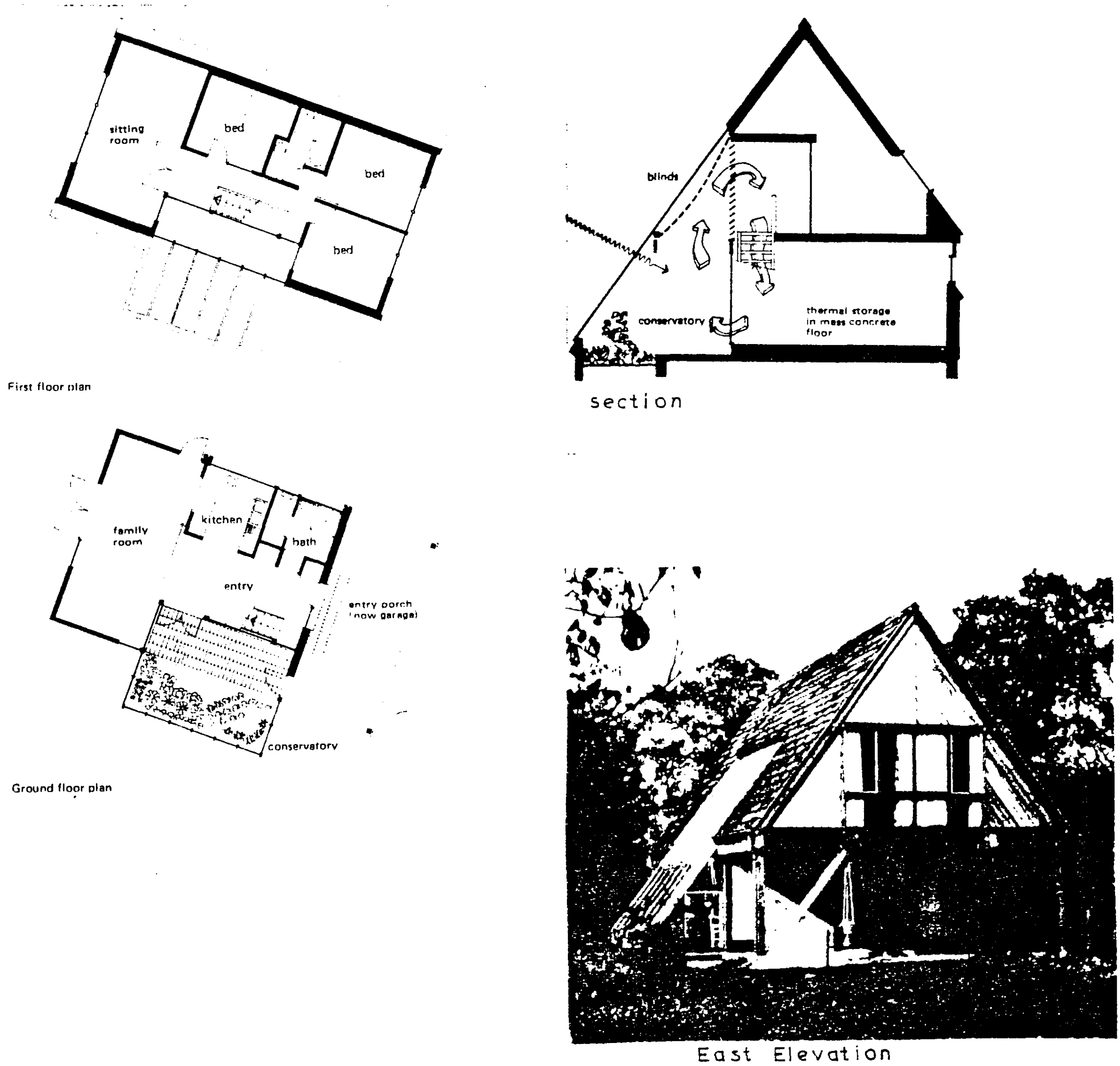


- THE ATASCADERO 'SKYTHERM' HOUSE - PLAN -



In concept, an attached greenhouse is a combination of direct and indirect systems. Indeed, many of the systems are a combination of all three concepts. The glazed space maintains a higher temperature than the external condition, due to the greenhouse effect, and thereby attenuates the conduction heat losses through the adjacent fabric. Additionally, there is a reservoir of warm air which may be ducted into the living space and thus reduce the required heating load. Such a scheme is depicted in Figure 2.6 below.

Fig. 2.6 The Delta House-England-1974



2. 3 Simulation Models

2. 3.1 The Problem

To date, architects and builders have made little use of the information available concerning passive systems. The interest in solar buildings has waned because modelling the systems is too technical, cumbersome and speculative.

To be of use, models must operate on the data available at each particular stage of the design process, and lead to results which suggest the better tactical decisions. The degree of accuracy the designer can expect will relate to the fullness of the description which he can offer to the model.

A number of energy design processes have evolved, and have been accepted as professional standards. Since most of these processes involve repetative calculation procedures, inevitably, accurate thermal models have arisen in conjunction with computers.

2.3.2 The Assessments

There are several ways in which the success, or likely performance of a particular solar design may be assessed. The most expensive way, and the least flexible, involves the construction of a full-scale prototype for each design, and monitoring their performance in use. Less expensive would be the use of scale models. This idea has in fact led to the use of 'test-cells'; the Los Alamos, in the USA, and the Liege in Belgium. The basis for selecting the cell dimensions, glazing ratios and other thermal properties of these models is not quite clear, (16).

A third method of assessment would involve 'perfect' analogue or digital simulation models. Such a perfect model would be able to handle changes of climate, location, occupancy and design. Ideally it would interact with the designer. It should be capable of rapid response to 'what if?' questions. Prediction of probable performance will remain difficult. However, increasing use is likely to be made by computer simulation studies to predict performance of such complex results of actual field trials.

Needless to say, such a model does not exist. If however, a reasonably good model existed, it would be enormously useful to the design-research community of practising design teams.

2.4 Dynamic Thermal Models

A dynamic model differs from a 'static' in that it accounts for the time delay in the transmission of heat pulses by virtue of the thermal capacitance of the building's structure. The situation faced by the modeller or mathematician is further complicated by the possibility that some of the parameters of the system will change unpredictably in time, either through direct physical effects such as variation in cloud cover or moisture content of the fabric, or through the actions of the occupants of the building, such as altering the ventilation rates by the opening of doors and windows.

Using the analogy of electrical circuitry, the thermal connections of a building are a complex network of thermal resistances and capacitances linked by convective, conductive and radiative pathways. Consequently, direct electrical analogue networks can be created to model 'fixed' networks.

2.4.1 Design Studies

The problem of making dynamic thermal models accessible to non-specialist building designers has already been mentioned.

There are a number of approaches to this problem which reflect individual attitudes to the role of computation in design. At the extremes, one of these has been to develop computer aids which include sophisticated input and output procedures, so that complex finite element or finite difference analyses can be undertaken. Here, the building is described as an assembly of 'nodes' each node having thermal capacitance and connections to other nodes. (This is in fact a 'digital' situation of the electrical analogue process described above). Energy flows are generated by the temperature differences between the internal and external environments, and heat flows may be calculated between nodes as a product of the temperature difference acting across that node as modified by it's thermal conductance. Figure 3.7 below shows a network for a 'domestic' building.

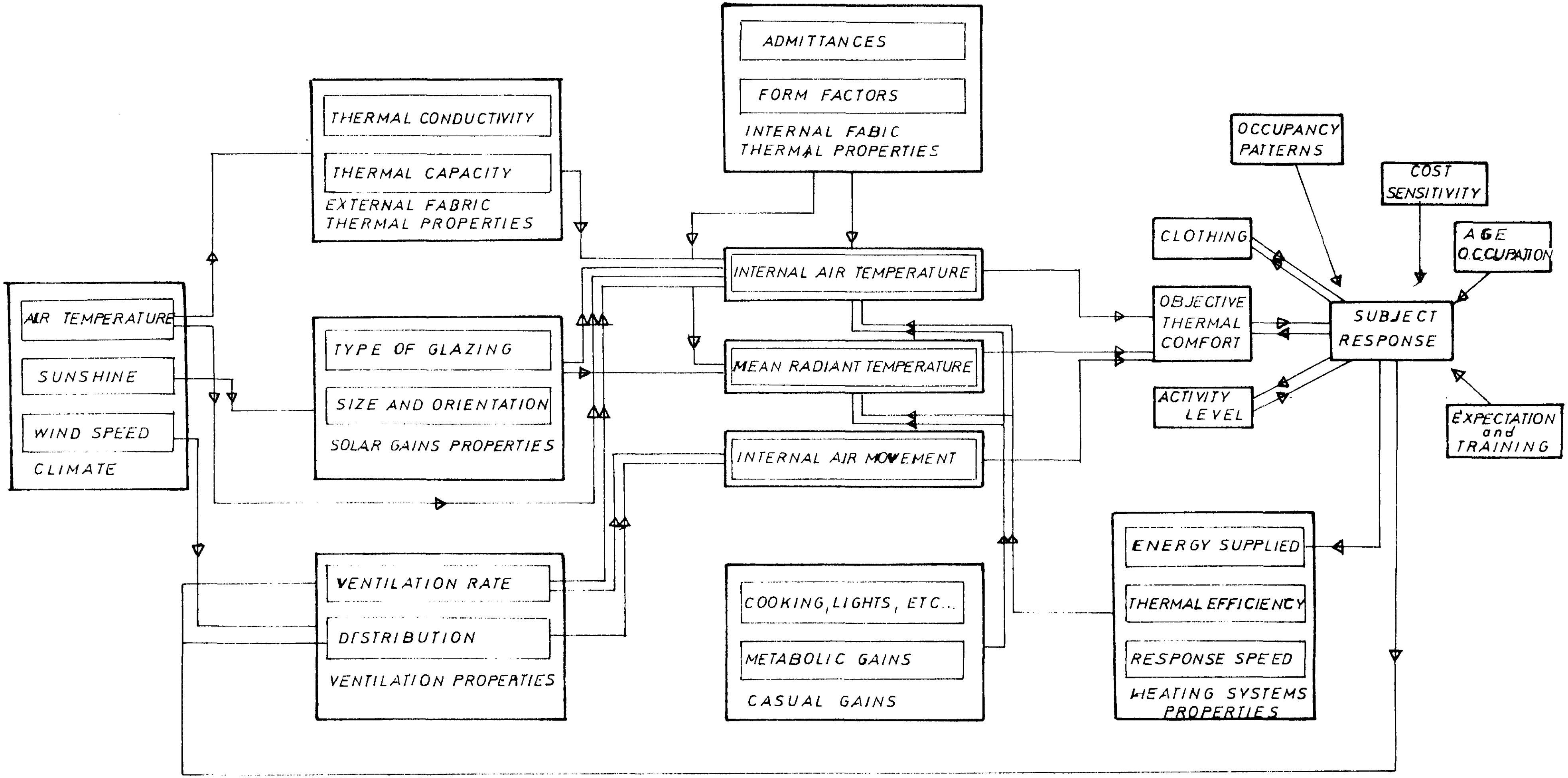


FIG-2.1 MODEL FOR A DOMESTIC BUILDING

An alternative approach at the other end of the spectrum, seeks to exploit the observed inter-relationships between monitored parameters in real buildings. Here, those parameters having the most significant correlation with the energy consumption, and/or heat flux, are identified. Rules of thumb, and design guides, are then prepared through the tabulation of the relevant variables. Such systems may themselves be coded to be run on microcomputers with far greater economy than is possible with finite element analysis.

However, there is a body of opinion that suggests that the difficulties in energy consumption prediction compared to the benefits which such predictions yield, does not warrant any further investment of resources by the designers until such time as the situation makes such investment viable. This attitude places great reliance upon the traditional way in which architects perceive the properties of buildings and are able to manipulate their designs to advantage.

2.4.2 Aids and Physical Models

Design aids vary widely in objectives and content; from purely introductory descriptions in publications and other media, through rules of thumb for use at the earlier design stages to detailed prognostications, simplified design methods which may, provide a basis for finalising the buildings' design, and finally detailed analysis, (almost invariably computer based), of the overall thermal performance.

2.4.3 An Analytical Method

Of the several models which do exist, selecting the most appropriate is difficult. Questions to be answered include:

- are the program machine transportable?
- what combination of passive features does the model include ?
- how intelligeable is the system, i.e. documentation, sequence of procedure etc?
- how apparent are the assumptions upon which the system is based ?
- how useable and informative is the output?
- how accurate is it ?
- is it interactive ?

2.5 Conclusion

The aim of energy design is to maintain an internal environment within the boundaries of comfort conditions, with the least aid of heat generating equipment using fossil-fuels. One re-emergent strategy is to fully utilise solar energy for passive environmental control.

A first attempt was to be made by examining the effects of design variables on the internal temperature or heating load, by designing or specifying a 'test-rig' which could then be modelled.

A similar study undertaken by Cherouti concluded:

> "The design of a test cell that would in turn be heated by different solar systems in different climates and the analysis of different performances would have been the primary shaft for a map that would relate each of its climatic regions to an optimum passive solar system.
>
> The attempt to identifying an optimum passive solar system to a particular climate will raise three main problems.

i) The problem of boundaries
ii) The problem of a representative cell
iii) The problem of comfort and performance definition " (30)

Prior to, and independent of Cherouti's thesis, the problem of a "representative test cell" had been identified as an area for further research and investigation. This conclusion was reached by the writer as the result of :

a) Analysing the use of energy in buildings, (See Chapter 1)
b) Consideration of the simulation models (See Chapter 2)
c) The paucity of the (then) published results of comparative testing of the various test cells by the various simulation models, (See Appendix 3, Section 3.5)

The principle was to take a fundemental mathematical model, METHOD 5000, keeping all but one variable fixed in order to study the performance curves thus predicted. METHOD 5000 was selected because :

a) it was considered to have good documentation available at the time, and
b) the French Building Regulations are similar to those in force in Algeria.

One problem which became evident at an advanced stage in the research project was the paucity of Algerian climate data, and secondly, the surprising discovery that there is no documentation supporting the creation of climate files for use in METHOD 5000.

Whilst various parameters can be 'optimised' by consideration of steady-state principles, it does not follow that they remain optimal when considered dynamically.

CHAPTER 3. DEMONSTRATION - CELL BASED ON 'SOLDAY' MODEL.

CHAPTER 3

3.1 Introduction

3.1 Modelling Energy Transfer in Buildings.

Several decades ago, basic data describing patterns of heat gain and loss in buildings were difficult to acquire; few architects had advanced innovative designs, and the financial information for comparing various options was unavailable. Today the situation has changed markedly.

The common goal behind these diverse efforts is the reduction of the equipment costs, in use as well as in acquisition, and simultaneously a decreased reliance upon fossil-fuels.

The basic principles being applied are quite straightforward, by using materials to slow down the rate at which internal conditions react to the variations in those external, and by admitting as much sunlight as possible during the heating season, the capacity of the necessary heating plant can be reduced, and in some circumstances eliminated entirely.

Different designs are of course needed for different types of buildings, climates and economic levels of operation. Nevertheless, in most cases the underlying principles are similar. The walls, roofs and windows of conventional buildings transfer a great deal of heat energy during periods of extreme temperature difference between inside and outside, due to the processes of conduction, convection and radiation.

As research progressed it became evident that retarding energy losses through the fabric was perhaps more beneficial than admitting sunlight through the glazing in order to minimise energy demand.

For a better understanding of the thermal behaviour of buildings, the thermal transfer equations used to compute the heating load of a buildin are explained in Appendix 1.

Currently, the most widely applied ways to consider the thermal design of buildings are based upon the concept of steady-state conditions in which the heat entering a building is totally balanced by the heat loss and the storage of heat in the fabric is totally ignored. Concepts such as the 'U-Value' and the 'minimum rate of heat loss' are based upon this approach.

Unfortunately, such steady-state concepts are unable to answer a number of questions that are being asked in the quest for energy conservation, where there is a need to improve our knowledge and understanding of the way in which buildings respond to fluctuating external conditions, and intermittent heat supply.

Although there are a number of ways in which the limitations of steady-state heat analysis are by-passed, for example, by the introduction of correction factors, many of these correction factors are based upon empirical studies.

Many of the factors depend upon the designer making erude classifications. For example, to obtain a factor for 'time-lag' of a heat pulse through a building fabric, the designer has to decide whether the structures density is greater than or less than 1500 kgl m^3 (17)

Such a coarse distinction introduced error. Moreover, the errors are compounded when correction factors are multiplied together.

3.2 Processes Considered in a Simulation

The importance of accurately assessing building performance, coupled with the increasing availability of powerful but low-cost computing power has resulted in much research in the field of computer-based energy simulation modelling.

The computational power of computers now means that dynamic performance can be modelled, whereas in the past designers were limited to very simplistic steady-state models. Any advanced system must be capable of handling accurately and dynamically the following processes:

i) The transient conduction of heat through the enclosure envelope and therefore the associated lag and thermal storage effects.

ii) The casual gains from occupants, lights, processing equipment etc, and the relative split of these gains into radiant and convection parts which will dictate how they are developed in time by the system.

iii) Infiltration, natural and controlled ventilation and inter-zone air movement.

iv) The effects of shortwave solar-radiation impinging on exposed external and internal surface

v) The longwave radiation exchange between internal surfaces

vi) The longwave radiation exchange between exposed external surfaces and the sky vault and the surroundings.

vii) The shading of external surfaces as caused by surrounding buildings as well as a variety of facade obstruction.

viii) The mapping of moving insulation patches from windows to internal receiving surfaces.

xi) The essential link between controller location and type plant characteristics and inter-action points, and properties of the building system.

x) Effect of moisture.

Many modelling systems exist which purport to address these processes at different levels of accuracy (Appendix 3: Simulations models).

3.3 'SOLDAY' Model

From the literature survey it has become evident that there is still a serious lack of useful practical, simple information as far as the estimation of cooling and heating requirements of unconditional buildings with structural elements under periodically fluctuating heat flow is concerned.

The aim of the designers' endeavour is to keep the inner environment within the comfort zone with the least aid of mechanical apparatus and with minimum recourse to fossil-fuels.

One method which can achieve such a goal is the environment control by natural means ie passive environment control.

The first attempt to reach such a goal was by examining the effects of design variables on the internal temperature/heating load. Then by designing or specififying a test rig and applying theoretical and experimental studies using computer calculations, the thermal principles were considered in detail, so that they could be taken into account in the overall design process.

The variables considered included the building shape, the degree of insulation, the size and orientation of windows, the thermal capacity and the control of ventilation.

A considerable amount of time was spent studying a number of computer appraisal methods for assessing energy demand. This study is included in Appendix 3.

Despite the desirability of obtaining such simulation programs, those available were limited by the computer hardware within this institution. This includes a Hewlett-Packard 9604 desk top micro-computer, BBC - B micro-computers, and a number of Apple micro-computers. This immediately ruled out the use of the large dynamic simulation models, such as ESP.

As a consequence of the review of computer models, it was initially decided that Method 5000 would be adopted.

The main justifications for this decision are:

a) It would run on an available computer (Apple)
b) It is recognised by the EEC as one of three approved appraisal methods.
c) It is orientated towards passive solar features
d) It has a monthly 'recuperation factor' which provides a useful indication of overheating risk
e) It takes into account overshadowing and site obstruction.
f) The manual version has already been used in Algeria.

Method 5000 was also recognised to have several disadvantages:

a) It is a computerised version of a manual method
b) It is not a 'dynamic' program but is a steady-state model which includes admittance factors
c) It has a 'coarse' sampling period, i.e. it uses monthly mean climate data
d) It is very lengthy to users.

Considerable delay was experienced in the acquisition of the program and after it was installed it was discovered that the climate data could not be modified through normal editing procedures. Although the program authors were contacted, it did not seem likely that the program could be implemented within the time scale allowed.

In order to overcome this delay, a crude energy appraisal program was written by the Research Supervisor, a listing of which is included below, Fig 3.1. This program was implemented on a BBC - B micro-computer.

```
10 REM guesstimated climate data.
20 REM Line 1: Air Temp.
30 REM Line 2: Horizontal radiation
40 REM Line 3: South Radiation
50 REM Line 4: West Radiation
60 REM Line 5: East Radiation
80 DATA 17.5,18,18,18,1[illegible].5,17,15.5,14,11.5,9.5,8,7,5,4,3,3,3.5,4.5,6.5,9,12,14,16,17,17.5,18,18,18,17.5,17,15.5,14,11.5,9.5,8,7
85 DATA 1050,1000,850,700,500,300,0,0,0,0,0,0,0,0,0,0,0,0,300,500,700,850,1000,1050,1050,1000,850,700,500,300,0,0,0,0,0,0
90 DATA 210,305,300,270,180,140,0,0,0,0,0,0,0,0,0,0,0,0,140,180,270,300,305,310,310,305,300,270,180,140,0,0,0,0,0,0
100 DATA 0,400,460,500,480,400,250,130,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,400,460,500,480,400,250,130,0,0,0,0,0
110 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,40,90,130,300,400,460,490,450,0,0,0,0,0,0,0,0,0,0,0
120 DIM [illegible],AtB,[illegible]
130 FOR I=1 TO 4
140 FOR J=1 TO 35
150 READ [illegible]
160 NEXT J: NEXT I
170 REM Construction Data
180 [illegible]
185 [illegible] "[illegible]GW," GR= "[illegible]GR
190 [illegible] 0.35:UG=5.7
195 PRINT "UH= "[illegible]," US= "[illegible]," UE= "[illegible]UE," UW= "[illegible]UW," UR= "[illegible]UR," UG= "[illegible]UG
200 [illegible]0.4:DEW=0.4:DER=0.4
204 [illegible]
205 PRINT "DEH= "[illegible]DEH," DES= "[illegible]DES," DEE= "[illegible]DEE," DEW= "[illegible]DEW," DER= "[illegible]DER
206 PRINT "FHH= "[illegible]FHH," FHS= "[illegible]FHS," FHE= "[illegible]FHE," FHW= "[illegible]FHW," FHR= "[illegible]FHR
210 AH=0.4:AS=0.4:AE=0.4:AW=0.4:AR=0.[illegible]:EV=0:EH=0
215 PRINT "AH= "[illegible]AH," AS= "[illegible]AS," AE= "[illegible]AE," AW= "[illegible]AW," AR= "[illegible]AR
216 PRINT "EV= "[illegible]EV," EH= "[illegible]EH
220 INPUT "H=",X,"D=",[illegible],"H=",H
230 WAH=H*X*(1-GH):GAH=H*X*GH
240 WAS=H*X*(1-GS):GAS=H*X*GS
250 WAE=H*X*(1-GE):GAE=H*X*GE
260 WAW=H*X*(1-GW):GAW=H*X*GW
270 [illegible]
280 REM Convention: All incoming energy is POSITIVE
290 [illegible]
300 REM START OF LOOP
310 FOR I=1 TO 35
320 GOSUB 470
330 IF I[illegible] GOSUB 620
340 IF I[illegible]24 GOSUB 560
350 IF I[illegible]24 GOSUB 670
[illegible]
[illegible] IF [illegible] GOTO [illegible]
[illegible]
380 [illegible]
390 [illegible]
400 IF [illegible] GOTO 415
410 [illegible]
415 [illegible]
420 FOR [illegible] TO [illegible]
430 [illegible]
435 NEXT [illegible]
440 [illegible]
445 IF [illegible] GOTO [illegible]
450 PRINT [illegible]
455 NEXT I
456 GOTO [illegible]
460 REM HORIZONTAL
470 [illegible]
480 IF [illegible] GOTO 510
490 [illegible]
500 [illegible]
510 [illegible]
520 RETURN
530 REM
540 REM SUBROUTINE EAST
550 [illegible]
560 IF [illegible] GOTO [illegible]
570 [illegible]
580 [illegible]
590 [illegible]
600 RETURN
610 REM
620 REM SUBROUTINE WEST
630 [illegible]
640 IF [illegible] GOTO 670
650 [illegible]
660 [illegible]
670 [illegible]
680 RETURN
[illegible] END
```

FIGURE 3.1 LISTING OF 'SOLDAY'

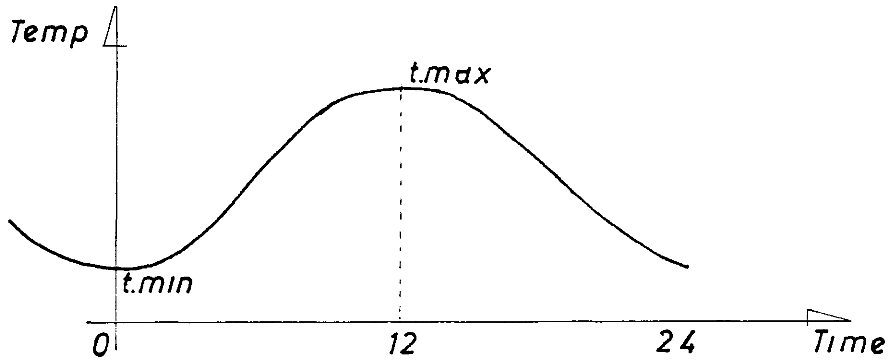
Nevertheless, the program is open to many major criticisms, and the results should be regarded as indicative of likely performance, rather than an objective assessment, and the figures produced have a correspondingly small level of confidence associated.

3.4 CRITICISMS OF SOLDAY

A finer analysis, however, brought up some contradictions to the already known rules.

Having made such remarks we went back to the content of the program.

3.4.1 The climate data is 'guesstimated'. External air temperatures were derived by producing a sinussidal wave function over 24 hours, through a maximum and minimum temperature, as illustrated in Figure 3.2



Significantly, although 'guesstimated' the climate data pertains to the U.K. and not to Algeria.

3.4.2 The Solar Gain through the opaque fabric is subject (in the program) to both a Decrement Factor and a time-lag. The conduction loss through the fabric is not. Consequently, the conduction losses from the building are instantaneous, whilst the solar pulse is decremented and delayed.

This is a serious source of error, and it results in a gross attenuation in the solar gain. This can be demonstrated by the observation that despite varying the time-lag and Decrement Factors of the cell walls (see Table 3.6) the graphs are not noticeably skewed, contrary to what could be expected.

3.4.3 The building geometry is limited to a simple rectangle, having a flat roof.

3.4.4 The radiation data written in to the program was derived from the publication 'Solar Gain' published by Pilkington Ltd, and is for Latitude 56 °N, for only one fixed orientation. More over, the data assumes clear sky conditions and a fixed ground reflected component of radiation applies.

3.4.5 The program attempts to make an allowance for the rise in internal air temperature due to solar gain and, when it occurs, fabric gain. However, the temperature swings are not responsive despite the fact that a twelve hour lead-in period is written into the program. It is noticeable in the output, that during the course of a simulation the internal temperature always rises.

It seems contradictory to attempt to include internal temperature swings in a steady-state model, particularly when no account is taken of thermal capacity.

4.5 OMISSIONS

A closer look at the listing also revealed some serious omissions.

3.5.1 Diffuse and Ground Reflection Radiation.

The first lines encode the data concerning the external air temperature, the solar intensities on a horizontal plan and the solar intensities on vertical plans.

However, the diffuse solar radiation falling on a vertical north facing plane are not included.

Hence the program is dealing with direct solar radiation only. The diffuse and ground reflection components to the north are omitted.

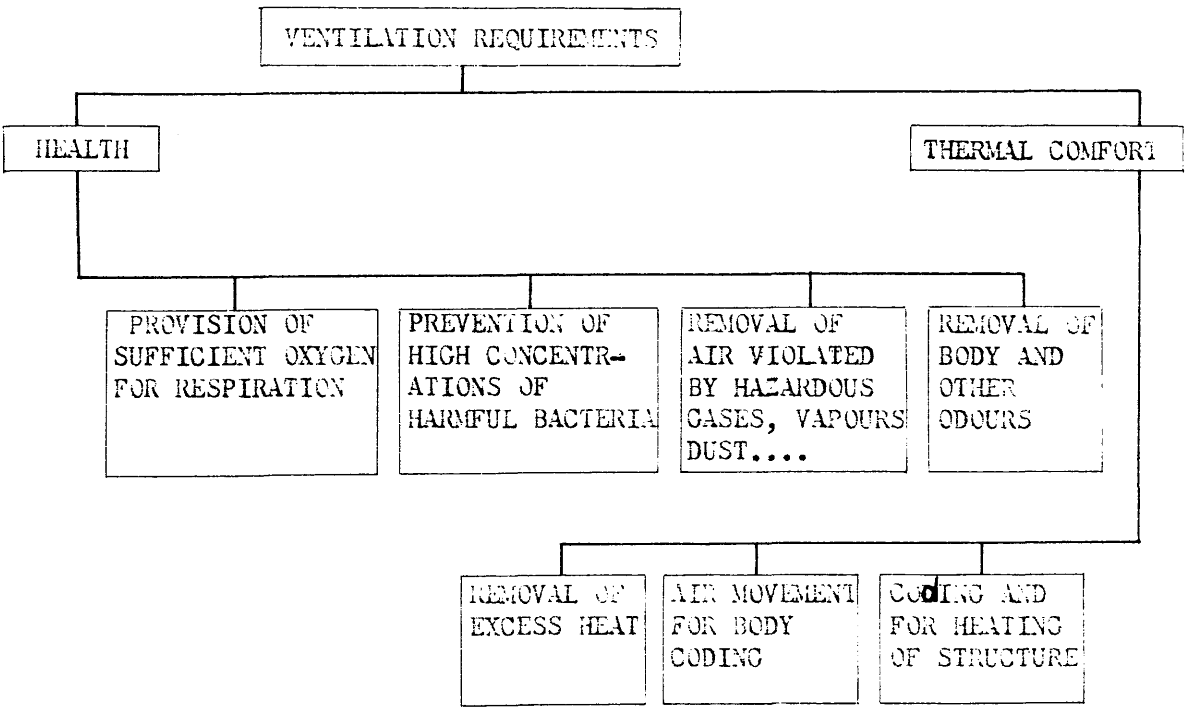
The diffuse component of radiation scattered from the sky itself can be approximately 10% of the direct radiation on a horizontal plan, and half of this value for a vertical surface. This is a crude approximation but a detailed expression is a function of atmospheric conditions and surroundings surface characteristics not easily modelled.

Radiation can also reach a surface from ground reflection. For a vertical surface, this can represent half the total horizontal incident radiation multiplied by a nominal reflection coefficient depending on the nature of the ground.

We may conclude at this stage that the diffuse and reflected radiation might have significant effects on the building design.

3.5.2 Ventilation Requirements.

Ventilation is necessary because of the considerations illustrated in Diagram 3.3 below.



3.3 SCHEMATIC ILLUSTRATION OF VENTILATION REQUIREMENTS.

It will be seen that a distinction is made between requirements for health and those for comfort. The former, which should be satisfied under all weather conditions, are generally referred to as requirements for permanent conditions whilst the latter, which are usually required during certain weather conditions only are referred to as requirements for occasional ventilation.

In the context of control it raises two issues, how the rate of natural ventilation can be controlled and secondly how the effect of the rate of natural ventilation on conditioning system control can be identified.

Vantilation this represents a real load on heating system and therefore also a 'disturbance' to the control system. Estimates of how that disturbance might be simulated in a control appraisal are at present mainly of a conjonctural nature due to the difficulty of modelling turbulent fluid flows in three dimensional space.

3.5.3 Light Requirements.

Since the level of daylight can vary over wide limits in a short space of time, it is not possible to recommend daylight levels on the same basis as the recommendations for levels of artificial light. Instead recommendations are made in terms of a minimum daylight factor ie. the ratio of the horizontal illumination measured at a main point in a room to the horizontal illumination from the whole sky, exclusing sunlight, measured simultaneously. The less natural light, the greater the requirement for artificial. Hence window sizing has a knock-on effect on energy demand through this consideration.

3.5.4 Effect of Moisture Content.

3.5.4.i) The thermal conductivity of a material is influenced by several factors including moisture content, temperature, density and porosity of the materials.

A part from the higher conductivity of water, as compared with air, temperature gradients across building materials in practice result in a redistribution of moisture and the heat carried by water and/or vapour migration will also contribute to an increase in heat transfer.

It is not possible to quote explicit data with respect to the effect of increased moisture content in the thermal conductivity of building materials. Although much has been published on this subject there is still a great deal of controversy amongst authorities as to the validity of the data. An accurate method for determining thermal conductivity whilst taking account of moisture conditions within the sample has still to be developed.

3.5.4 ii) Temperature.

The effect of temperature on the thermal conductivity of materials is small over the range of temperatures normally encountered in building. In general, however, thermal conductivity tends to increase with rising temperature. This is more pronounced in the case of light weight materials with a large proportion of air in the pores or voids.

3.5.4 iii) Density and Porosity.

As would be expected, thermal conductivity varies appreciably with density, which is very much a function of porosity. Generally, the less dense a material the more air is contained between the pores or particles, and the lower its thermal conductivity. The difference in thermal conductivity of materials with the same density is mostly due to the structural differences including the size, distribution and interconnection of pores or voids.

3.6 Design and Specifications of Demo-Cell.

3.6.0 In order to specify and design a'demonstration cell' it is necessary to start with some basic assumptions.

As previously noted earlier test cells bore little relation to an actual building. Consequently it can be argued that the cell now under consideration in this study, should be based upon a 'typical' house, primarily because housing represents a large proportion of a nations building stock, and secondly, because a house is of an order of magnitude which may be relatively easily constructed and monitored.

Since this demonstration cell is considered in the context of Algeria, it was logical to adopt the Algerian Building Regulations (Normes du Comedor) as a basis for the specification.

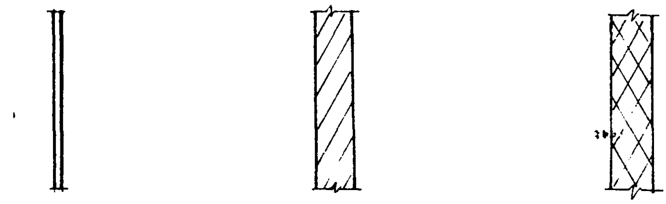
3.6.1 Initial Assumptions.

Initially the U-Value for the walls were fixed to 0.58 $W/m^{2o}C$.
The demonstration cell is a typical 50m2 (for two persons) building.
There is no glazing on the flat roof.

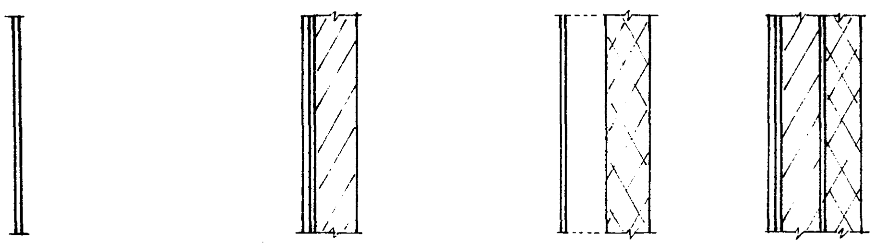
The ratio of glazing are 0.30 on the north wall, 0.5 on the south wall and 0.2 on the east wall and west walls.

3.6.2 To evaluate the range of the thermal transmittance of the building four cases were tested.
Having decided that, initially two additional panels might be placed over the glazing, then only four possibilities exist as shown in Figure 3.4 below.

The south wall is composed of three layers. The first one is entirely glass and the two other layers are lightweight concrete which can be moved, or placed in any combinations. Figures, 3.5.1, 3.5.2, 3.5.3, 3.5.4, overleaf.



Glass (g) Layer 1(a) Layer 2(b)



i) g ii) g + a iii) g + b iv) g+a+b

Figure 3.4: Possible combination of 2 panels and a fixed layer of glass.

3. The U-Value for the four possibilities were calculated and the phase-shift corresponding to each of them were taken from the IHVE Guide. Section A3 (17)

Table 3.1 : U. Values ($W/m^{2o}C$) and Phase-Shift (HRS)

Us	% Us	PHS	%
0.39 (1)	100	13	100
0.63 (2)	160.5	11	84.6
0.66 (3)	169.2	8	61.5
5.7 (4)	1461.	0	0

i.e. 60% change in U2 produces a - 16% change in PHS 2
a 10% change in U2 produces a - 38% change in PHS3
This is a non-linear relationship and appears quite arbitrary.

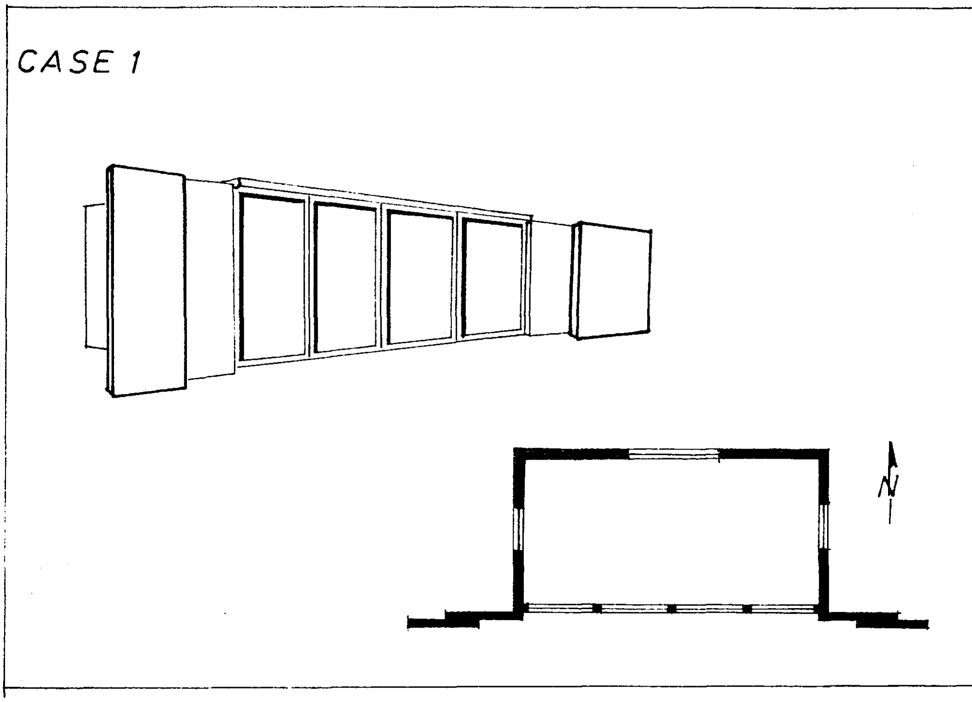


FIGURE. 3.5.1 SOUTH WALL ALL GLAZED

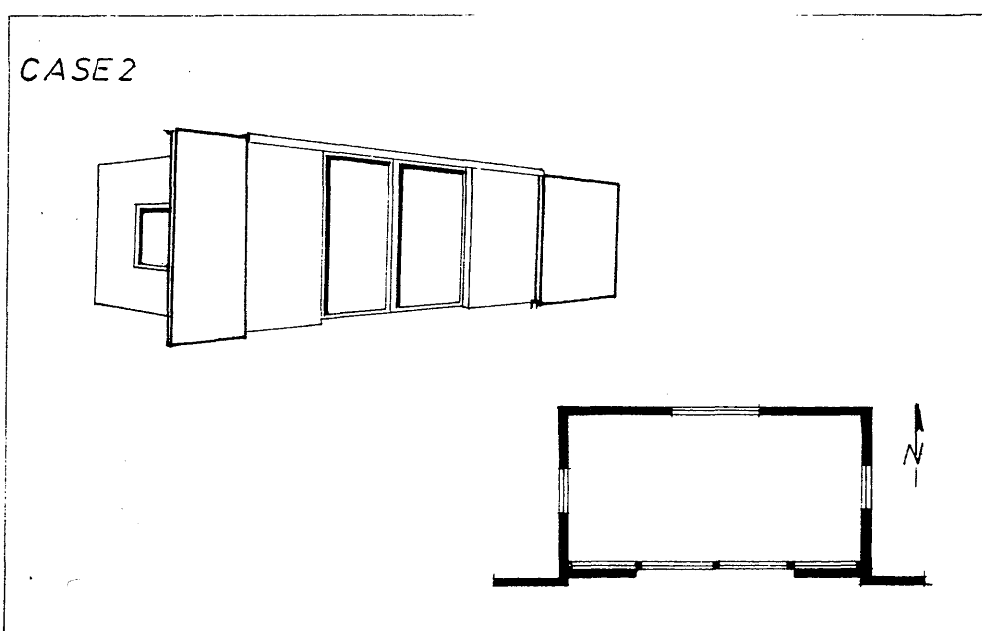


FIGURE. 3.5.2
SOUTH WALL MADE UP OF PANEL 1 AND LAYER OF GLASS

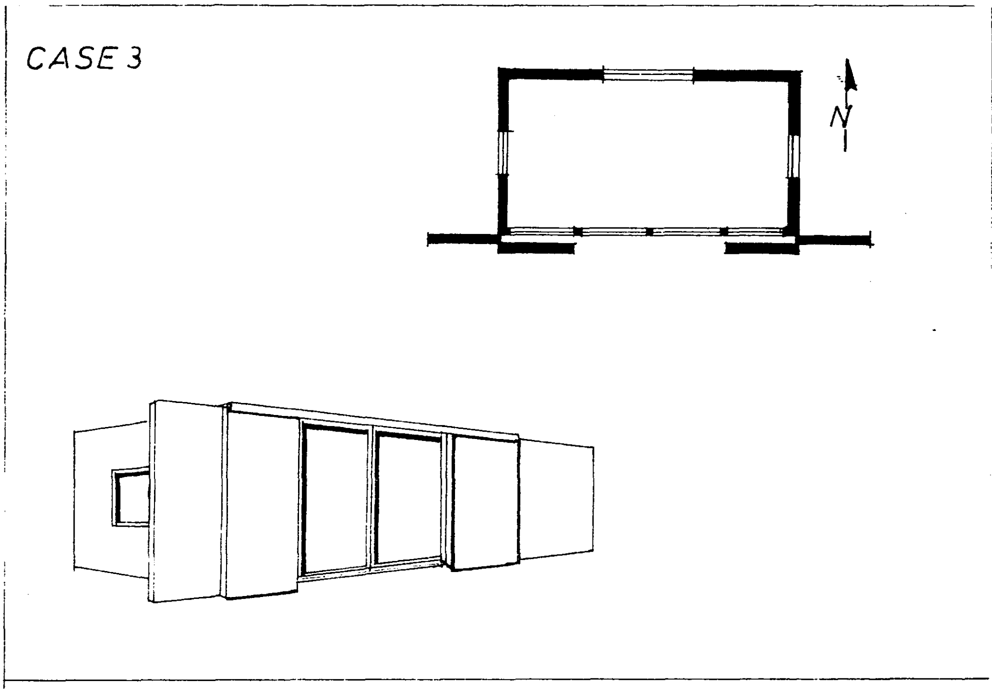


FIGURE. 3.5.3
SOUTH WALL MADE UP OF PANEL 2 AND LAYER OF GLASS

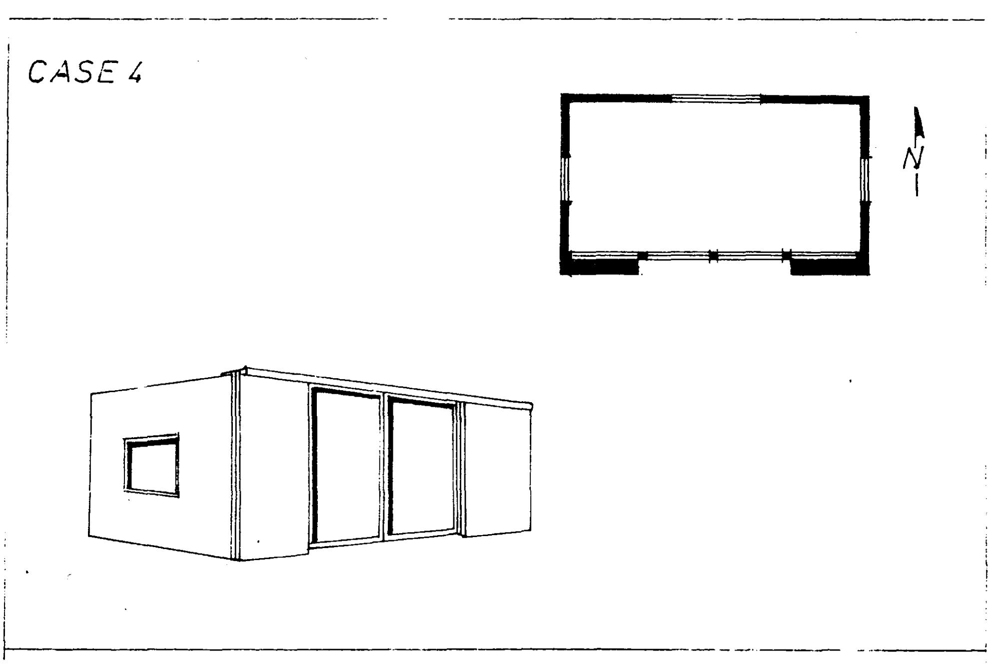


FIGURE. 3.5.4
SOUTH WALL MADE UP OF PANEL 1 AND 2 AND LAYER OF GLASS

The steady-state fabric heat loss equation assumes that the total flux is proportional to the product of the area, temperature difference and 'U-Value.

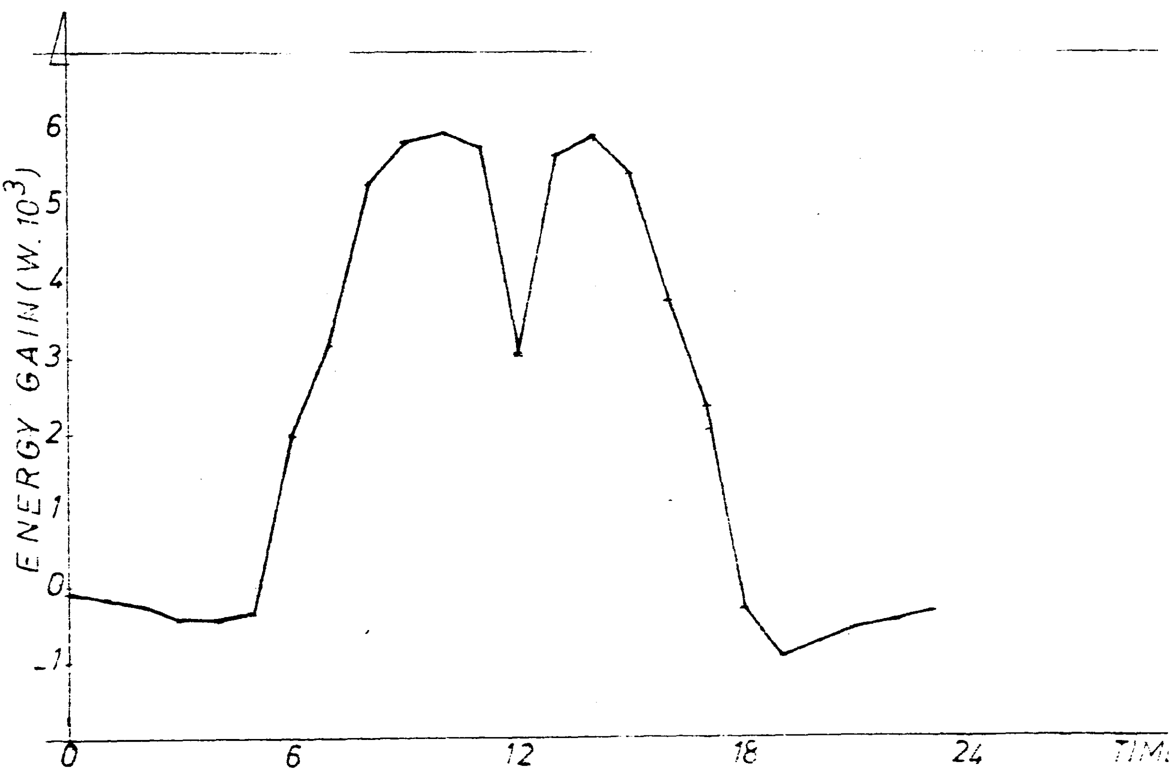
If both area and temperature are held constant then the heat flux will be in linear relation to the 'U'-value.

However, since the proposal is to amplify fluctuations, it was considered more valuable to modify the phase-shift values rather than the 'U'-values.

Thus, although the U-values of the two 'add-on' panels are very similar (0.63 and 0.66 $W/m^{2o}C$) the phase shift values for the panels have a greater variation (11 and 8 hrs respectively).

DIMENSIONS: L=10 m, D=5m, H=3m

```
>   .RUN
GN= 0.3       GS= 0.5       GE= 0.2       GW= 0.2       GR= 0
UN= 0.58      US= 0.39      UE= 0.58      UW= 0.58      UR= 0.35   UG= 5.7
DFN= 0.4      DFS= 0.1      DFE= 0.4      DFW= 0.4      DFR= 0.4
PHN= 8        PHS= 13       PHE= 8        PHW= 8        PHR= 4
AN= 0.4       AS= 0.4       AE= 0.4       AW= 0.4       AR= 0.75
EV= 0         EH= 0
L=?10
D=?5
H=?3
```

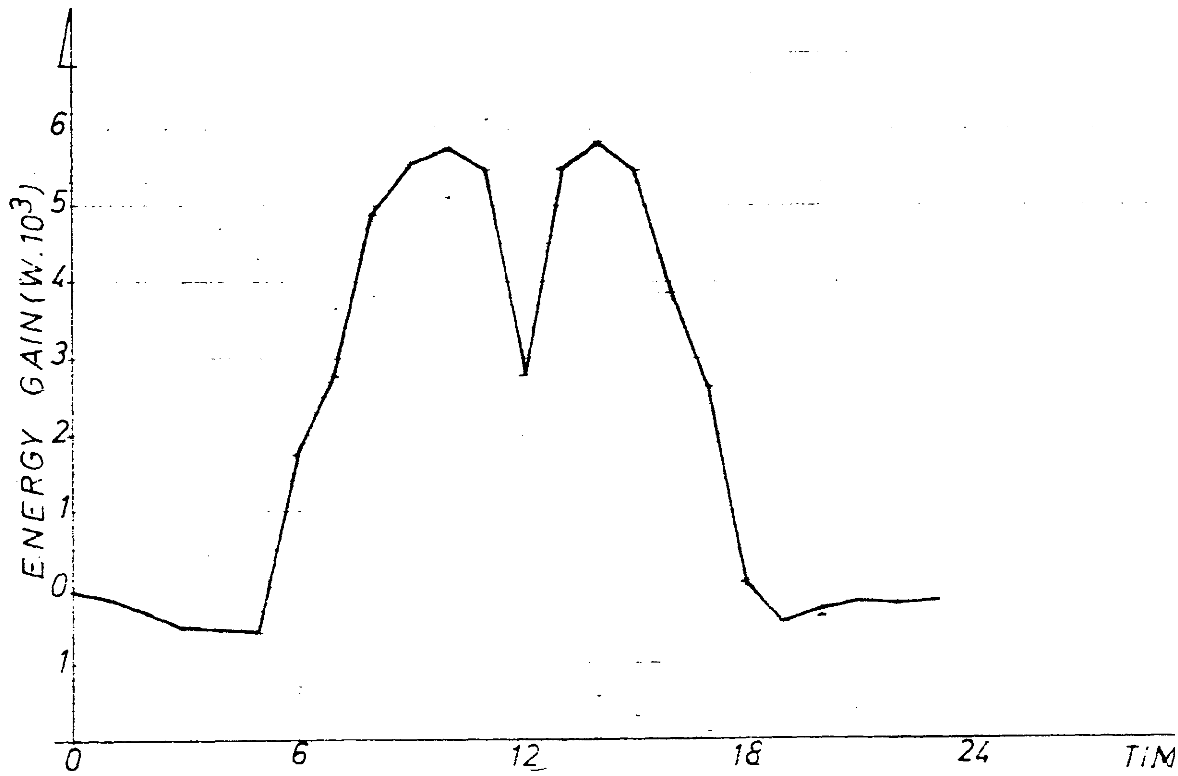


1	-0.100433349
2	-0.168376419
3	-0.289635566
4	-0.447517558
5	-0.458574469
6	-0.394249472
7	1.9958597[illegible]
8	3.[illegible]5085[illegible]96
9	5.2[illegible]14[illegible]45
10	5.842[illegible]52[illegible]
11	5.9[illegible]12969
12	5.744847[illegible]
13	3.0590797[illegible]
14	5.67[illegible]8838
15	5.9118033[illegible]
16	5.40348351
17	3.72663973
18	2.35586526
19	-0.322176558
20	-0.926824958
21	-0.729088314
22	-0 53[illegible]911694
23	-0 4624358[illegible]2
24	-0 3176480[illegible]

FIGURE .3.6.1 ENERGY BALANCE WITH Us=(

- DIMENSIONS: L=10m, D=5m, H=3m

```
>RUN
GN= 0.3      GS= 0.5      GE= 0.2      GW= 0.2      GR= 0
UN= 0.58     US= 0.63     UE= 0.58     UW= 0.58     UR= 0.35     UG= 5.7
DFN= 0.4     DFS= 0.1     DFE= 0.4     DFW= 0.4     DFR= 0.4
PHN= 8       PHS= 31      PHE= 8       PHW= 8       PHR= 4
AN= 0.4      AS= 0.4      AE= 0.4      AW= 0.4      AR= 0.75
EV= 0        EH= 0
L=?10
D=?5
H=?3
```

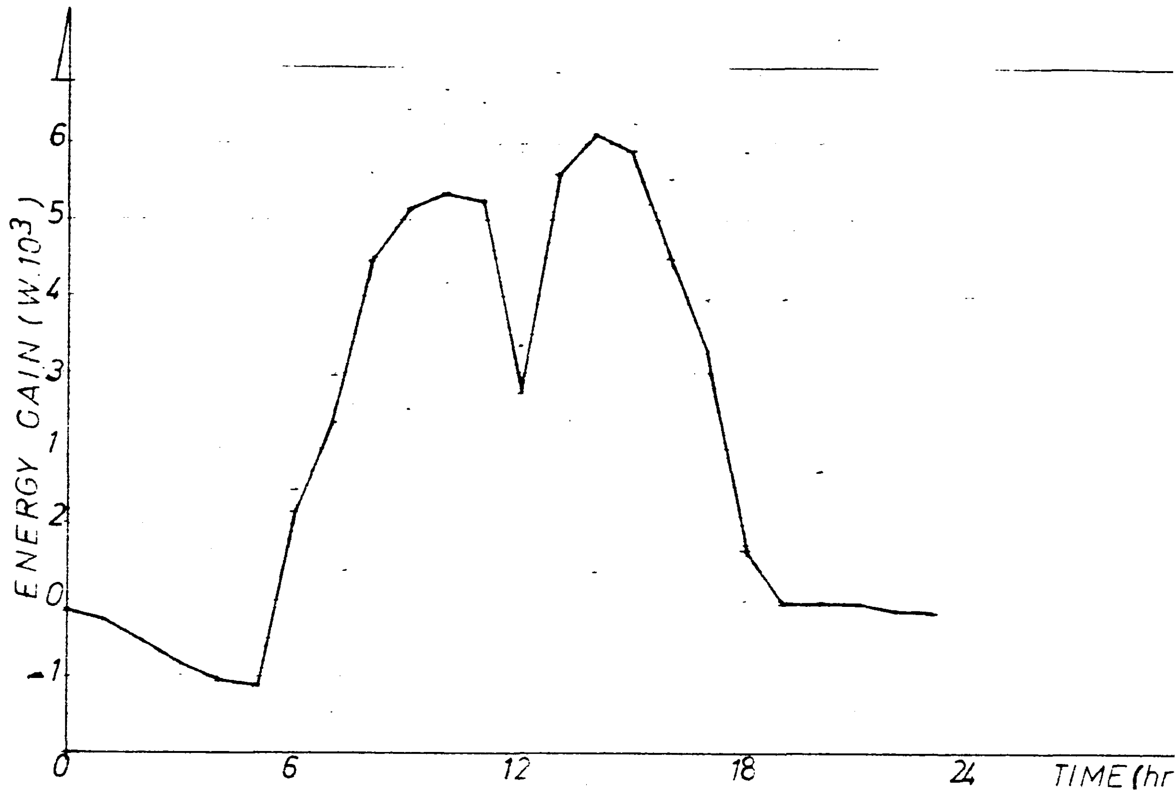



```
 1   -5.94857339E-2
 2   -0.143209382
 3    0.312565437
 4   -0.515492317
 5   -0.567741284
 6   -0.587680336
 7   1.7233679
 8   2.79955336
 9   4.89915865
10   5.53730409
11   5.74967761
12   5.48188931
13   2.79597129
14   5.49996925
15   5.82146968
16   5.4433573
17   3.85382366
18   2.61721082
19   6.55084738E-2
20   -0.457202423
21   -0.308042289
22   -0.200524783
23   -0.21672312
24   -0.200325165
```

FIGURE. 3.6.2 ENERGY BALANCE WITH Us= 0.63

DIMENSIONS: L=10m, D=5m, H=3m

```
>RUN
GN= 0.3      GS= 0.5      GE= 0.2      GW= 0.2      GR= 0
UN= 0.58     US= 0.68     UE= 0.58     UW= 0.58     UR= 0.35    UG= 5.7
DFN= 0.4     DFS= 0.3     DFE= 0.4     DFW= 0.4     DFR= 0.4
PHN= 8       PHS= 8       PHE= 8       PHW= 8       PHR= 4
AN= 0.4      AS= 0.4      AE= 0.4      AW= 0.4      AR= 0.75
EV= 0        EH= 0
L=?10
D=?5
H=?3
```

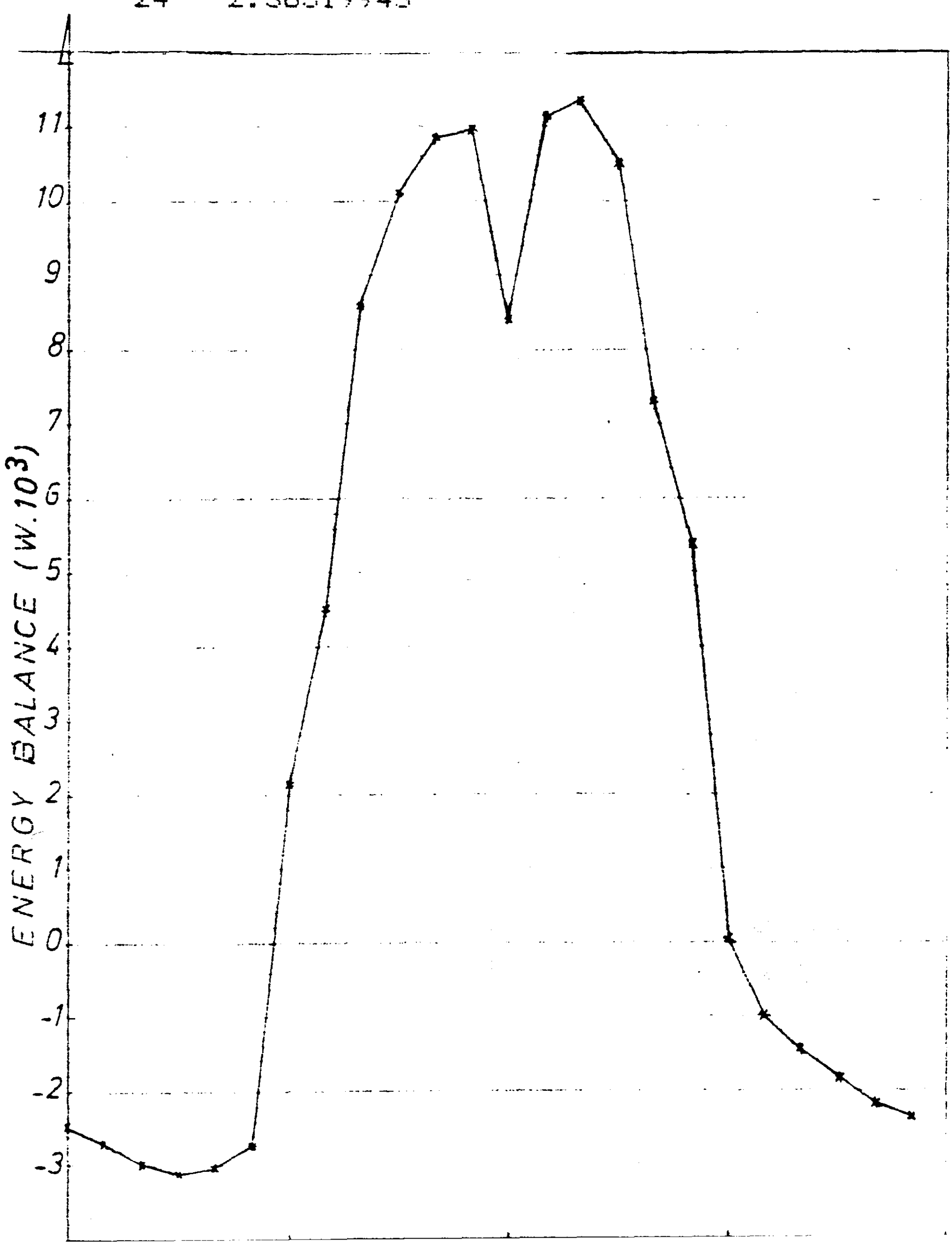



```
 1   -0.135630738
 2   -0.2641134
 3   -0.569749099
 4   -0.851264823
 5   -1.0722948
 6   -1.12889957-
 7   1.18169611
 8   2.38703202
 9   4.48285745
10   5.16274692
11   5.37374799
12   5.28015089
13   2.72670416
14   5.60782125
15   6.11661936
16   5.91643861
17   4.50644465
18   3.26448884
19   0.667352756
20   -3.19669797E-2
21   -1.57453395E-2
22   -2.95726932E-2
23   -0.13278606
24   -0.163112184
```

FIGURE. 3.6.3: ENERGY BALANCE WITH U_S=0.

```
>RUN
GN= 0.3        GS= 1          GE= 0.2        GW= 0.2        GR= 0
UN= 0.58       US= 5.7        UE= 0.58       UW= 0.58       UR= 0.35    UG= 5.7
DFN= 0.4       DFS= 0         DFE= 0.4       DFW= 0.4       DFR= 0.4
PHN= 8         PHS= 0         PHE= 8         PHW= 8.        PHR= 4
AN= 0.4        AS= 0.4        AE= 0.4        AW= 0.4        AR= 0.75
EV= 0          EH= 0
L=?10
D=?5
H=?3
          1    -2.4543401
          2    -2.69273781
          3    -3.01370734
          4    -3.14802023
          5    -3.04829158
          6    -2.74385303
          7    2.15424776
          8    4.47183322
          9    8.60653058
         10    10.1397723
         11    10.8237121
         12    10.9403568
         13    8.39121928
         14    11.1651367
         15    11.3743878
         16    10.4621272
         17    7.31147801
         18    5.18337916
         19    3.82420472E-2
         20    -1.00306209
         21    -1.43407709
         22    -1.84800294
         23    -2.19690969
         24    -2.38319943
```

FIGURE.3.6.4: ENERGY BALANCE WI



3.6.3 ANALYSIS OF THE OUTPUTS

3.6.3.1 Graph 3.6.1 -3.6.4 show that the solar gain peaks at 10 hrs and 14 hrs respectively remain constant in spite of the variations in phase shift (crit. section 2)

As predicted by the steady-state theory, the magnitude of the 10 hrs peak decreases with the U-Value i.e.

U	%	10 hrs Gain	%
0.39	100	5.97	100
0.63	160	5.75	96
0.69	170	5.37	90
5.7	1462	10.82	181.2

Table 3.2 MAGNITUDE OF HEAT FLUX OF THE 10 hrs PEAK

But this is a non-linear relationship. This is due to the consequence of the phase-shift.

However, an anomaly occurs with the 14 hrs peak

U	%	14 hrs Gain	%
0.34	100	5.91	100
0.63	160	5.82	98.5
0.69	170	6.11	103.3
5.7	1462	11.37	192.4

Table 3.3 MAGNITUDE OF HEAT FLUX OF THE 14 hrs PEAK

The peak-value seems to reach a minimum value, when the U-Value is between 0.39 and 0.66 W/M^{2} ^{o}C. This is due to the smaller values of PHS which means that the solar energy stored in the morning is adding to the solar gain in the early afternoon.

3.6.2.2 A significant feature is the drop in solar gain at mid-day. This is due to the cut-off of insulation through the east and west glazing at 12.00 hrs. However, the magnitude of the east and west solar gain appears to be a significant proportion of the total, perhaps as much as 50%. This does not seem plausible because of the small area of east and west glazing, in addition to their respective solar insolation values. This error might be attributable to a logical fault in the simulation program.

3.6.3.3 Despite the variation in the PHS value, the duration of the solar gain does not appear to vary between 5 hrs and 13 hrs.

3.6.3.4 The ratio of day-time gain to night-time fabric loss (as depicted by the area beneath the curve and the 'time' axis) is very large in all cases, varying by a factor of 10.

Due to the lack of demonstrated effect of the time lag(which would be expected to produce a noticeable skewness in the curves) an almost linear relationship might be anticipated between the magnitude of the heat flux and U-Value. This does not appear to be the case, and therefore the implication is that the simulation program is not producing the result it purported to do.

3.6.3.5 The same experiment is done with 5 different U-Values 0.35, 0.5, 0.65, 0.8 and 0.95 $W/M^{2\,o}C$. From the results, Figure 3.7.3 the graph of the maximum magnitude of the heat flux, and the minimum magnitude were drawn, Figure 3.7.1 and 3.7.2

As expected an almost linear relationship appears between the magnitude of heat flux and the U-Value.

```
1. GN= 0.3     GS= 0.5      GE= 0.2      GW= 0.2      GR= 0
   UN= 0.35    US= 0.35     UE= 0.35     UW= 0.35     UR= 0.35    UB= 5.7
   DFN= 0.3    DFS= 0.3     DFE= 0.3     DFW= 0.3     DFR= 0.4
   PHN= 7      PHS= 7       PHE= 7       PHW= 7       PHR= 4
   AN= 0.4     AS= 0.4      AE= 0.4      AW= 0.4      AR= 0.75
   EV= 0       EH= 0
   L=?10
   D=?5
   H=?3
               1   -0.255671325
               2   -0.54154676
               3   -0.808691063
               4   -1.23543418
               5   -1.34069951
               6   -1.29601546
               7   1.11175762
               8   2.63270652
               9   4.45715864
              10   5.14586811
              11   5.49590029
              12   5.46990443
              13   2.97766359
              14   5.98497725
              15   6.52899231
              16   6.3665189
              17   4.78990175
              18   3.52717596
              19   0.781720863
              20   4.20194639E-2
              21   1.25757432E-2
              22   -5.87915185E-2
              23   -0.166944686
              24   -0.263885933
```

```
2  GN= 0.3     GS= 0.5      GE= 0.2      GW= 0.2      GR= 0
   UN= 0.5     US= 0.5      UE= 0.5      UW= 0.5      UR= 0.35    UB= 5.7
   DFN= 0.3    DFS= 0.3     DFE= 0.3     DFW= 0.3     DFR= 0.4
   PHN= 7      PHS= 7       PHE= 7       PHW= 7       PHR= 4
   AN= 0.4     AS= 0.4      AE= 0.4      AW= 0.4      AR= 0.75
   EV= 0       EH= 0
   L=?10
   D=?5
   H=?3
               1   -0.255029637
               2   -0.552238081
               3   -0.828203119
               4   -1.26872049
               5   -1.38384967
               6   -1.34656831
               7   1.05626969
               8   2.57460955
               9   4.39472192
              10   5.07914842
              11   5.42931067
              12   5.4061343
              13   2.91903949
              14   5.93809477
              15   6.49502761
              16   6.34787967
              17   4.78083299
              18   3.52696681
              19   0.785217776
              20   4.28118656E-2
              21   2.00766773E-2
              22   -5.13214239E-2
              23   -0.160574348
              24   -0.262283336
```

```
3. GN= 0.3     GS= 0.5      GE= 0.2      GW= 0.2      GR= 0
   UN= 0.65    US= 0.65     UE= 0.65     UW= 0.65     UR= 0.35    UB= 5.7
   DFN= 0.3    DFS= 0.3     DFE= 0.3     DFW= 0.3     DFR= 0.4
   PHN= 7      PHS= 7       PHE= 7       PHW= 7       PHR= 4
   AN= 0.4     AS= 0.4      AE= 0.4      AW= 0.4      AR= 0.75
   EV= 0       EH= 0
   L=?10
   D=?5
   H=?3
               1   -0.25438795
               2   -0.562929401
               3   -0.847715174
               4   -1.30200762
               5   -1.4270027
               6   -1.39712604
               7   1.00077497
               8   2.51650565
               9   4.33227817
              10   5.01242356
              11   5.36271928
              12   5.34236823
              13   2.86042699
              14   5.89123273
              15   6.46109304
              16   6.32928075
              17   4.77181545
              18   3.52682054
              19   0.788789205
              20   4.36792944E-2
              21   2.76734431E-2
              22   -4.37473752E-2
              23   -0.154094219
              24   -0.260567815
```

FIGURE 3.7.3: VARIATION OF U_VALUES

4	GN= 0.3	GS= 0.5	GE= 0.2	GW= 0.2	GR= 0	
	UN= 0.8	US= 0.8	UE= 0.8	UW= 0.8	UR= 0.35	UB= 5.7
	DFN= 0.3	DFS= 0.3	DFE= 0.3	DFW= 0.3	DFR= 0.4	
	PHN= 7	PHS= 7	PHE= 7	PHW= 7	PHR= 4	
	AN= 0.4	AS= 0.4	AE= 0.4	AW= 0.4	AR= 0.75	
	EV= 0	EH= 0				
	L= 10					
	D= 5					
	H= 3					

1	-0.253746263
2	-0.573620722
3	-0.86722723
4	-1.33529557
5	-1.4701586
6	-1.44768868
7	0.945273458
8	2.45839483
9	4.26982738
10	4.94569353
11	5.29612613
12	5.2786062
13	2.8018261
14	5.84439113
15	6.42718563
16	6.31072215
17	4.76284914
18	3.52673718
19	0.792435165
20	4.46217632E-2
21	3.53660521E-2
22	-3.60693676E-2
23	-0.147504299
24	-0.258739382

5	GN= 0.3	GS= 0.5	GE= 0.2	GW= 0.2	GR= 0	
	UN= 0.95	US= 0.95	UE= 0.95	UW= 0.95	UR= 0.35	UB= 5.7
	DFN= 0.3	DFS= 0.3	DFE= 0.3	DFW= 0.3	DFR= 0.4	
	PHN= 7	PHS= 7	PHE= 7	PHW= 7	PHR= 4	
	AN= 0.4	AS= 0.4	AE= 0.4	AW= 0.4	AR= 0.75	
	EV= 0	EH= 0				
	L= 10					
	D= 5					
	H= 3					

1	-0.253104575
2	-0.584312043
3	-0.886739285
4	-1.36858434
5	-1.51331737
6	-1.49825621
7	0.889765164
8	2.40027709
9	4.20736956
10	4.87895833
11	5.22953122
12	5.21484824
13	2.74323679
14	5.79756997
15	6.39331437
16	6.29220386
17	4.75393408
18	3.52671673
19	0.796155661
20	4.56392762E-2
21	4.31545078E-2
22	-2.82874015E-2
23	-0.1408346
24	-0.256798058

FIGURE 3.7.3 : VARIATION OF U_VALUES

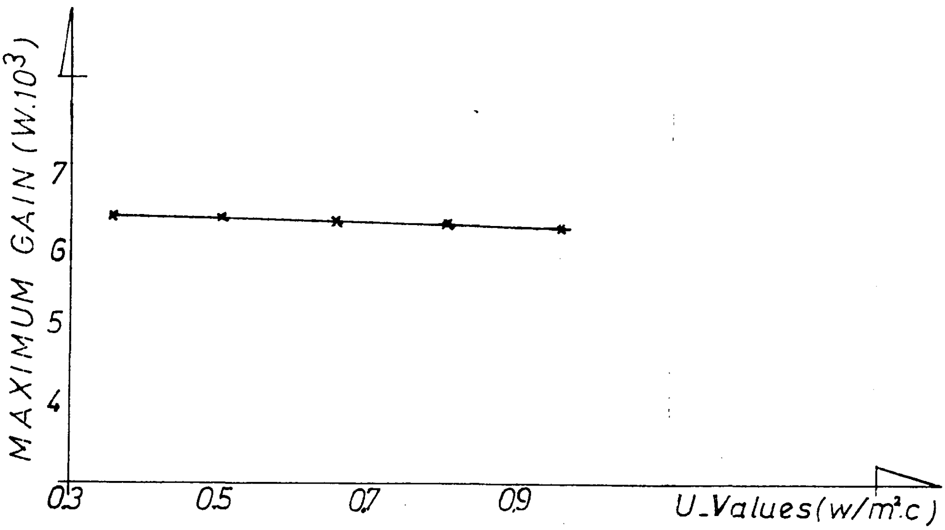
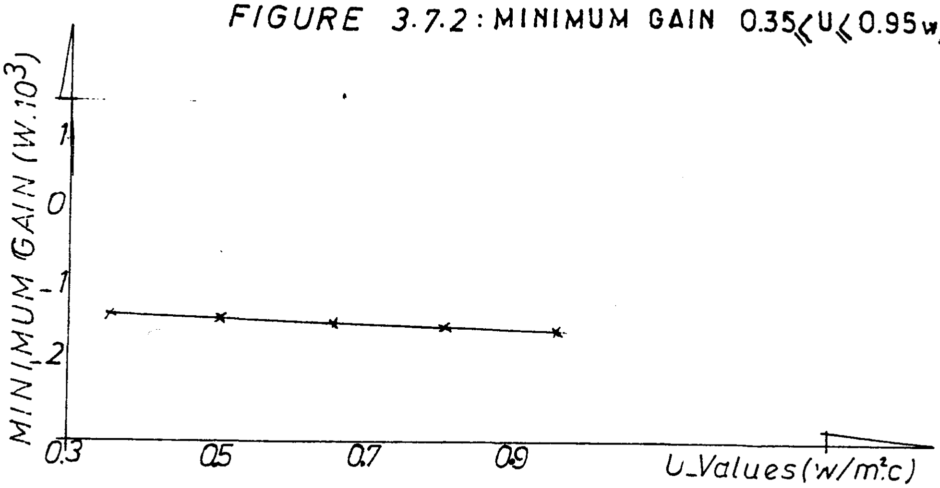


FIGURE 3.7.1: MAXIMU GAIN, $0.35 \leqslant U \leqslant 0.95 w/m^2c$

FIGURE 3.7.2: MINIMUM GAIN $0.35 \leqslant U \leqslant 0.95 w/m^2c$



However, in these tests it should be noted that the phase-shift and the decrement factor were maintained constant, PS = 7 and DF = 0.3.

3.6.4 PLAN RATIO

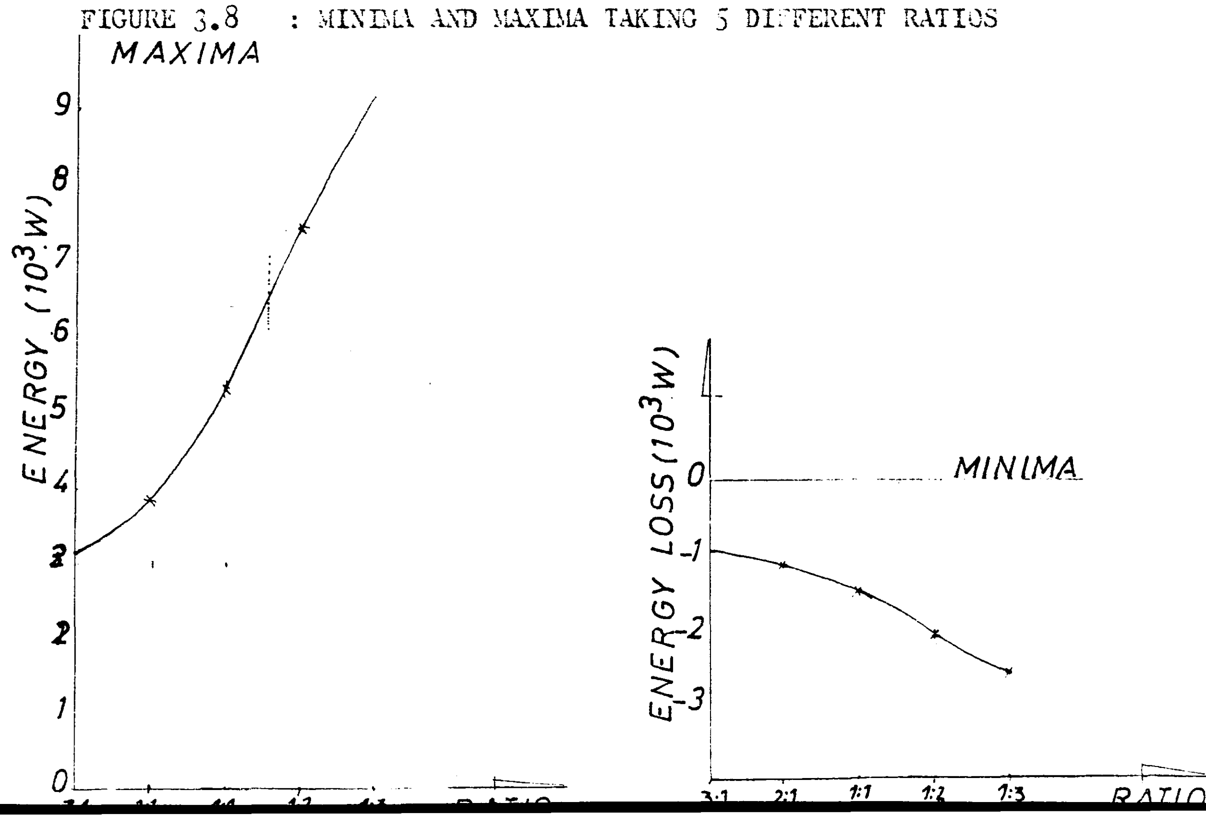
3.6.4.1 As predicted by the steady-state theory, the overall energy flux should vary as the ratio of heat absorbing and heat emitting surfaces are varied. The theory predicts that for a given building volume, an optimum length, breadth and height can be derived in order to maximise solar gain for any particular fabric specification and known climatic conditions.

Taking five different ratios and computing the energy consumption give the results shown in graphs 3.9.1, 3.9.2, 3.9.3, 3.9.4 and 3.9.5

The graph of the minima and maxima was also drawn, figure 3.9.4 The results show that between the ratio 1:1 and 1:25 seems to be a straight line relationship. Therefore in that range plan ratio does not have disproportioned effect.

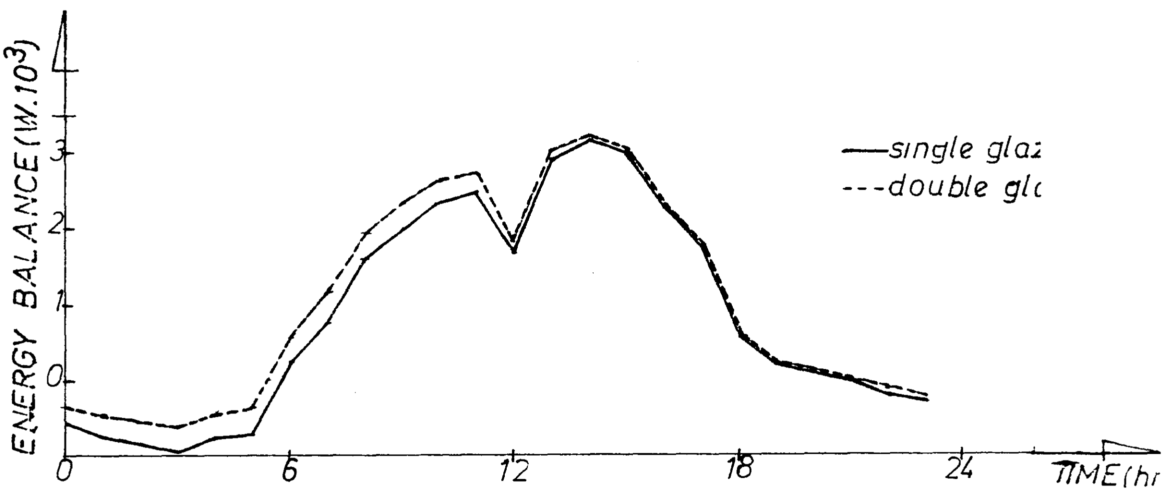
The graphs in figures 3.9.1, 3.9.2, 3.9.3, 3.9.4, 3.9.5, show that double glazing in this model does not have a significant effect on the energy flux. In that respect the ratio 1L2 and single glazing were adopted.

FIGURE 3.8 : MINIMA AND MAXIMA TAKING 5 DIFFERENT RATIOS



GN=0.3 , GS=0.5 ; GE=0.2 , GW=0.2 , GR=0
UN=0.58 ; US=0.58 ; UE=0.58 ; UW=0.58 ; UR=0.35
DFN=0.3 ; DFS=0.3 ; DFE=0.3 ; DFW=0.3 ; DFR=0.4
PHN=4 ; PHS=4 ; PHE=4 ; PHW=4 ; PHR=4
AN=0.4 ; AS=0.4 ; AE=0.4 ; AW=0.4 ; AR=0.75
AV=0 ; EH=0

DIMENSIONS: L=4m ; D=12 H=3m



UG=5.7 (single glazing)	
[illegible]	[illegible]

-3

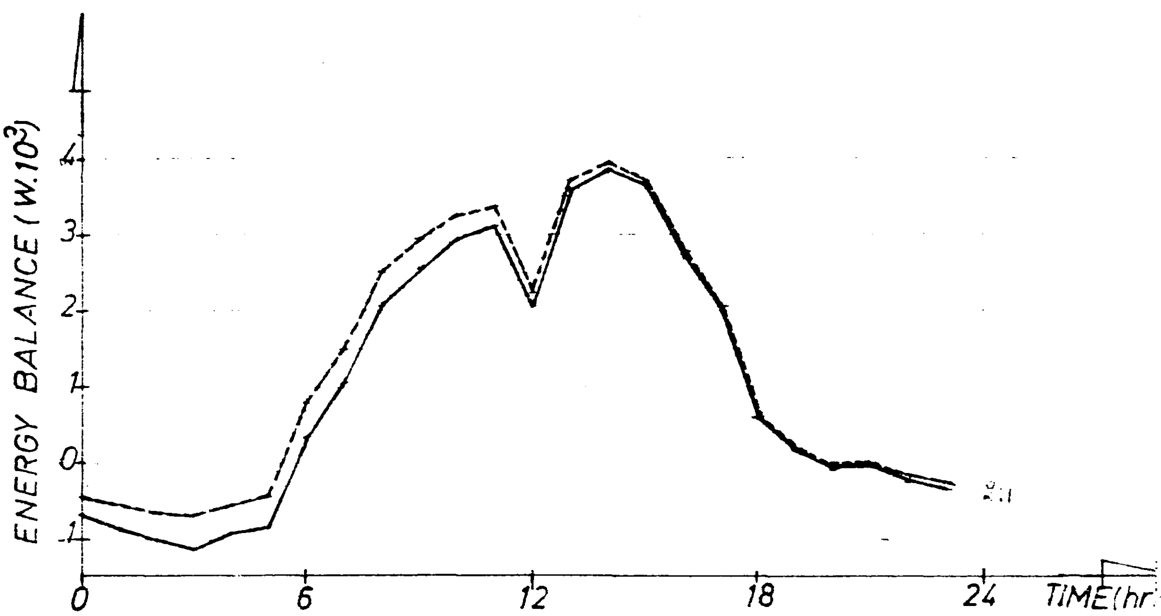
UG=2.8 (double glazing)	
[illegible]	[illegible]

-2

FIGURE 3.9.1 : ENERGY BALANCE FOR CELL OF 3:1 RATIO.

GN=0.3 ; GS=0.5 ; GE=0.2 ; GW=0.2 ; GR=0
UN=0.58 ; US=0.58 ; UE=0.58 ; UW=0.58 ; UR=0.35
DFN=0.3 ; DFS=0.3 ; DFE=0.3 ; DFW=0.3 ; DFR=0.4
PHN=4 ; PHS=4 ; PHE=4 ; PHW=4 ; PHR=4
AN=0.4 ; AS=0.4 ; AE=0.4 ; AW=0.4 ; AR=0.75
AV=0 ; EH=0

DIMENSIONS: L=5m ; D=10m ; H=3m



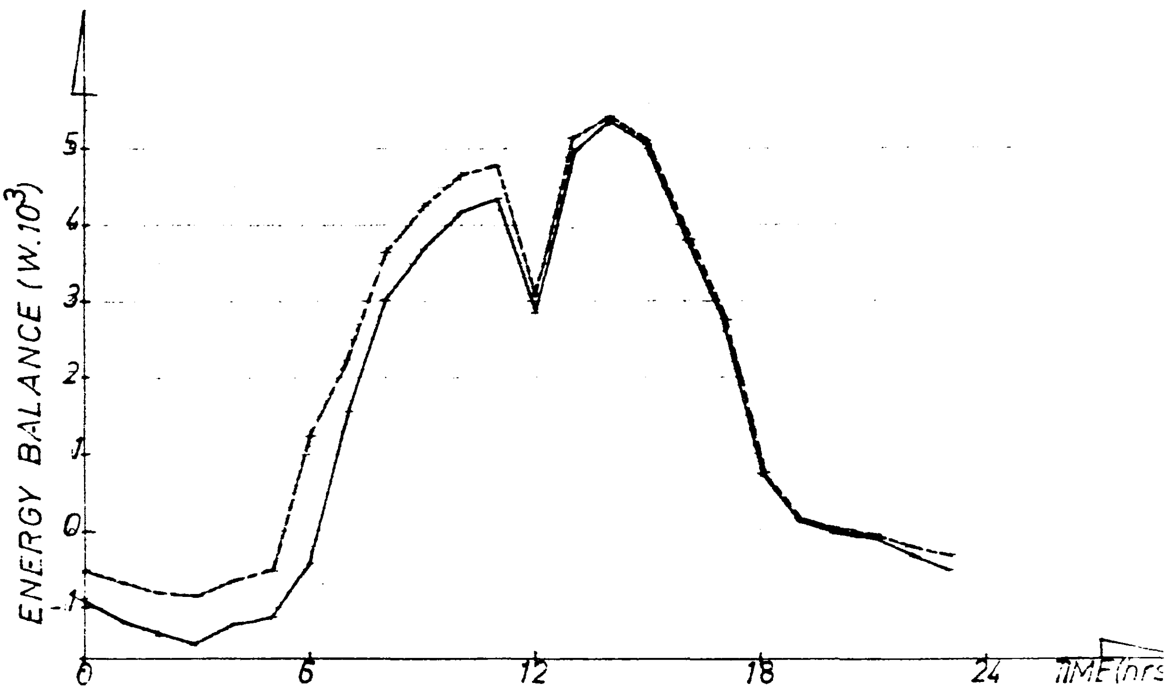
UG=5.7 (single glazing)	
1	-0.67348253
2	-0.573106[illegible]
3	-1.0226498
4	-1.[illegible]
5	-0.[illegible]
6	-0.[illegible]
7	0.35[illegible]
8	1.05[illegible]
9	2.07[illegible]
10	2.55[illegible]
11	2.9[illegible]
12	[illegible]
13	[illegible]
14	3.[illegible]
15	3.87702027
16	3.6757539
17	2.76868217
18	2.06864584
19	0.616835324
20	0.178925128
21	7.2419902E-2
22	-3.72050547E-2
23	-0.25050746
24	-0.37996401

UG=2.8 (double glazing)	
[illegible]	[illegible]

FIGURE 3.9.2 : ENERGY BALANCE FOR CELL OF 2:1 RATIO

GN=0.3 ; GS=0.5 ; GE=0.2 ; GW=0.2 , GR=0
UN=0.58 ; US=0.58 ; UE=0.58 ; UW=0.58 ; UR=0.35
DFN=0.3 ; DFS=0.3 ; DFE=0.3 ; DFW=0.3 ; DFR=0.4
PHN=4 ; PHS=4 ; PHE=4 ; PHW=4 ; PHR=4
AN=0.4 , AS=0.4 ; AE=0.4 ; AW=0.4 , AR=0.75
AV=0 ; EH=0

DIMENSIONS: $L=\sqrt{50}$ m ; $D=\sqrt{50}$ m ; H=3m



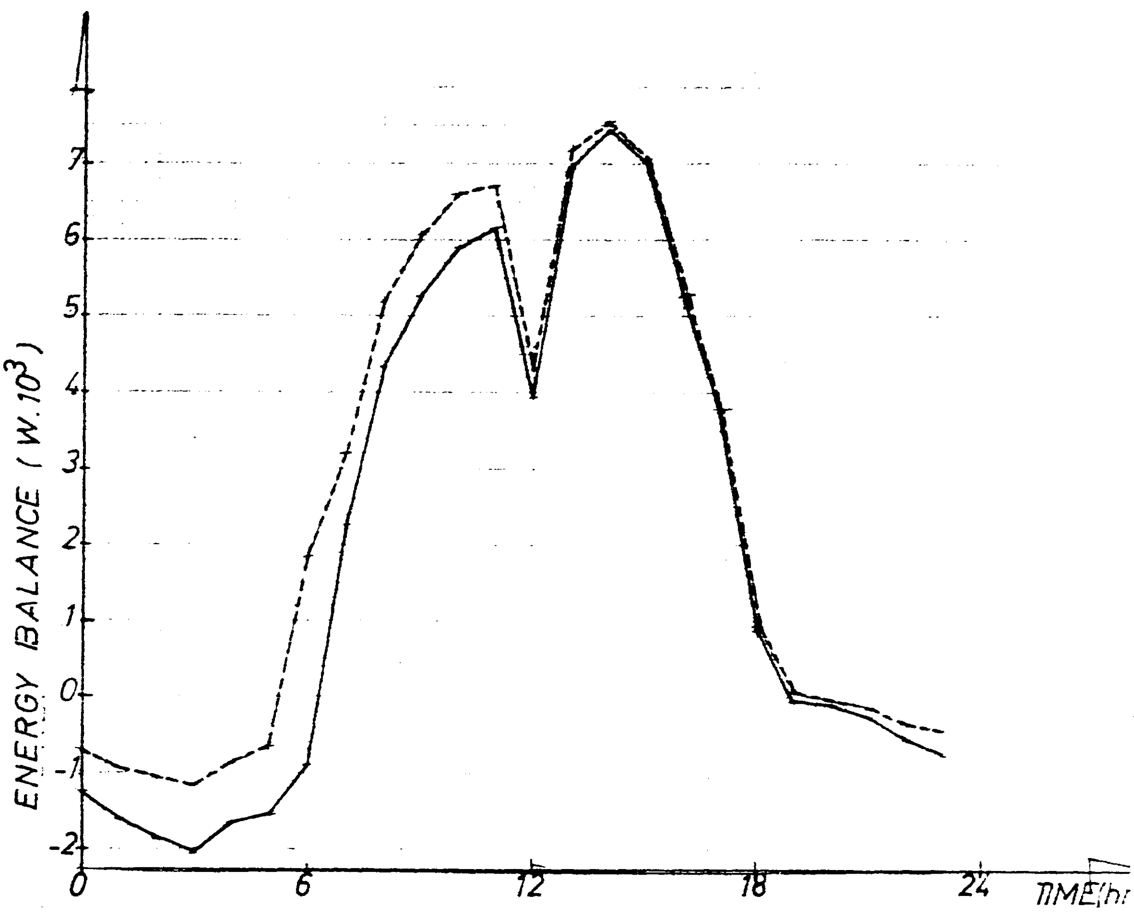
UG=5.7 (single glazing)
[illegible]

UG=2.8 (double glazing)
[illegible]

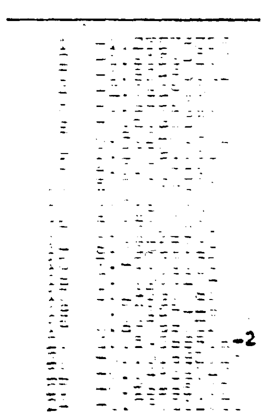
FIGURE 3.9.3 : ENERGY BALANCE FOR CELL OF 1:1 RATIO.

GN=0.3 ; GS=0.5 ; GE=0.2 ; GW=0.2 ; GR=0
UN=0.58 ; US=0.58 ; UE=0.58 ; UW=0.58 ; UR=0.35
DFN=0.3 ; DFS=0.3 ; DFE=0.3 ; DFW=0.3 ; DFR=0.4
PHN=4 ; PHS=4 ; PHE=4 ; PHW=4 ; PHR=4
AN=0.4 ; AS=0.4 ; AE=0.4 ; AW=0.4 ; AR=0.75
AV=0 ; EH=0

DIMENSIONS: L=10m ; D=5m ; H=3m



UG=5.7 (single glazing)



UG=2.8 (double glazing)

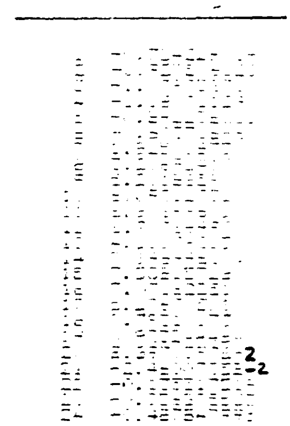
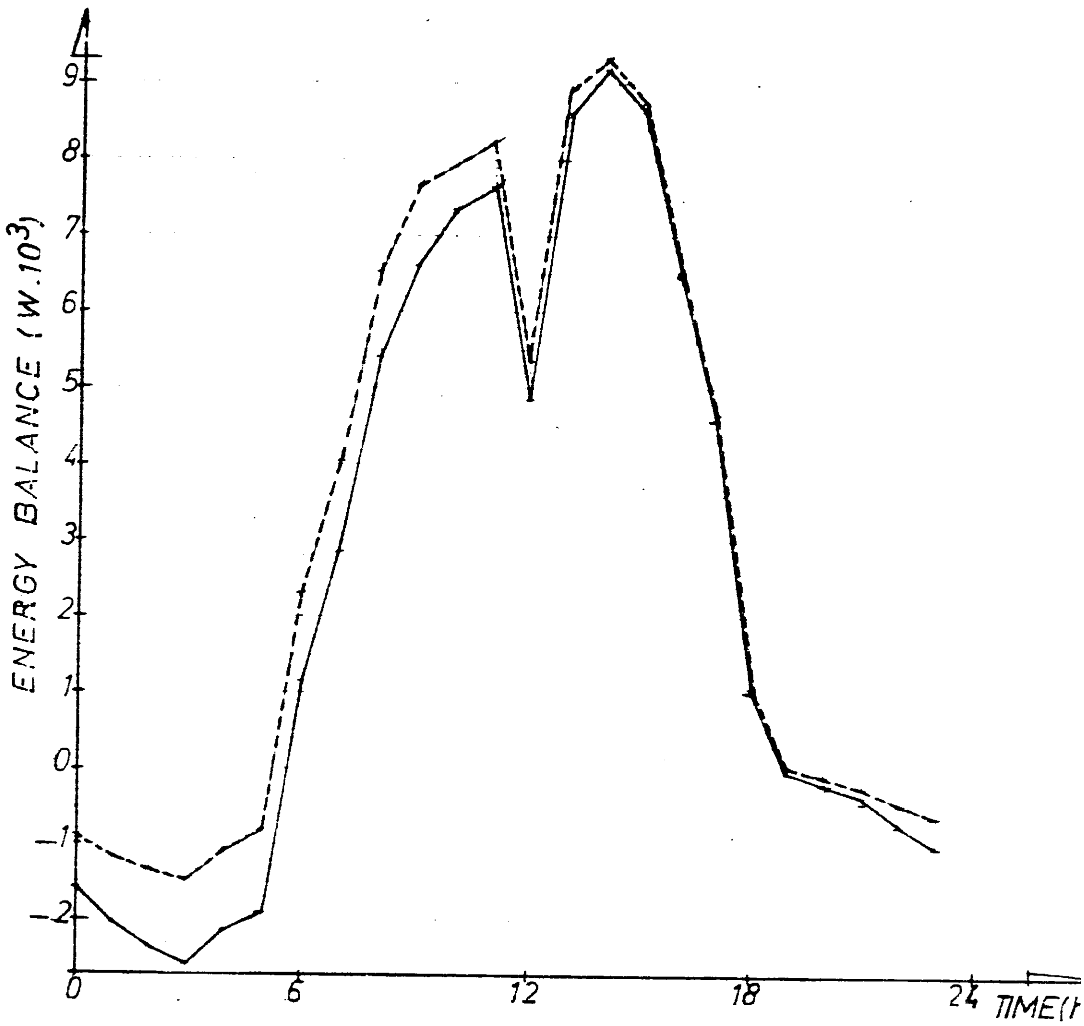


FIGURE 3.9.4: ENERGY BALANCE FOR CELL OF 1:2 RATIO

GN=0.3 ; GS=0.5 ; GE=0.2 ; GW=0.2 ; GR=0
UN=0.58 ; US=0.58 ; UE=0.58 ; UW=0.58 ; UR=0.35
DFN=0.3 ; DFS=0.3 ; DFE=0.3 ; DFW=0.3 ; DFR=0.4
PHN=4 ; PHS=4 ; PHE=4 ; PHW=4 ; PHR=4
AN=0.4 ; AS=0.4 ; AE=0.4 ; AW=0.4 ; AR=0.75
AV=0 ; EH=0

DIMENSIONS: L=12.5 m ; D=4 m ; H=3 m



UG=5.7 (single glazing)
[illegible]
-2

UG=2.8 (double glazing)
[illegible]
-2

FIGURE 3.9.5
ENERGY BALANCE FOR CELL OF 1:3 RATIO

In all cases the area and specifications of the roof fabric remains constant. The resulting graphs therefore show the variation due to the walls surfaces.

The area beneath each curve is integrated and the following tables can be drawn:

For single glazing:

Y : X	$LOG\,10^{\,Y/X}$	$\int_0^{24} Q$
12.5 : 4	0.49485	19.3
10 : 5	0.30103	24.9
50 : 50	0.00000	34.9
5 : 10	-1.69897	42.5
4 : 12.5	-1.50515	59.5

TABLE 3.4 LOG 10 PLAN RATIO
(See Graph 3.10)

As anticipated by a steady-state theory including a solar gain element, the overall heat gain over a 24 hour cycle has an almost linear relationship with the plan ratio until the area of south facing collector area exceeds that of the east and west wall by a factor of 2. Then, the rate of heat gain rapidly rises. This is because of the disproportionate increase in south facing glazing compared with the decrease in heat emitting east and west facing surfaces.

Similarly, the peak heat flux in this case occurring at 11 and 14 hrs can be tabulated against plan ratio.

Single glazing.

Y : X	LOG 10 $^{Y/X}$	11 hrs	14 hrs
12.5 : 4	0.49485	2.49	3.16
10 : 5	0.30103	3.11	3.88
50 : 50	0.00000	4.38	5.35
5 : 10	-1.69897	6.17	7.43
4 : 12.5	-1.50515	7.68	9.19

Table 3.5 : LOG 10 Plan ratio and Magnitude of Peak Gains (See Graph 3.11)

Predictably, in graph 2 the peak temperatures can be seen to be related to the plan ratio, and they increase in magnitude as the area of southern collector increases.

Note that in this set of computer runs, the phase-shift (PHS) was set at about only 4 hours.

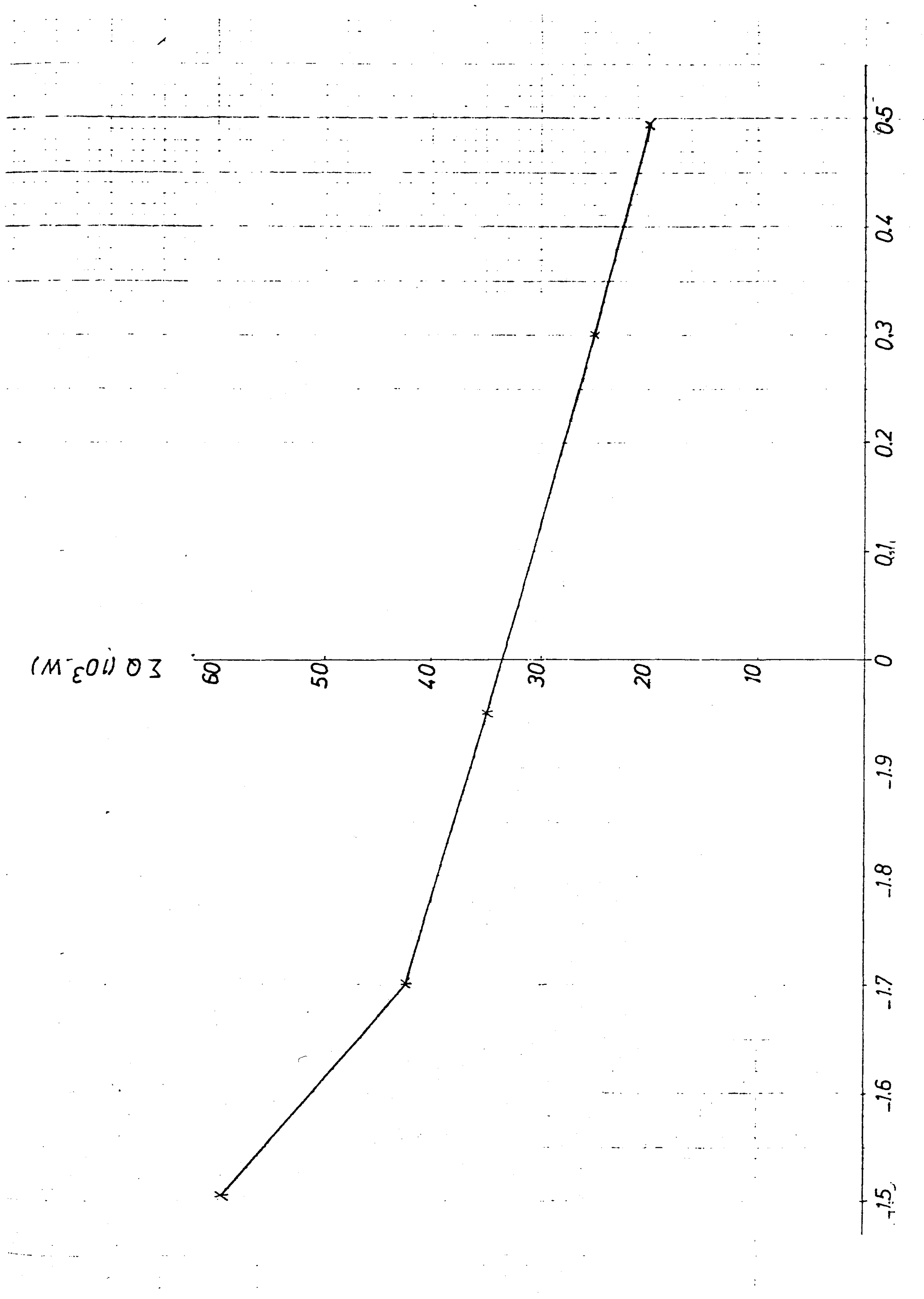


FIGURE. 3.10 _ GRAPH 1: LOG10 PLAN RATIO

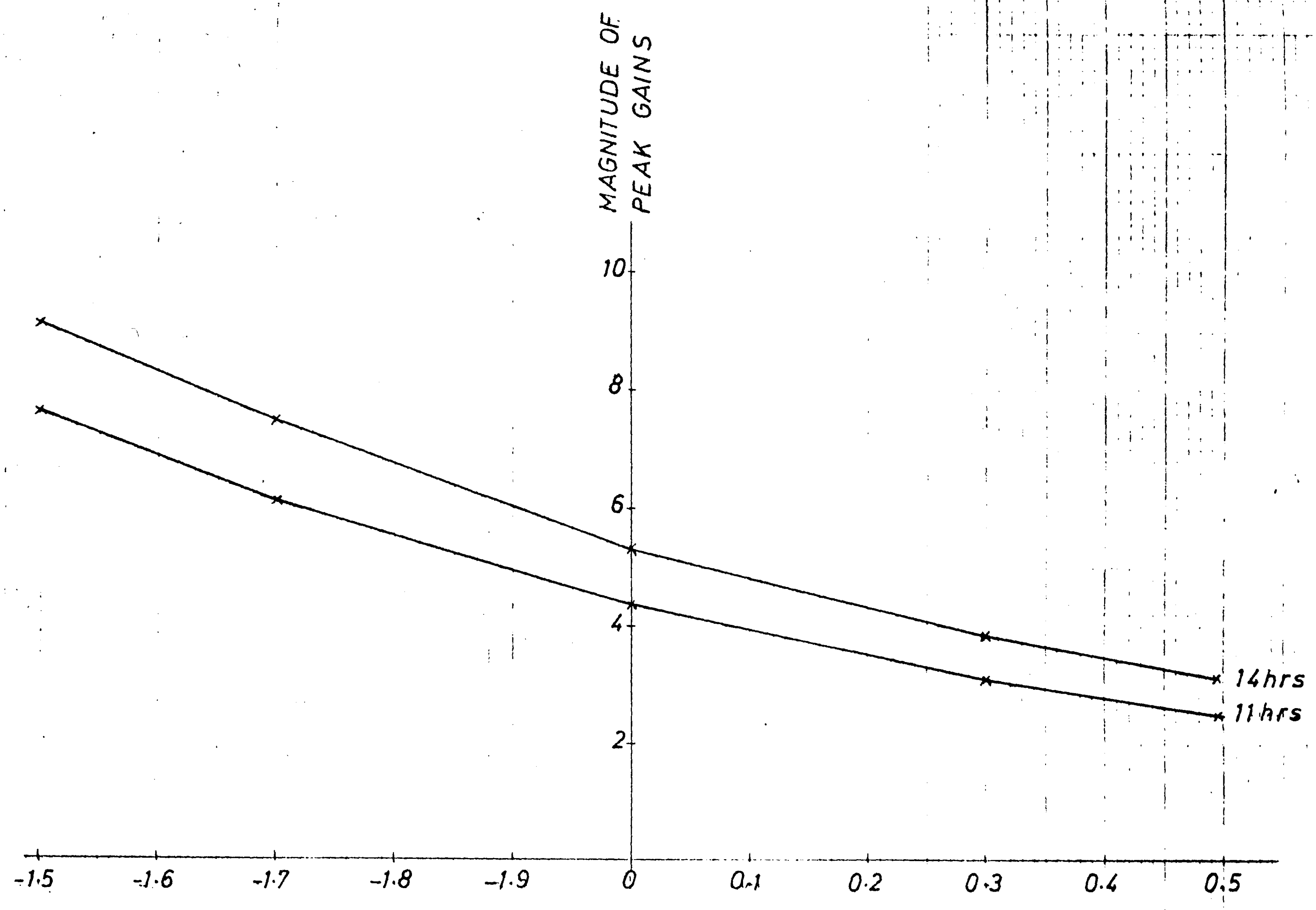


FIGURE: 3.11 _GRAPH 2 : LOG.10 PLAN RATIO

TABLE 3.6 : SUMMARY OF THE PHASE-SHIFT TEST

PHS	PEAK (HRS)	PEAK(HRS)	Q	MIN	MAX
1	7.12 (11)	7.67(14)	48.98	-2.19	7.67
2	6.85 (11)	7.62(14)	48.66	-2.07	7.62
3	6.58 (11)	7.56(14)	48.40	-2.07	7.56
4	6.15 (11)	7.44(14)	48.22	-2.08	7.44
5	5.79 (11)	7.17(14)	48.13	-1.91	7.17
6	5.50 (11)	6.89(14)	48.10	-1.69	6.89
7	5.37 (10)	6.46(14)	48.15	-1.42	6.46
8	5.36 (10)	6.11(14)	48.22	-1.13	6.11
9	5.50 (10)	5.81(14)	48.32	-0.78	5.81
10	5.64 (10)	5.67(14)	48.44	-0.35	5.67
11	5.54 (11)	5.59(14)	48.59	-0.69	5.59
12	5.67 (10)	5.59(14)	48.70	-1.11	5.67
13	5.94 (9)	5.73(14)	48.88	-1.46	5.94
14	6.38 (9)	5.87(14)	48.13	-1.75	6.28

In order to test the important part played by the phase-shift in the calculation of the energy balance, 6 different values were chosen: PH = 1, 3, 6, 9, 11 and 13. The results showed that with a PHS equal to 11 hours the peak increase. The same happens with a PHS equal to 13 hours. To be sure before putting any conclusions we decided to vary the phase-shift from PH = 1 hrs to PH = 14 hrs. Figure 3.12.1 to figure 3.12.14 give the results. Note that the decrement factor was maintained equal to 0.4 then the maxima and the minima were reported on a graph as shown in figure 3.13

Between PH = 12 and PH = 14 hrs the curve is going up. While for the minima, between PH = 1 to 10 hrs the magnitude of heat flux increase and then drops again between PH = 11 and PH = 14 hrs.

Figures 3.14 1 to 3.14.3 were drawn to show that a noticeable skewness in the curves as it would have been expected is in fact nearly inexistent. This is just to confirm the lack of demonstrated effect of the time-lag which resides in the program 'SOLDAY'.

```
GN. 0.3          GS. 0.5         GE. 0.2         GW. 0.2         GR. 0.
UN= 0.58         US= 0.58        UE= 0.58        UW= 0.58        UR= 0.35     UG= 5.7
DFN= 0.4         DFS= 0.4        DFE= 0.4        DFW= 0.4        DFR= 0.4
PHN= 1           PHS= 1          PHE= 1          PHW= 1          PHR= 4
AN= 0.4          AS= 0.4         AE= 0.4         AW= 0.4         AR= 0.75
EV= 0            EH= 0
L=710
D=75
H=73
            1   -2.04501453
            2   -1.91561295
            3   -2.05844573
            4   -2.19807474
            5   -1.96612739
            6   -1.59546887
            7   1.12415948
            8   2.79934216
            9   5.10542637
           10   6.34123138
           11   6.95681586
           12   7.12244482
           13   4.61259687
           14   7.41242493
           15   7.67367462
           16   7.10422522
           17   5.25232504
           18   3.64263576
           19   0.68750347
           20   -0.36665160
           21   -0.64000008
           22   -1.0410824
           23   -1.40536212
           24   -1.62029799
RUN
GN= 0.3          GS= 0.5         GE= 0.2         GW= 0.2         GR= 0
UN= 0.58         US= 0.58        UE= 0.58        UW= 0.58        UR= 0.35     UG= 5.7
DFN= 0.4         DFS= 0.4        DFE= 0.4        DFW= 0.4        DFR= 0.4
PHN= 3           PHS= 3          PHE= 3          PHW= 3          PHR= 4
AN= 0.4          AS= 0.4         AE= 0.4         AW= 0.4         AR= 0.75
EV= 0            EH= 0
L=710
D=75
H=73
            1   -1.6211033[illegible]
            2   -1.8962618
            3   -2.0790665[illegible]
            4   -1.9423008[illegible]
            5   -1.8479044
            6   -1.6894682[illegible]
            7   0.8895414[illegible]
            8   2.346498[illegible]
            9   4.4463[illegible]
           10   5.5587218[illegible]
           11   6.2[illegible]
           12   6.5842894[illegible]
           13   4.2268[illegible]
           14   7.22[illegible]
           15   7.5641[illegible]
           16   7.0775544[illegible]
           17   5.29447[illegible]
           18   3.7661640[illegible]
           19   0.8816[illegible]
           20   -3.81021054E-2
           21   -0.18[illegible]
           22   -0.48[illegible]
           23   -0.7873648[illegible]
           24   -1.14226[illegible]
RUN
GN= 0.3          GS= 0.5         GE= 0.2         GW= 0.2         GR= 0
UN= 0.58         US= 0.58        UE= 0.58        UW= 0.58        UR= 0.35     UG= 5.7
DFN= 0.4         DFS= 0.4        DFE= 0.4        DFW= 0.4        DFR= 0.4
PHN= 6           PHS= 6          PHE= 6          PHW= 6          PHR= 4
AN= 0.4          AS= 0.4         AE= 0.4         AW= 0.4         AR= 0.75
EV= 0            EH= 0
L=710
D=75
H=73
            1   -0.5466[illegible]
            2   -0.83[illegible]
            3   -1.[illegible]
            4   -1.6531[illegible]
            5   -1.69[illegible]
            6   -1.[illegible]
            7   1.[illegible]
            8   [illegible]
            9   4.2[illegible]
           10   [illegible]
           11   [illegible]
           12   [illegible]
           13   [illegible]
           14   6.[illegible]
           15   6.8[illegible]
           16   [illegible]
           17   [illegible]
           18   [illegible]
           19   [illegible]
           20   [illegible]E-2
           21   [illegible]E-2
           22   -5.[illegible]E-2
           23   [illegible]
           24   [illegible]
```

FIGURE. 3.12 TEST RUN VARYING THE PHASE-SHIFT

```
GN= 0.3        GS= 0.5        GE= 0.2        GW= 0.2        GR= 0
UN= 0.58       US= 0.58       UE= 0.58       UW= 0.58       UR= 0.35       UG= 5.7
DFN= 0.4       DFS= 0.4       DFE= 0.4       DFW= 0.4       DFR= 0.4
PHN= 9         PHS= 9         PHE= 9         PHW= 9         PHR= 4
AN= 0.4        AS= 0.4        AE= 0.4        AW= 0.4        AR= 0.75
EV= 0          EH= 0
L=210
D=25
H=23
               1   -1.44246266E-2
               2   -0.148072242
               3   -0.273769763
               4   -0.578134588
               5   -0.627431494
               6   -0.782743875
               7   1.43969645
               8   2.5568418
               9   4.33508224
              10   5.2932168
              11   5.50297223
              12   5.27003578
              13   2.64393422
              14   5.45459882
              15   5.81489429
              16   5.5568979
              17   4.08106479
              18   2.99026939
              19   0.399870234
              20   -0.156636975
              21   -9.23541927E-2
              22   -7.41143132E-2
              23   -0.122106729
              24   -0.145853913
>RUN
GN= 0.3        GS= 0.5        GE= 0.2        GW= 0.2        GR= 0
UN= 0.58       US= 0.58       UE= 0.58       UW= 0.58       UR= 0.35       UG= 5.7
DFN= 0.4       DFS= 0.4       DFE= 0.4       DFW= 0.4       DFR= 0.4
PHN= 11        PHS= 11        PHE= 11        PHW= 11        PHR= 4
AN= 0.4        AS= 0.4        AE= 0.4        AW= 0.4        AR= 0.75
EV= 0          EH= 0
L=210
D=25
H=23
               1   3.23023148E-2
               2   -3.14820779E-3
               3   -3.89426058E-2
               4   -0.165569679
               5   -5.47501095E-2
               6   -5.91139632E-2
               7   2.23859356
               8   3.17028461
               9   4.77322739
              10   5.32741765
              11   5.50023744
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FIGURE. 3.12

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FIGURE. 3.12

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FIGURE 3.12

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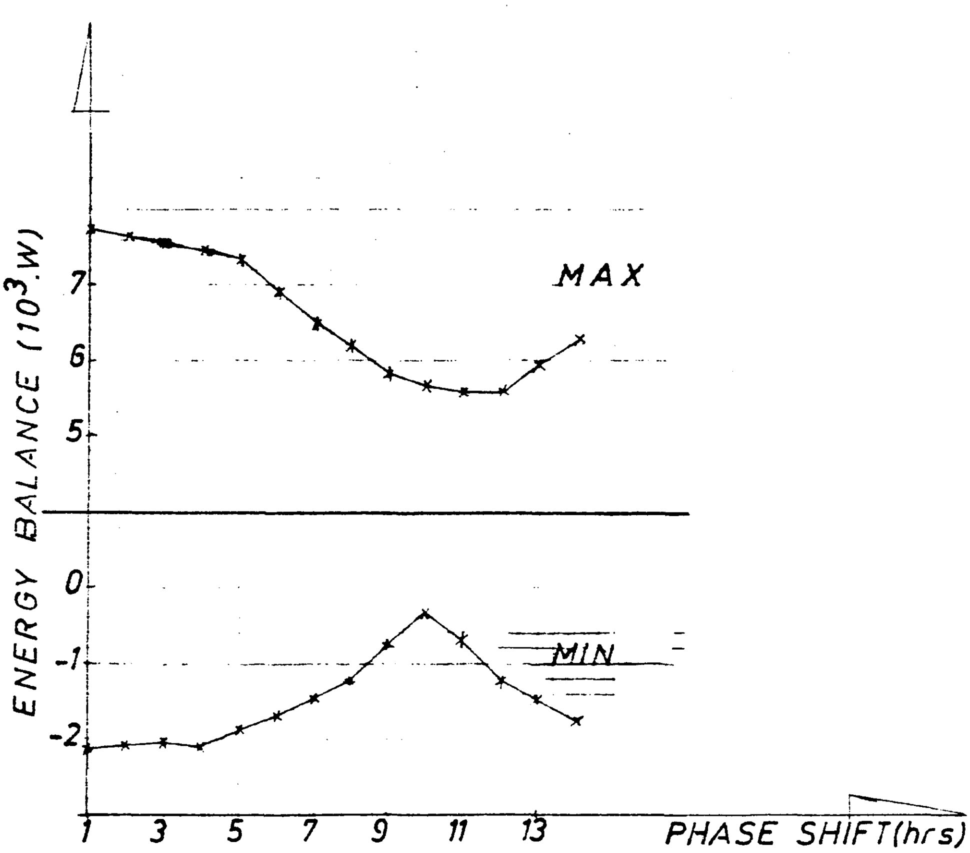


FIGURE 3.13 MINIMA AND MAXIMA _ PHASE-SHIFT VARYING FROM 1 TO 14

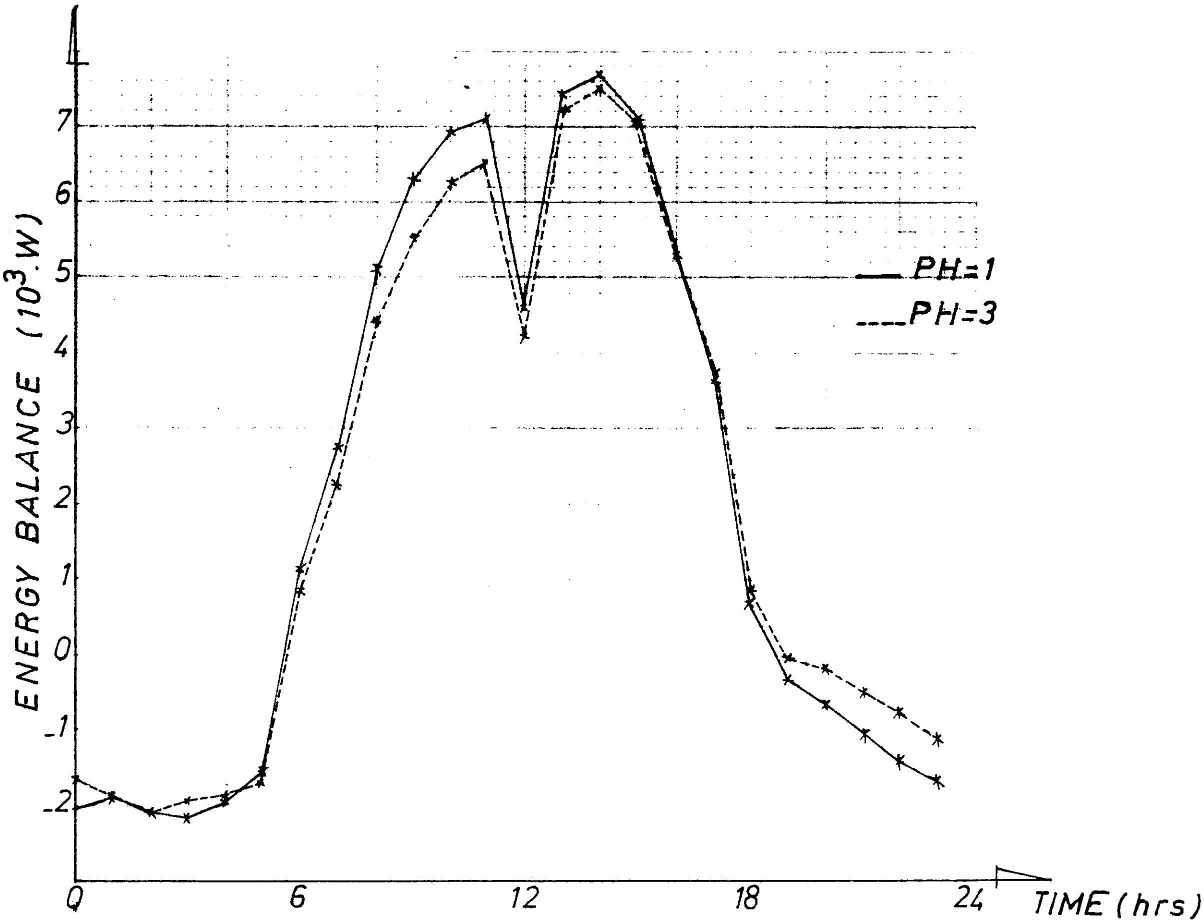


FIGURE: 3.14.1 : ENERGY BALANCE _ PHASE SHIFT = 1 AND 3

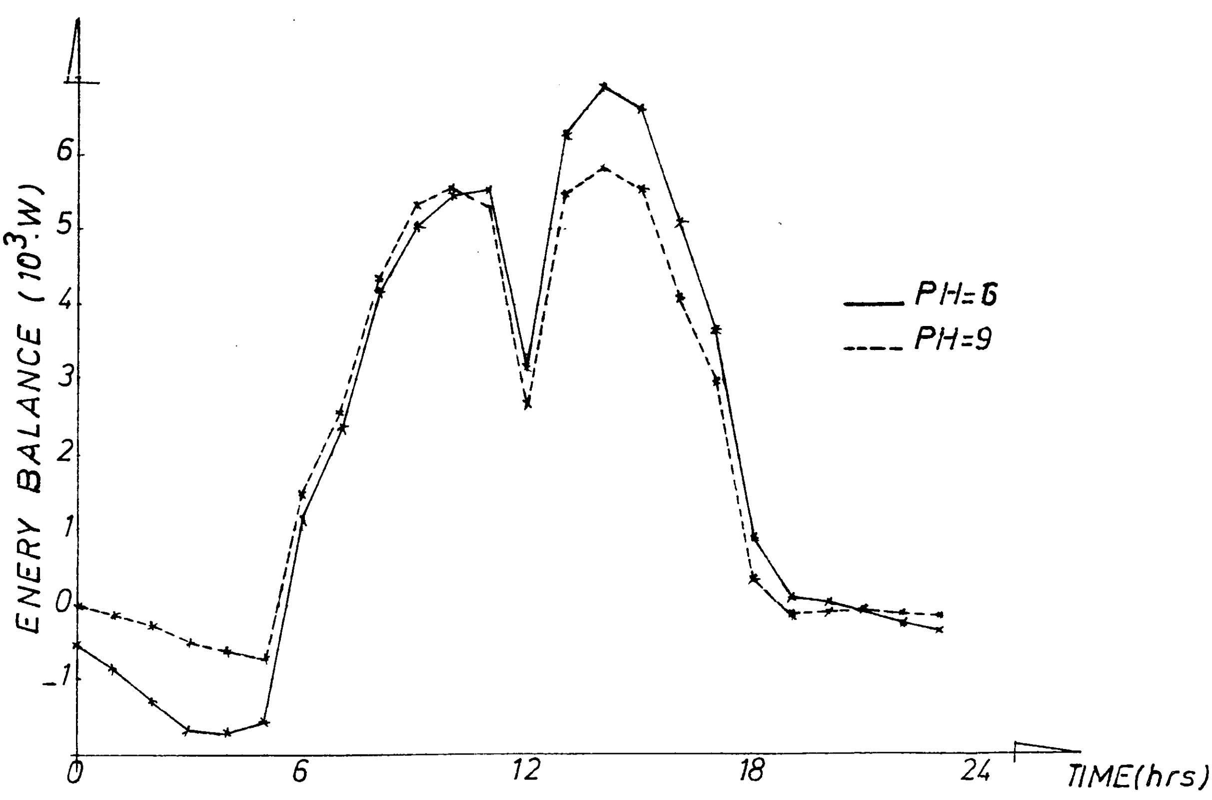


FIGURE: 3.14.2: ENERGY BALANCE _ PHASE-SHIFT = 6 AND 9

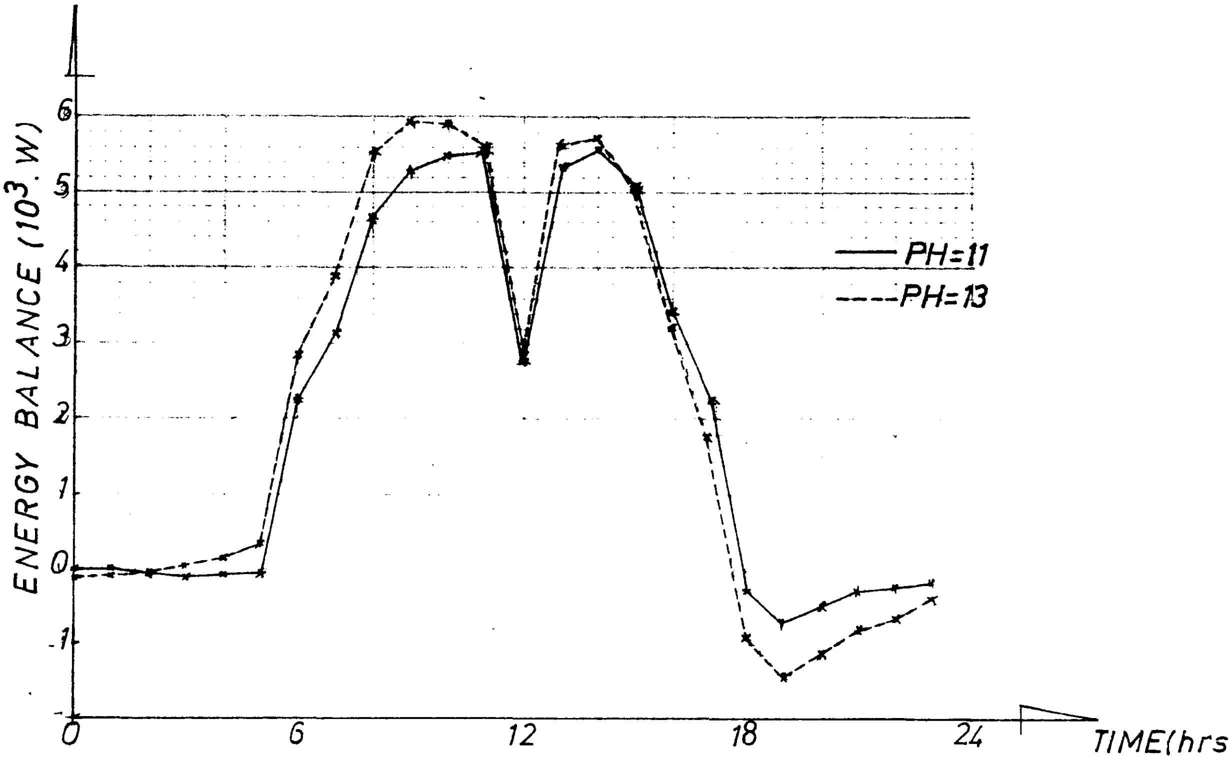
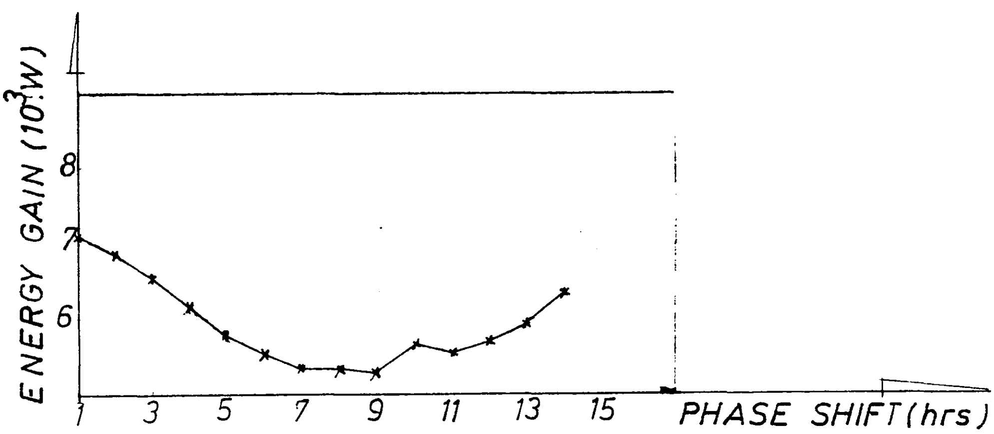
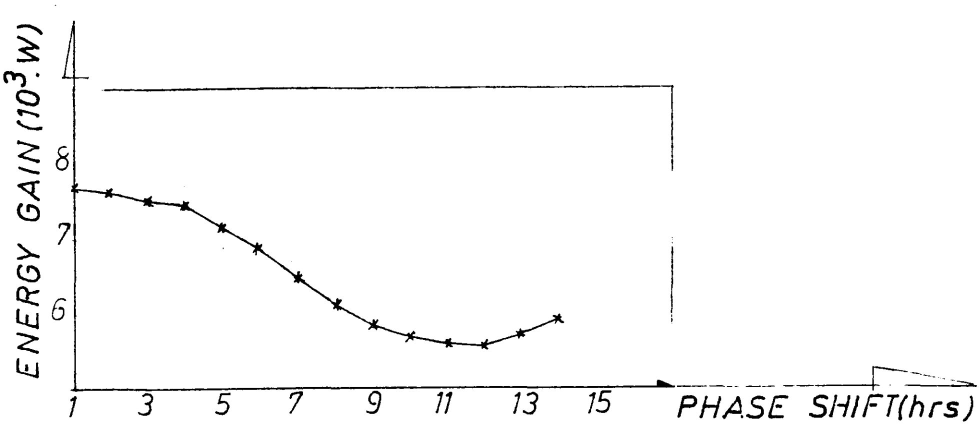


FIGURE:3.14.3: ENERGY BALANCE _ PHASE SHIFT = 11 AND 13



PEAK AT 11 HRS.

FIGURE: 3.15.1



PEAK AT 14 HRS.

FIGURE: 3.15.2

3.7 SUMMARY

1. One of the priorities in Algeria is housing. Many projects have been erected throughout the country. Even although the main objective is reached i.e. building construction, the qualitative and economic aspect of these buildings is not yet satisfactory.

Building Regulations in Algeria are mainly restricted to planning and building structures therefore the architectural offices are often left to their own judgement when faced with the thermal comfort, choice of materials, orientation.....

Hence the public authorities have promoted two complimentary research lines:

- One of standard type which consists of a compulsory thermal insulation, solar protection, inertia factors..
- the other one, more fundamental, which in fact, includes the first one, is concerned with the use of local resources in energy and materials.

The fossil-fuel resources, even although important in gas, for example, are not infinite and in short terms the energy problem will rise in Algeria as anywhere else (See chap 1.) Even more, the fossil-fuel resources are exportable and represent the main income for the country.

The building construction is playing an important part in the developing countries. The Algerian Ministry of Planning and Building Construction has fixed an annual objective of 100,000 houses. So it is indispensable to the quantitative production to be qualitative. The actual production which often ignores the climatic parameters must disappear to the profit of 'bio-climatic' realizations.

2. The more southerly latitude of Algeria compared to U.K. would suggest that greater winter availability of sunshine would increase the efficiency of solar devices (18).

An appreciation of both Algerian climate and solar devices was undertaken, but not included in this thesis as not being directly related to the study.

3. 'SOLDAY' Model was stated in view of the study of methematical modelling. However, because of its serious omissions and errors (See Chp 3) and in relation to other models (see Chp 2) it is not recommended.

'SOLDAY' was only used because of the lack of time in which to get a suitable replacement for Method 5000.

4. The results expected from the design were a range of different values such as U-Values, glazing ratio, plan ratio, phase-shift.... in order to give the most suitable guideline to the architect concerned with the energy conservation in buildings

Unfortunately, as stated before, the choice of the 'SOLDAY' model did not allow us to elaborate such a design.

3.8 CONCLUSION

The aim of energy design is to maintain an internal environment within the boundaries of comfort conditions, with the least aid of heat generating equipment using fossil-fuels. One re-emergent strategy is to fully utilise solar energy for passive environmental control.

An attempt was made to examine the effects of design variables on the internal temperature or heating load, by designing or specifying a 'test-rig' which could be modelled.

The conclusions reached are:

a) The cell chosen emonstrates the consequences of using a range of building fabrics in practise i.e.

- Range of U-values
- Range of glazing
- Range of phase-shift etc.

b) The methodology, that is the design of a cell to show the greatest variation in thermal environment as a consequence of design decisions, is sound.

c) Thereby, lay building uses and public can get a first hand experience of design consequences, and perhaps their attitudes toward energy matters can be changed.

d) This work should be regarded as a pilot-study for a more rigorous project in future, using Algerian climate data.

FUTURE

1. First of all the design and construction of a physical test cell must be done as specified by the Building Regulations.

2. Then, redo the methodology with a far superior model, which can be selected from those available and especially taking account of the factors that were left out (see Omissions, Chp 3, section 3.5)

3. Finally, include provision in the cell for collection. Because in the methdology adopted the only system used is the direct gain. Therefore the same method could be used with the other systems i.e. sunspaces, Trombe Wall, mass wall, etc. A Wider range of thermal environment could then be reached.

4. CONCLUSION

0. 'Passive' and 'natural solar designs' are terms used to differentiate between the use of sunlight which provides warmth without the use of complicated controls, pumps and fans, from 'active solar designs' which employ solar collectors and fairly complex controls.

1. It is of interest to realise that active solar systems associated with large thermal storage could be used to provide all space heating and hot water requirements in a building, even in the U.K. On the other hand, passive designs could not be expected to achieve the same in Northern Europe, and such systems must be regarded as 'fuel savers'. In the southern USA and other countries (southern Europe and Algeria for examples) which have more intense and regular winter sunshine it is possible in cold but clear regions to rely entirely on passive solar space heating.

2. Apart from the insolation in a particular region, there are other constraints acting on the design team when considering passive solar buildings. For example, the density in housing layout varies regionally, and different sun-angles in differing locations introduce unique shading cycles for each project. The point is exacerbated because passive techniques usually rely upon replacing vertical opaque surfaces with glazing, rather than horizontal - and it is the vertical surfaces which are more subject to shading.

A comprehensive understanding of the interaction between the thermal properties of materials, climatic influences and thermal processes are needed by designers in order to achieve the desired results from low energy consuming building designs.

3. The great beauty of passive solar design is its fundamental simplicity, and there are many ways of harnessing solar energy through naturally occurring processes. Solar buildings do not have to be uniformly ugly or dull. Many different types of passive solar buildings have appeared in the past decade as designers have attempted to translate the simple principles of energy efficiency into comodious, economic and attractive buildings. Surprisingly many of these new energy efficient buildings look conventional, and easily blend into any residential or commercial development.

4. The sun's energy has been used to heat and cool buildings for thousands of years. Long ago, we learned to describe the movement and cycles of the sun and wind and to design buildings that derived comfort from responding to these movements. But more recently, modern developments in mechanical heating, ventilation and air conditioning systems allowed building design to deviate from natural cycles, no matter how divorced a building design was from its environment the mechanical system could make up for it. The price was in fossil-fuel energy which is now in short supply, and in psychic loss of identidy with the environment.

5. The more dramatical effect of depleted energy is the recent collapse of the oil price and for some countries, Algeria for instance, it means an economic crisis, Hence, if such countries i.e. which base the main income on oil (or fossil-fuel) do not take strong measures to save energy there will be facing irremediable banrupcies. Using the sun's energy is just one of the largely proceeding step to overcome the crisis.

Therefore, it is our duty, as architects, to persuade the politicians to educate people in matters concerning energy savings.
The publication of the large number of research papers, data lists, evaluation, produced the last few years in order to identify the characteristics of energy when used for space heating must lead to an irrefutable conviction that energy problems can be partly solved.

APPENDIX 1

1. Thermal Properties of Building Materials

    1.1 Mode Transfer

    1.2 Thermal Conductivity

        1.2.1 Factors affecting Thermal Conductivity

    1.3 Thermal Resistance

        1.3.1 Thermal Resistance of Multi-layer Element

        1.3.2 Heat Transfer between Surface and Air

            1.3.1(i) The Internal Surface

            1.3.1(ii) The External Surface

        1.3.3 Thermal Resistances of Air Spaces

    1.4 Thermal Transmittance - 'U'-value

        1.4.1 Case of Window

2. Heat Loss by Fabric

3. Heat Loss by Ventilation

4. Influence of Solar Radiation

    4.1 Emissivity - Absorptivity of Element

    4.2 Sol-Air Temperature

APPENDIX 1.

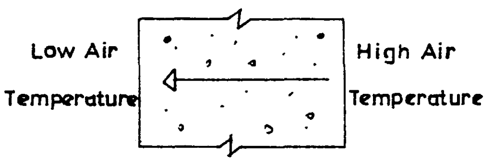
1. Thermal Properties of Building Materials

1.1 Mode Transfer

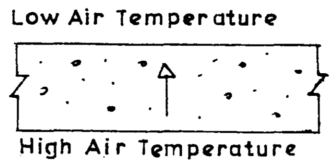
Heating engineering depends upon the transfer of heat from one place to another. As it is heated, a material seeks to achieve transfer processes: CONDUCTION - CONVECTION - RADIATION.

CONDUCTION

Walls



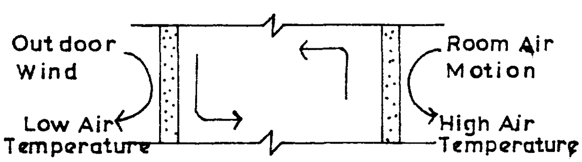
Roofs and Floor/Ceilings



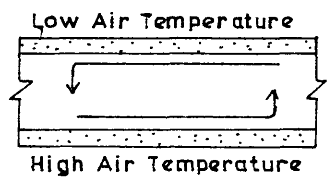
Conduction is the flow of heat through a material by transfer from warmer to colder molecules in contact with each other.

CONVECTION

Walls



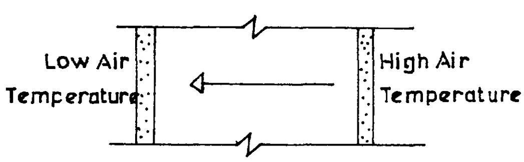
Roofs and Floor/Ceilings



Convection heat is transferred with the flow of molecules from one place to another with a change in their heat content.

RADIATION

Walls



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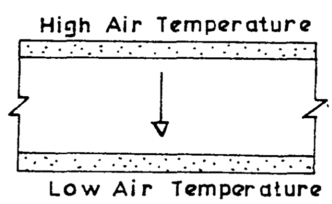


Radiation is the transfer of heat through space by electromagnetic waves.

Note: (The arrows indicate the direction of heat flow by conduction, Convection or Radiation. Little heat flows by convection in attic spaces during summer months)

The properties of materials which affects the rate of heat transfer in and out of a building, and consequently the indoor thermal conditions and comfort of the occupants are:

Thermal conductivity; resistance and transmittance.

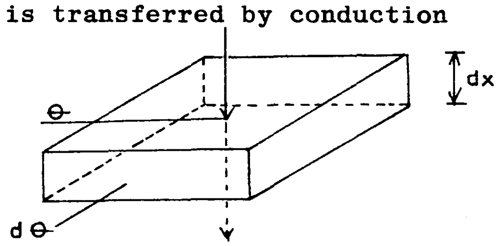
Surface characteristics with respect to radiation, absorptivity, reflectivity and emissivity.

Heat capacity.

Transparency to radiation of different wavelengths.

1.2 Thermal Conductivity

Within a body heat is transferred by conduction



According to the experimentally determined law for flow in one direction (Fourier).

$$dq = kA \left(\frac{d\theta}{dx}\right) dt \qquad (1)$$

where:

A is the area of the body perpendicular to the heat flow

$(d\theta/dx)$ is the temperature gradient

k is a characteristic property of the material called the thermal conductivity which is dependent on the capability of its molecules to send and receive heat.

If Q is the rate of heat flow between two falls then

$$Q = kA\ (t_1 - t_2) \qquad Js^{-1} \text{ or } W \qquad (2)$$

where:

$t_1 - t_2$ is the temperature difference between two faces

k is a constant

Tables giving the values of thermal conductivity for various building materials are published in the ASHRAE Handbook of fundamentals, the IHVE Guide.

1.2.1 Factors Affecting Thermal Conductivity

The value of the thermal conductivity is affected by both the density and the moisture content of the material.

Table (1.1)

Material	Density (Kgm^{3})	Thermal Conductivity (k) ($W/m^{2\,o}C$)
Brick work	1700	0.84
Concrete block	600	0.19
Paster	1300	0.5

It will be noticed from Table (1.1) that high density materials are generally good conductors while the low density materials tend to have a low value for k.

The thermal conductivity varies thus appreciably with density which is very much a function of porosity. Generally the less dense a material, the more air is contained between the pores or particules.

The thermal conductivity of water is about 25 times that of still air and it is thus not surprising that the replacement of air in the pores with water must have a significant influence on the thermal conductivity of the material.

1.3 Thermal Resistance - R

The thermal resistance is the ratio of thickness of the element to conductivity - ie. it is a measure of the resistance of the element to the flow of heat. Therefore:

Thermal Resistance, $R = e/k\ m^2 {}^oC/W$

A homogenous slab conducts heat at a rate that varies directly as the conductivity and inversely as the thickness. Hence:

$$Q = k/e \times A\ (t_1 - t_2) \qquad (3)$$

where

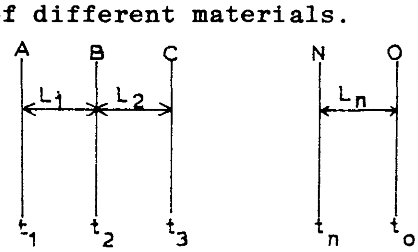
k/e = thermal conductance ($W/m^2 {}^oC$)

A = area (m^2)

$t_1 - t_2$ = surface temperature

1.3.1 Thermal Resistance of a Multi-layer Element

Consider a building element composed of a number of different layers each of different materials.



The innermost leaf of thickness L_1 and conductivity k_1, the next leaf of thickness L_2 and k_2 etc....

at A, inner surface temperature is t_1

at B, temperature between two layers is t_2..... etc;

at O, temperature at the outside is t_o

So the rate of heat flow per unit area between surfaces A and B is:

$$\frac{QAB}{A} = \frac{ki}{L_1}(t_1 - t_2) = \frac{1}{R_1}(t_1 - t_2) \qquad (4)$$

the rate of heat flow per unit area between B and C is:

$$\frac{QBC}{A} = \frac{k_2}{L_2}(t_2 - t_3) = \frac{1}{R_2}(t_2 - t_3) \qquad (5)$$

the rate of heat flow per unit area between N and O is:

$$\frac{QNO}{A} = \frac{k_n}{L_n}(t_n - t_o) = \frac{1}{R_n}(t_n - t_o) \qquad (6)$$

Let $\bar{R}$ = total resistance of entire element. Then, the rate of heat flow per unit area between A and O is:

$$\frac{Q}{A} = \frac{1}{\bar{R}}(t_1 - t_o) \qquad (7)$$

For steady-state condition the rate of heat flow per unit area between each surface must be the same, ie.:

$$\frac{QAB}{A} = \frac{QBC}{A} = \frac{QNO}{A} = \frac{Q}{A} \qquad (8)$$

Hence:

$$\frac{Q}{A} = \frac{1}{R_1}(t_1 - t_2) = \frac{1}{R_2}(t_2 - t_3) = \frac{1}{R_n}(t_n - t_o) \qquad (9)$$

if $\frac{a}{b} = \frac{c}{d} = \frac{e}{f} = \frac{a + c + e}{b + d + f}$

then $$\frac{Q}{A} = \frac{(t_1 - t_2) + (t_2 - t_3) + \ldots + (t_n - t_o)}{R_1 + R_2 + \ldots + R_n} \qquad (10)$$

But Q/A = 1/R therefore $\bar{R} = R_1 + R_2 \ldots + R_n$

ie: the total resistance = sum of individual resistance.

1.3.2. Heat Transfer between Surface and Air

Heat transfer that occurs between the external and internal surface of an element and the external and internal air can be treated as flow through thermal resistances.

1.3.2 (i) The Internal Surface

If it is assumed that Tai = internal air temperature and tsi = internal surface temperature then the rate of heat flow per unit area by convection is given by the approximate formula:

$$Qc/A = he\ (tai - tsi) \qquad (11)$$

and the rate of heat flow per unit area by radiation by:

$$Q_R/A = Ekr\ (tri - tsi) \qquad (12)$$

where hc = convection factor

E = emissivity

hr = radiation coefficient

Hence:

Total heat flow $= Q_R/A + Qc/A$

$$= Ehr\ (tmrti - tsi) + he\ (tai - tsi) \qquad (13)$$

where tmrti = mean radiant temperature as seen by inside surfaces. For most situations it is sufficiently accurate to assume that tmrti = tai. Therefore

Rate of heat flow per unit area at internal surface

$= Ehr\ (tai - tsi) + hc\ (tai - tsi)$

$$= (Ehr + hc)\ (tai - tsi) \qquad (14)$$

Let Rsi = internal surface resistance = $1/(Ehr + hc)$

then

Rate of heat flow per unit area at internal surface

$= (1/Rsi)\ (tai - tsi)$

$$Rsi = \frac{1}{Ehr + hc} \qquad (16)$$

where Rsi = surface resistance $M^{2o}C/W$

(1) hr = radiation coefficient $W/M^{2o}C$

(2) E = emissivity factor for normal temperature radiation

(3) hc = convection coefficient $W/M^{2o}C$

Using the equation (16) the inside surface resistances may be taken as follows:

Table (1.2)

Building element	Heat flow	Surface resistivity ($M^{2o}C/W$)	
		High emissivity surface (E=0.9)	low emissivity surface (E=0.05)
Walls	horizontal	0.123	0.304
Ceilings or roofs floors	upward	0.106	0.218
Ceilings & floors	downward	0.150	0.562

1.3.2 (ii) External Surface

In similar manner to that used for the internal surface it can be shown that the external surface resistance

$$Rso = 1/Ehr + hco \qquad (17)$$

Where Ehr can be taken as 4.14 $W/m^{2o}C$ (hr = 4.6 for mean surface temperature of 0^oC and E = 0.9)

In instances where air movement occurs over the surface the convection coefficient may be derived from:-

$$heo = 5.8\ 1+4.1\,v \qquad (18)$$

where v = wind speed, m/s

---

footnotes

(1) hr = 5.7 for a mean surface temperature of 20^oC
hr = 4.6 for a mean surface temperature of 0^oC

(2) E = 0.9 for ordinary building materials
E = 0.2 for dull aluminium
E = 0.05 for polished aluminium

(3) hc = 3.0 for walls (or heat flow horizonally)
hc = 4.3 for upward flow to ceilings
hc = 1.5 for downward flow to floors

Wind speed can have an important effect upon the rate of heat flow from an element hence the degree of exposure of a building has to be taken into consideration.

Consider three expanses, sheltered, normal and severe. Each one corresponding to a range of wind speeds. The corresponding values of hco (from equation 18) have been inserted in equation 17 to obtain the values listed in Table (1.3).

Table (1.3)

Values for Rso

Surface	Exposure	Wind speed (m/s)	hco ($W/m^2 {}^oC$)	Rso=1/Ehc + hco ($m^2 {}^oC/W$)
Roof	Sheltered	1.0	9.9	0.07
	Normal	3.0	18.1	0.045
	Severe	9.0	42.7	0.02
Walls	Sheltered	0.7	8.7	0.08
	Normal	2.0	14.0	0.055
	Severe	6.0	30.4	0.03

1.3.3 Thermal Resistances of Air Spaces

Air spaces can be treated as media with thermal resistances because the radiation and convection heat transfer across them is roughly proportional to the temperature difference between the boundary surfaces.

The thermal resistance of an air space depends on:

1. Surface emissivity
2. Thickness (ie width of cavity)
3. Direction of heat flow
4. Rate of air flow in the cavity

1.4 Thermal Transmittance - U. value

As shown earlier, the rate of heat flow per unit area for a composite element due to difference of surface temperature was

$$\frac{Q}{A} = \frac{t_1 - t_2}{R_1 + R_2 + \ldots + R_n}$$

It is possible thus to calculate the rate of heat flow due to the difference between an inside air temperature and an outside air temperature.

If tai = inside air temperature and tao = external air temperature then:

$$\frac{Q}{A} = \frac{tai - tao}{Rsi + R_1 + R_2 + \ldots + R_n + R_{so}}$$

Where U is defined as the thermal transmittance and is given by:

$$U = \frac{1}{\text{sum of resistances}} = \frac{1}{\Sigma R} \quad W/m^{2\,o}C$$

Therefore Q/A = U (tai - tao)

ie. the rate of heat flow per unit area, under steady-state conditions is equal to the thermal transmittance multiplied by the air-to-air temperature difference.

$$Q = AU\ (\Delta t) \quad .W \qquad (18)$$

1.4.1 Case of Windows

The thermal resistance of glass is assumed to be zero. Hence, the total resistance for a single sheet of glass is the addition of the external and internal resistance.

eg. for normal exposure

$$R = o.123 + 0.055 = 0.178\ m^{2\,o}C/W$$

Therefore:

$$U = 1/R = 5.6\ W/m^{2o}C$$

For double glazing the effect on air space has to be added

$$R = o.123 + 0.18 + 0.055 = 0.358\ m^{2o}C/W$$

thus

$$U = 1/R = 2.8\ W/m^{2o}C$$

As said earlier in order to assure a comfortable thermal environment certain components must be considered.

2.0 Heat Loss by Fabric

For steady-state the rate of heat flow through the fabric is given by:

$$Qf = AU\ (tai - tao)$$

tai = internal air temperature; tao = external air temperature

But the temperature difference between the inside and outside of a building is no longer expressed as the air-to-air temperature difference, but is given in terms of difference between the environmental temperatures on either side of the structure. Thus the internal air temperature is replaced by the environmental temperature, tei.

$$Qf = AU\ (tei - tao^*) \qquad (19)$$

*refer to sol-air temp. p.14

where

$$tei = \frac{1}{3}\ tai + tmrt$$

If the enclosed area has several external surfaces (walls, roofs, floors....) then the total fabric loss is given by:

$$Qf = \Sigma\ AU\ (tei - tao) \qquad (20)$$

3.0 Heat Loss by Ventilation

The rate of heat loss by ventilation is given by:

$$Qv = C\rho v \ (tai-tao) \qquad (21)$$

tai = internal air temperature; tao = external air temperature

c = specific heat capacity of air ($J/Kg^{o}C$)

ρ = density of air (Kg/m^3)

v = ventilation rate (m^3/hr) (the normal value for cC may be taken as 1.2 KJ/cm^3

Let Vol. = volume of enclosed space, n = number of air change per hour. Then volume to be heated = Volxn/3600

Therefore

$$Qv = \frac{1.2 \times 10^3 \times Volxn}{3600} \ (tai-tao)$$

$$= \frac{Volxn}{3} \ (tai-tao)\_W \qquad (22)$$

The heat loss from the building is then:

$$\Sigma Q = Qf + Qv$$

$$= \Sigma A\breve{U} \ (tei-tao) + \frac{Volxn}{3} \ (tai-tao) \qquad (23)$$

If the building is well insulated (ie. the elements have a low U-value) and there is a relatively small area of external surface, then it will be found that there is a little variation between the value of tei and tai. In that case the calculation can be based on tei ie.:

$$\Sigma Q = (\Sigma AU + \frac{Volxn}{3}) \ (tei-tao)$$

However, if there is a difference between tei and tai, eg. with convective heating then another method, should be used. This method has been developed by Loudon (20) and set out in the IHVE Guide. It involves the assumption of a conductance between environmental and air temperature such as: $\frac{1}{ha} = \frac{1}{hc} - Rsi$

where ha = conductance from environmental to air temperature

$hc = 3.0\ W/m^{2o}C$

$Rsc = 0.123\ m^{2o}C/W$

The difference between air and environmental temperatures can be calculated in terms of the heat flow through the conductance ha.

The heat flow paths can be represented as shown in Figure -a-

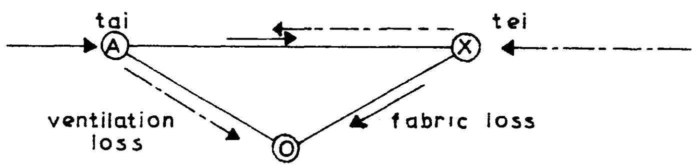


FIG. a

For convective heating systems with input to A, an equation may be written assuming that for steady-state conditions, the rate of heat flow from A to X must be the same as from X to O, ie.

$$\Sigma A\ ha\ (tai-tei) = \Sigma AU\ (tei-tao)$$

Therefore:

$$(tai-tei) = \frac{(\Sigma AU)}{(\Sigma Aha)}(tei-tao)$$

$$= \frac{\Sigma AU\ (tei-tao)}{4.8\ \Sigma A} = \frac{Qf}{4.8\Sigma A}$$

Similarly, for radient heating systems with input at X it may be shown that:

$$tei-tai = \frac{Qv}{4.8\Sigma A}$$

The expression Qv can be modified and written as

$$Qv = Cv\ (tei-tao) \qquad (24)$$

Where Cv = ventilation conduction and for convective heating

$$Cv = \frac{Volxn}{3}\left(1 + \frac{\Sigma AU}{4.8\Sigma A}\right) \qquad (25)$$

and for radiant heating:

$$\frac{1}{Cv} = \frac{3}{Volxn} + \frac{1}{4.8\Sigma A} \qquad (26)$$

4.0 Influence of Solar Radiation

The rate of heat flow (in both steady and fluctuating conditions) is affected by the radiant temperature as well as by the air temperature.

A high temperature source will radiate at a short wavelength and conversely a low temperature will radiate at a long wavelength. Hence at the inside surface, heat is transformed by longwave radiation from the surrounding room surfaces as well as by convection from the air. At the outside surface heat is received from solar radiation falling upon it, of this a proportion is transmitted by longwave radiation to sky and ground as well as convection to the outside air.

To take account of these aspects, it is necessary to define the temperature criteria appropriate to heat transfer as follows:

Internally: the environmental temperature (as defined before)
Externally: the sol-air temperature

4.1 Emissivity and Absorptivity

Before considering the sol-air temperature it is necessary to define the three properties, of the external surface of any opaque material, determining behaviour with respect to radiant heat exchange, namely its absorptivity, reflectivity and emissivity. Radiation impinging on an opaque surface, may be absorbed or reflected - being fully absorbed by a perfect 'black body' and fully reflected by a perfect reflector. Most surfaces, however, absorb only a part of the incident radiation, reflecting the remainder. If the absorptivity is denoted by 'a' and the reflectivity by 'r' then:

$r = 1 - a$

The emissivity of any body at a given wavelength is the ratio of its emission to heat of a 'black body' at the same wavelength.

$$E_{\lambda} = \frac{\text{Total power emitted per unit area of body}}{\text{Total power emitted per unit area by black body}}$$

Total power radiated = σAT^4 (Stefan - Boltzann Law)

where A = area (m^2)

T = absolute temperature (Kelvins)

σ = Stefan's constant = $5.710^{-8} W/m^2K^4$

4.2 Sol-Air Temperature

This is defined as the outside air temperature which in the absence of solar radiation would give the same internal temperature distribution (and heat flow through walls, roofs...) as exists with the actual external air temperature and the incident solar radiation ie.

Rate of heat flow due to solar temperature equals
Rate of heat flow due to solar radiation plus actual external air temperature

If tao, is the external air temperature; tso, the external surface temperature; Rso, the external surface resistance then:

Rate of heat flow at surface of fabric due to temperature difference per unit area equals (1/Rso)(tao-tso)

Let Ig = global irradiance on surface of fabric (direct and diffuse)

a = solar absorptivity of surface, then solar radiation absorbed per unit will be aIg. Hence:

Rate of heat flow at surface per unit area equals the flow due to actual temperature difference plus (+) gain due to solar radiation equals (1/Rso)(tao-tso) + aIg (27)

In addition to the heat flow the fabric will radiate heat to the sky and surroundings by longwave radiation. Therefore:

Heat loss by longwave radiation per unit area equals $E\ I_l$
where I_l = longwave radiation and
E = emissivity

Therefore:

Neat heat flow rate per unit area at surface
$= 1/Rso\ (tao-tso) + aI_g - EI_l$ (28)

Let teo= sol-air temperature, then the rate of heat flow at surface due to sol-air temperature is given by:

$(1/Rso)\ (teo-tso)$ (29)

But Rate of heat flow due to sol-air temperature equals
Rate of heat flow due to actual temperature difference
plus (I) Solar radiation effect

$(1/Rso)\ (teo-tso) = (1/Rso)\ (tao-tso) + \alpha I_g - EI_l$

This transposes to:

$teo = tao + Rso\ (aI_g - EI_l)$ (30)

where

teo = sol-air temperature (deg C)
tao = external air temperature (deg C)
Rso = external surface resistance ($m^2\ {}^oC/W$) (this is assumed to be 0.05 for walls and 0.04 for roofs in most applications)
a = absorption coefficient applying to the outer surface of a wall or roof.
Ig = intensity of direct and diffuse solar radiation on the outer surface (W/m^2)
E = emissivity of the outer surface to longwave radiation (this is assumed to be 0.9 except for dull and polished aluminium where values are 0.2 and 0.5 respectively)
I_l = longwave radiation from a black surface at air temperature (W/m^2)
(For a horizontal roof, a value of 100 W/m^2 may be taken for cloudless sky conditions. In the case of a vertical wall, it is assumed that the longwave radiation gain from the ground balances the longwave radiation loss to sky: I_l is thus zero).

APPENDIX 2

- MODELLING ENERGY TRANSFER IN BUILDINGS

CHAPTER 2

MODELLING ENERGY TRANSFER IN BUILDINGS

2.0 Introduction

A decade ago, basic data describing patterns of heat gain and loss in buildings were difficult to acquire; few architects had advanced innovative designs, and the financial information for comparing various options was unavailable. Today the situation is changing rapidly.

The common goal behind these diverse efforts is the reduction of the equipment costs, in use as well as in acquisition, and simultaneously decrease reliance upon fossil-fuels.

The basic principles being applied are quite straightforward; by using materials to slow down the rate at which internal conditions react to the variations in those external, and by admitting as much sunlight as possible during the heating season, the capacity of the necessary heating plant can be reduced, and in some circumstances eliminated entirely.

Different designs are, of course, needed for different types of buildings, climates and economic levels of operation. Nevertheless, in most cases the underlying principles are similar. The walls, roofs and windows of conventional buildings transfer a great deal of heat energy during periods of extreme temperature difference between inside and outside, due to the processes of conduction, convection and radiation.

As research progressed it became evident that retarding energy losses through the fabric was as essential as admitting sunlight through the glazing in order to minimise energy demand.

In order to get a better understanding of the thermal behaviour of buildings, this Section considers the thermal transfer equations used to compute the heating load of a building.

The first part examines the heat loss through the fabric by conduction, and due to ventilation.

Subsequently, in the second part, casual gains will be noted.

Finally, an examination is undertaken of those climatic parameters which most significantly effect the energy requirements of buildings.

2.1 Steady State Conditions.

Steady State means the assumption that the conditions in which the analysis takes place will endure indefinately, ie. that the internal and external temperature do not vary significantly throughout the time-span under consideration.

It is necessary to assess the effect of heat inputs on the internal temperature in buildings whether the purpose is to determine the winter heating or the summer cooling requirements.

The purpose is to assure a 'comfortable thermal environment', taking into account the external climatic conditions, the solar and other casual heat gains. To this end the combined effects of the following components must be considered:-

1) The heat transfer through the building fabric.

2) The heat transfer through ventilation air exchange.

2.2 A full understanding of the properties of building materials and heat transfer modes are desirable on the part of the reader in order to establish the fundementals of the energy balance.

Once these parameters are evaluated, the simplest way of estimating the thermal performance of a building is through the "U-value" technique, based upon the equation:-

$$\bar{q} = (\Sigma UA + Cv)\ (ti - to) \qquad (1)$$

where:-

q	= heat requirement	(w)
A	= area of a structural element	(m2)
U	= thermal transmittance of the element	(W/m2degK)
Cv	= ventilation loss	(W/K)
ti	= internal temperature	(degK)
to	= external temperature	(degK)

The equation is valid in situations where temperatures do not change significantly in time, ie. theoretical, or imaginary models only. It has greater valid if, when applied to buildings with little fenestration, in winter conditions of low external temperatures and little or no solar gains (19). It is a far poorer description of buildings designed to include passive solar gains on autumnal days when the sun appears intermittently through the clouds. There are also important reservations about the value of a technique based upon steady-state, one dimensional heat flow, to account for the problems of heat flow in building corners, thermal capacity, and inconstancy in the 'U-value' of the building fabric due, for example, to variation in moisture content. Alternatively, this description has the singular virtue of simplicity, and can be readily understood by those with basic mathematical ability.

2.3 Incidental Gains

Heat gains contribute towards heating of buildings during the cold season, and could be included in the assessment of heating loads; whereas during the warm seasons they can often lead to undesirably high temperature conditions within the building.

Heat gains arise from two sources:-

a) There are often internal gains produced from activity and equipment inside the building; these are known as casual gains, and,

b) Those sources arising from the outside climatic conditions leading to heat energy flowing into the building through the fabric. This is the direct result of either external air temperatures in excess of internal, or the effect of solar energy falling upon the building fabric coupled with the insolation entering directly through the fenestration.

2.3.1 Metabolic Heat

Animate bodies produce energy from the processes of food ingestion and digestion at a rate which depends upon the bodies' activity.

When work is performed, only a small part of the energy is used for mechanical work, and the remainder is transformed into heat.

The efficiency of the human body considered as a machine is about 25% at or near maximum effort; so that for every Watt of physical energy output, 3W are produced as heat, (3) (15) 1978. This internal heat production should balance heat losses and gains to and from the environment, if stabilized inner body temperature is to be maintained. Heat exchange between the body and the environment takes place through convection and radiation exchanges with the ambient air and the surrounding surfaces respectively. In addition, heat loss from the body by evaporation of sweat, and the exhalation of water vapour from the lungs, (see Figure 2.1), illustrates all the factors to be taken into account when considering human comfort and heat loss.

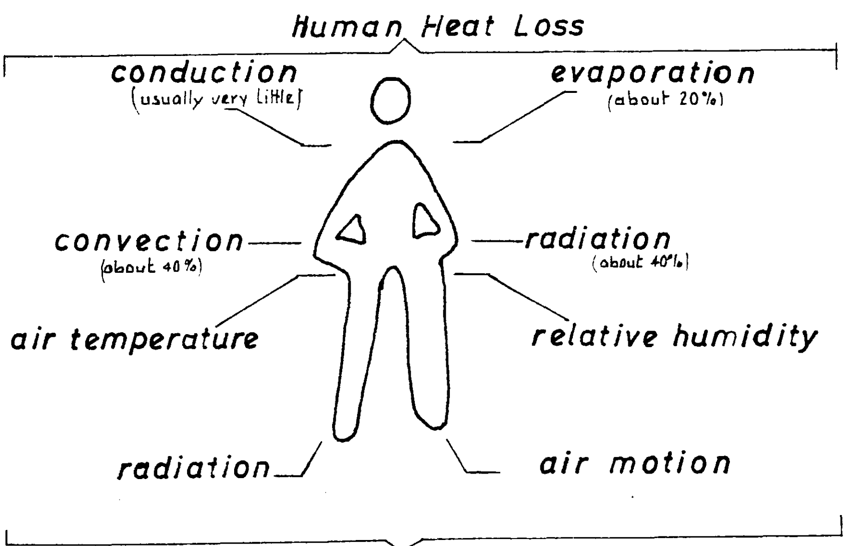


FIG 2.1 _ HUMAN COMFORT AND HEAT LOSS FACTORS _

The basic formula which describes the heat exchange between the body and environment is:-

$$M +/- R +/- C +/- E = Q \qquad (2)$$

where:

M = the metabolic rate

R = the radiative exchange

C = the convective exchange

E = the evaporative exchange and

Q = the change in the heat content of the body.

The heat is given off in two forms, sensible heat and latent heat. In straightforward ventilation problems, it is only necessary to take sensible heat into consideration; but if the air is to be conditioned, latent heat loads must also be included.

Table 2.1 shows the heat output from the human body as a function of activity.

2.3.2 Heat Produced by Artificial Lighting

With the high illumination levels sometimes required to perform certain tasks, light fittings can be a major source of heat production.

All lamps emit conducted, convected and radiated heat, and it is important that the relative proportions of these components are known. General values for these emissions are given in Table 2.2 below, for both fluorescent and tungsten light sources. (17)

TABLE 2.1 - TYPICAL VALUES FOR SENSIBLE AND LATENT HEAT

APPLICATION Degree of Activity	Typical	Total	Sensible (s) & Latent (1) Heat Emission, W. At the stated dry buld. Temperature, deg.C. 15 (s)	15 (1)	20 (s)	20 (1)	22 (s)	22 (1)	24 (s)	24 (1)	26 (s)	26 (1)
SEATED AT REST	Theatre Hotel Lounge	115	100	15	90	25	80	35	75	40	65	50
LIGHT WORK	Office Restaurant	140	110	30	100	40	90	50	80	60	70	70
WALKING SLOWLY	Store,Bank	160	120	40	110	50	110	60	85	75	75	85
LIGHT BENCHWORK	Factory	235	150	85	130	105	115	120	100	135	80	155
MEDIUM WORK	Factory Dance Hall	265	160	105	140	125	125	140	105	160	90	175
HEAVY WORK	Factory	440	220	220	190	250	165	275	135	305	105	335

TABLE 2.2 - ENERGY INPUT TO LIGHT FITTINGS

	Tungsten %		Fluorescent %	
Convection and Conduction	20		41	
Light	10		15	
Invisible Radiation	70		35	
Ballast	-		11	
	100		100	
Distribution of Energy confined within and outside luminaires of 50% efficiency confined within:				
Convection and Conduction	20		41	
Light	5		7.5	
Ballast	-		11	
Invisible Radiation	35	60	16.5	76
Outside				
Light	5		7.5	
Invisible Radiation	35	40	16.5	24
		100		100

In instances where a preliminary assessment of the heat gain due to the lighting load, is required prior to the establishment of the design arrangement, the figures quoted below in Table 2.3 may be used. (17)

It should be noted that the full lighting gain is unlikely to occur simultaneously with the direct solar heat gain through glazing. Regard must be given to the 'depth' of the space, because often core areas may receive insufficient natural lighting.

2.4 Daily and Seasonal Solar Variation

2.4.1 Terrestrial Geometry and Movement

The apparent movement of the sun through the sky is the result of the earth's rotation on its own exis every 24 hours whilst it describes an annual orbit around the sun every 365 days. In order to design buildings which precisely respond to direct radiation, the designer must be able to establish easily and quickly the sun's position for any instant throughout the year. (20)

The change in season is explained by the fact that as the earth orbits the sun. it's axis always remains at a constant slope to the solar disc, as depicted in Figure 2.2. This means that at its opposite point, half a cycle later, the axis is tipped towards the sun. These times are known as the summer and winter solstices.

TABLE 2.3 - CONNECTED LOAD FOR LIGHTING EQUIPMENT

LEVEL OF ILLUMINATION (LUX)	APPROXIMATE TOTAL REQUIREMENT, W/m^2 floor areas							
	TUNGSTEN		MERCURY	FLUORESCENT				
				65w WHITE			65w de Luxe Warm	White
	Open enamel Industrial Reflector (300w)	Genatal diffusing (200w)	MBF Industrial Reflector (250)	Enamel or Plastic Trough	Enclosed diffusing Fitting	Louvred Ceiling Panels	Enclosed diffusing Fitting	Louvred Ceiling Panels
200	25-32	32-45	-10-15	75	10	10	15-20	17-22
400	50-65	65-90	20-30	15	15-22	20	30-40	32-45
1000			55-75	32-45	42-55	45-65		

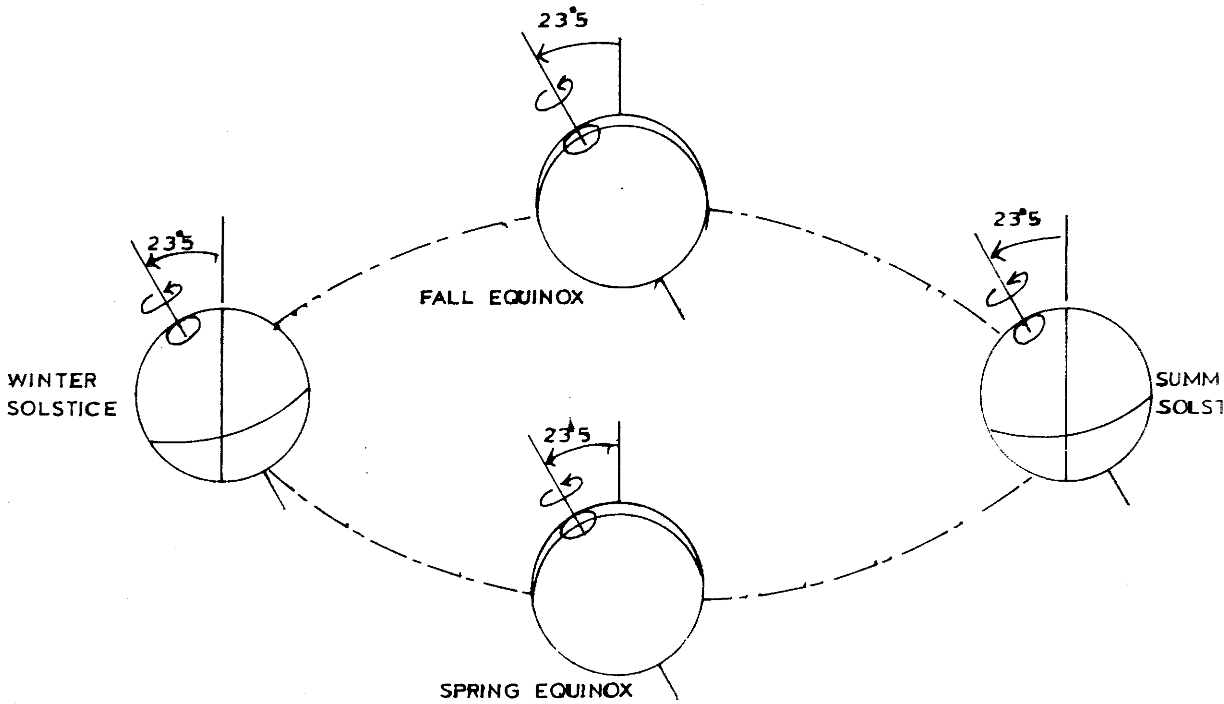


FIG 2.2 – EARTH'S ORBIT AROUND THE SUN –

There are two occasions in the annual cycle when the sun path coincides with the equator. These instances are known as the equinoxes, because the night-time darkness endures for exactly the same time period as the daylight.

At a point in the earth's orbit halfway between the solstices, the earth's axis is perpendicular to the incoming solar rays. Here the sun stands directly over the equator, and everywhere in the globe the day and night are of equal duration. These periods are known as the 'equinoxes. See Figures 2.3, 2.4, and 2.5

2.4.2 Solar Geometry

The sun describes an apparent path in the sky each day; it appears from below the horizon and rises through the zenith, (the highest point on it's path), of 90 deg. at noon at the equator on September 21st and March 21st, (the equinoxes), and on June 21st, (summer solstice), at the Tropic of Cancer - 23.5 deg. N, and on December 21st, (winter solstice), at the Tropic of Capricorn 23.5 deg. S.

The angle between the earth-sun line, and the earth's equatorial plane is known as the 'angle of declination'. Clearly this angle varies with the date, and the orbital velocity of the earth travelling around the eclliptic plane. This velocity has a small variation, thus a clock adjusted to run at a uniform rate will show slight deviations from 'true Solar Time' as determined, for instance, by a sundial.

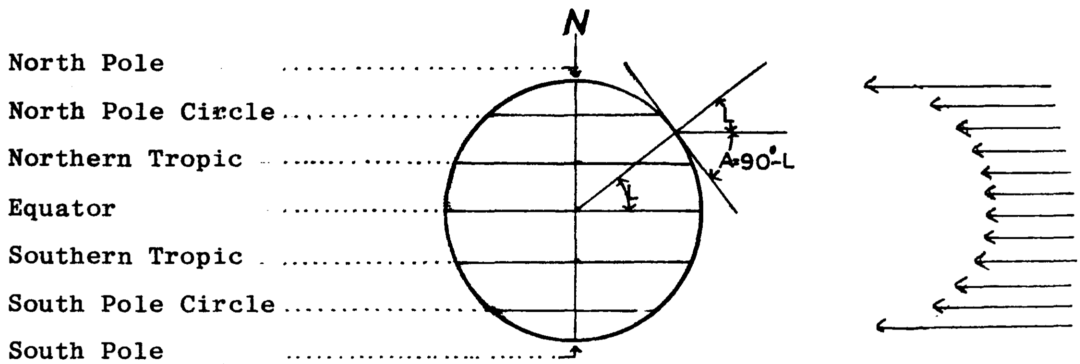


Fig. 2.3 - On the equinox the sun's altitude (a) at solar noon at any place on earth is equal to 90° minus the latitude (L)

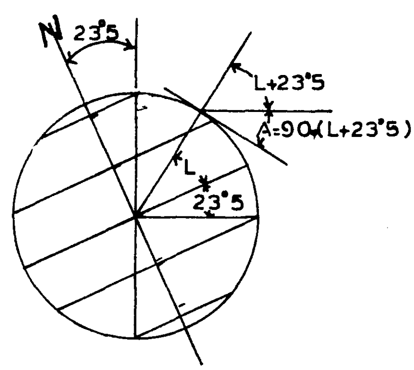


Fig. 2.4 - On the winter solstice the sun's altitude (A) at solar noon is 23°5 less than on the equinox.

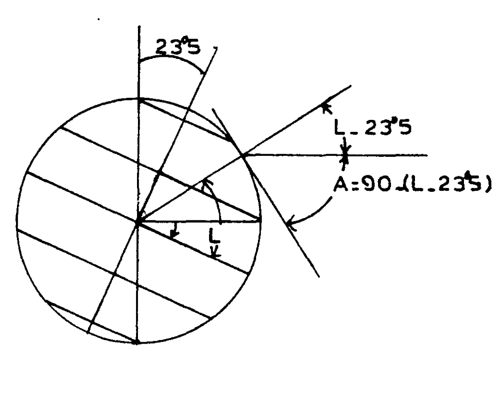


Fig. 2.5 - On the summer solstice the sun's altitude (A) at solar noon is 23°5 greater than on the equinox.

The positive or negative correction is known as the 'equation of time' - an amount that has to be added or subtracted from the uniform 'mean solar time' as indicated by the clock, to obtain true solar time; ie. the instant at which noon occurs simultaneously as the sun is due south of the observer.

The two angles which completely define the sun's position are the solar altitude, B, measured between 0 and 90 degrees above the horizon, and the solar azimuth, measured between 0 and 180 degrees from the south of the observer. Conventionally, the angle is considered positive when the sun is to the east, and negative when to the west of the observer.

To determine these two angles given the latitude and longtitude of the observer, and the instant at which the solar angles are required, the following calculation is carried out when the time is converted to H, the 'hour angle', expressed in terms of the earth's rotation. Thus :-

$$H = o.25 \times n \qquad (3)$$

where:

H = hour angle (in degrees)

n = the number of minutes from solar noon

then:

$$\sin b = \cos L.\ \cos d.\ \cos H + \sin L.\ \sin d \qquad (4)$$

and

$$\sin \emptyset = \cos d.\ \sin H \ / \ \cos B \qquad (5)$$

where:

L = latitude (degrees), and
d = declination (degrees)

Values of B and $\emptyset$ are tabulated in a number of Almanacs and guides. Computer programs exist to generate solar intensities for any given time, latitude and longtitude.

The altitude and azimuth, when known, allow further important angles to be calculated, (see Figure 2.6 overpage)

The first of these is the angle of incidence, ie. this is a vital piece of information, for the intensity of direct irradiance is a function of the angle of incidence, being a maximum when perpendicular to the irradiated surface. The angle of incidence is always measured from the normal to the surface, and intensity decreases in proportion to the cosine of the angle of incidence until it reaches zero at 90 deg. incidence.

The second set of angles are the shadow angles. These are the angles made on section, (the vertical shadow angle ε) and on plan, (the horizontal shadow angle δ). These angles allow the shadows cast, and sun-patches on both internal and external surfaces to be predicted.

The third angle is the 'surface solar azimuth', γ , ie. the sun angle adjusted for the tilt and orientation of the irradiated surface (17) (18). The relation between the azimuth and the surface solar, is depicted in Figure 2.6. It is calculated by use of the following equation:

$$\text{Cos}i = \cos B.\ \cos\gamma.\ \sin s + \sin B.\ \cos s \qquad (6)$$

where:

s = slope of the surface from the horizontal (degrees)

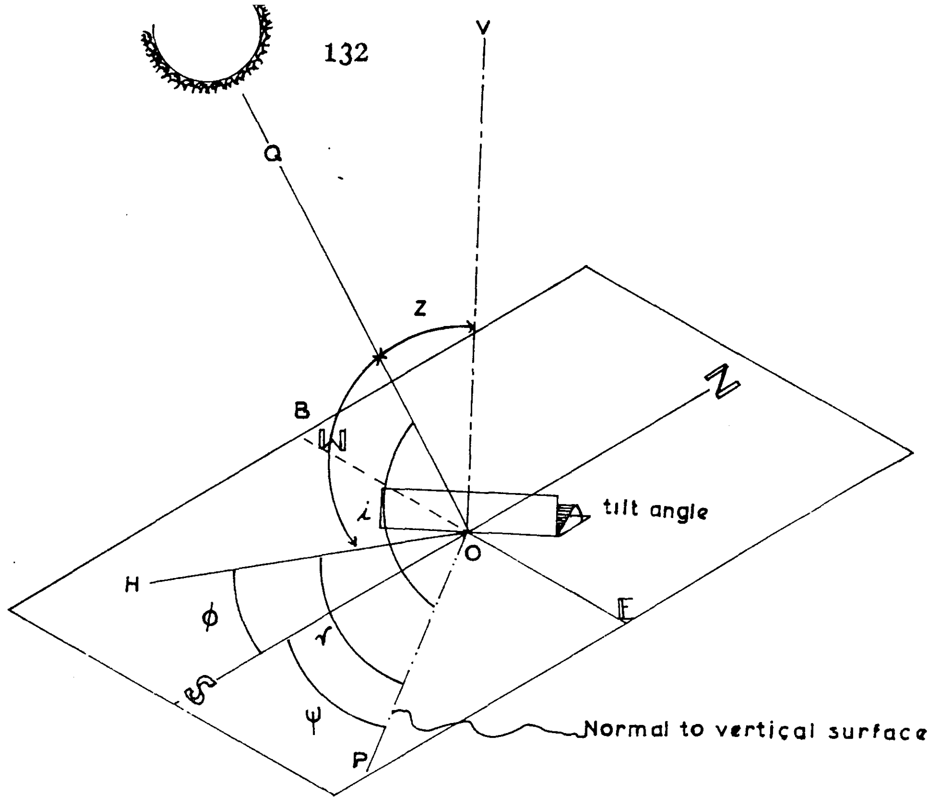
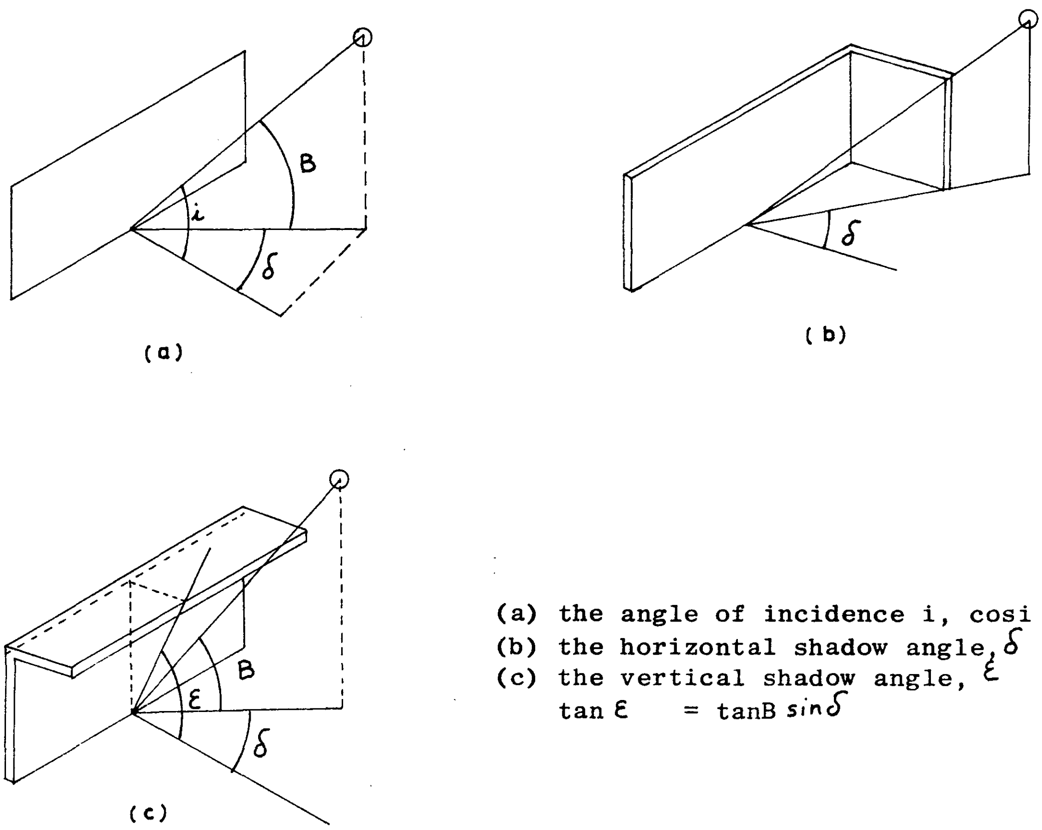


Fig. 2.6 - Solar Angles for Vertical, Sloping and Horizontal surfaces
solar altitude = B = QOH; Zenith angle = QOV = 90^{o} B
incident angle i = QOP; wall solar azimuth = SOP;
Azimuth γ = HOP.



(a) the angle of incidence i, cosi = cos cos
(b) the horizontal shadow angle, δ
(c) the vertical shadow angle, ε
tan ε = tanB sinδ

for vertical surfaces where s = 90 deg.

$$\cos i = \cos B . \cos \vartheta \qquad (7)$$

for horizontal surfaces where s = 0 deg.

$$\cos i = \sin B \qquad (8)$$

2.4.3 Effect of Land and Ocean Mass

Because of the daily rotation and the seasonal shift of the earth there will be differences regarding the local climate. (Corriolis effect due to the earth's rotation combined with convection currents). Even the land and ocean masses, and geographical location will interfere and shape different climates.

In the tropical zone, the solar energy causes a great upsurge of air which spreads out as it rises, and subsequently cools as it travels towards the poles to descent thousands of miles away. At the same time, air moves in to replace the rising air. The complicated sequences of air movement, allied with the eddies and secondary currents of the movement of heavy polar air, create an overall pattern of wind and weather. This is shown in Figure 2.7 below.

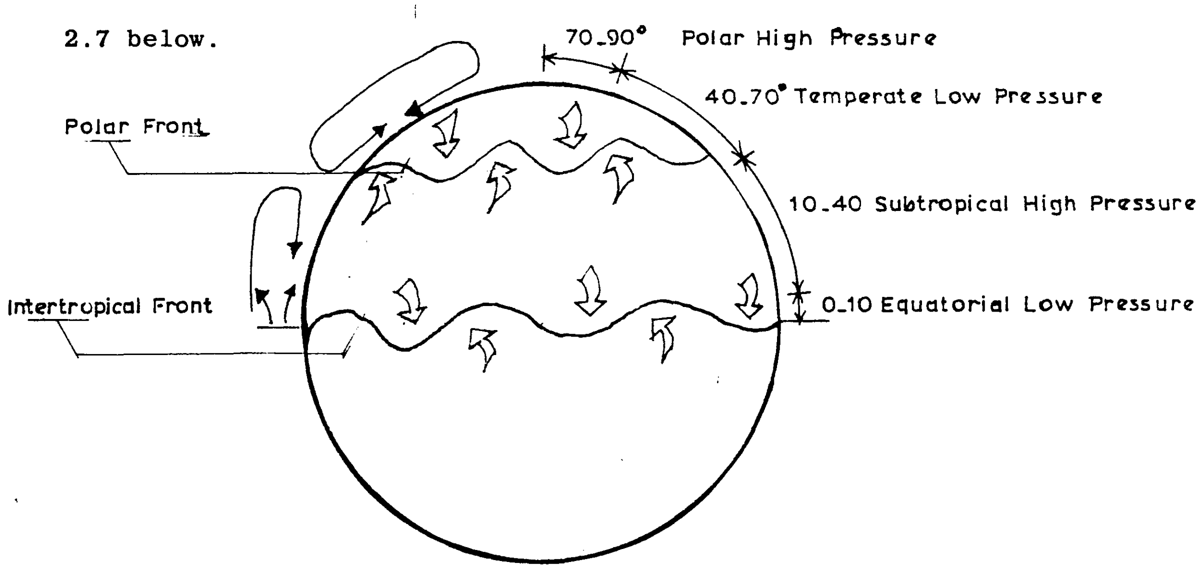


FIG. 2.7—GENERAL CIRCULATION OF WINDS (DIAGRAMATIC)—
N.B-This idealised pattern is modified by the distribution of land masses and oceans

However, the surface configuration of the earth is by no means uniform: the greater part, (more than two-thirds), of it's surface area is water, whilst the remainder is irregularly disposed land masses, which are concentrated in the northern hemisphere.

Radiant energy from the sun heats the land more rapidly than the ocean masses, giving rise to strong convection currents at the land/sea interface. Water, having a greater thermal mass than the land, is slower both to heat and cool. Locations far inland in continental masses are relatively unaffected by the oceans. Such areas have a diurnal temperature range far in excess of it's seasonal range.

All these variations in behaviour give rise to a complex pattern of air movement which is still further modified by the density and humidity of the air. Warm air passing over water absorbs vapour and becomes increasingly humid until that air becomes saturated. Cold air cannot hold as much vapour as warm. It is the interaction between these types of air, meeting each other as they swirl around driven by the basic global pattern, which establishes the sequence of high and low pressure systems.

Obviously, climatic conditions are almost impossible to predict with precision hence we have to rely upon statistical data if we wish to 'model' the thermal behaviour in buildings.

2.5 Solar Heat Gain through Opaque Elements - Non-Steady State

The method of calculation of solar heat gain described in the preceeding sections is applicable only under steady state assumptions. As this situation is seldom experienced in practice, it is mainly of theoretical interest. It does, however, give a valuable insight into the more complex problems of non-steady state (dynamic), energy flux.

As described in Appendix 1, the Sol-air temperature does not remain constant, and hence the temperature difference effective across a building construction also varies with insolation - a secondary function of time. Under these conditions, the 'U-value' of the construction alone is an insufficient index of it's thermal behaviour.

When the Sol-air temperature is varying, there is a time-determinancy which is a physical characteristic of the materials of construction. The thermal mass of the material will attenuate heat pulses in operation at it's exposed faces, and introduce significant time delays between casual fluctuations impinging upon the exterior face, and the subsequent attenuated effect emerging from the interior face. The difference between the thermal behaviour of lightweight and heavyweight structures in relation to transient heat flow due to solar radiation is discussed by van Straaten (23). (Thermal Performance of Buildings. Elsevier Publishing Co. 1967.) This is predicted in Figure 2.8 below. In Figure 2.8, the heavyweight material in Fig. (b), shows a greater attenuation and larger phase shift than the lightweight material in Fig. (a). The damping effect is known as the 'decrement factor', f , ie. the ratio of

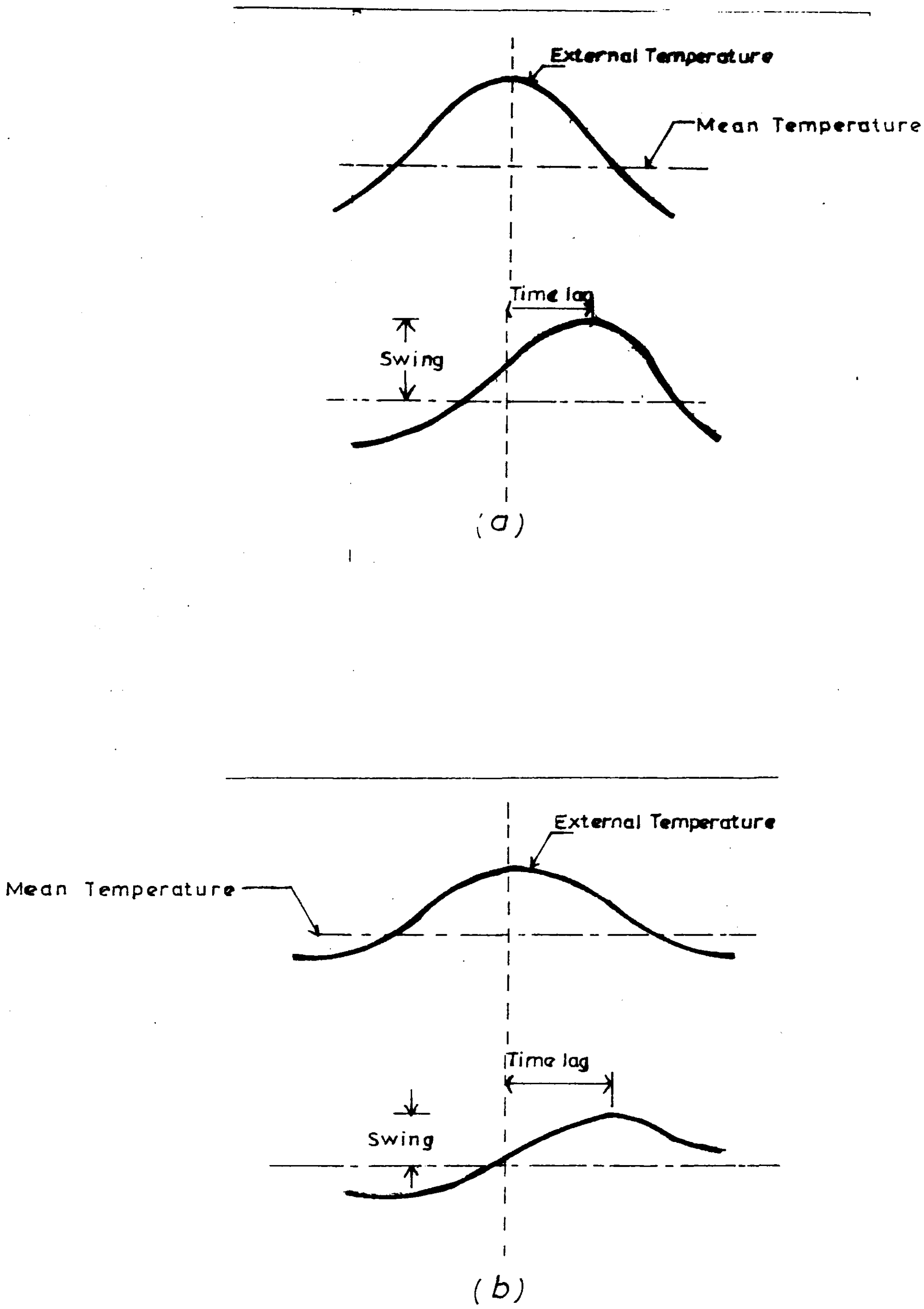


FIG. 2.8 EFFECT OF (a) LIGHTWEIGHT AND (b) HEAVYWEIGHT STRUCTURE

the maximum internal and external surface temperatures of the material. The increase in time-lag and damping effect are related to the heat storage effect, ie. the thermal capacity of the material. This is given by the equation:

$$T = c.p.V \qquad (9)$$

where:

c = the specific heat of the material (cal/grm. deg.C)

p = density (grm/m3)

V = volume of the material (m3)

T = thermal capacity (cal/deg.C)

The calculation of instantaneous solar heat gain through an element under periodic variations. occuring both at the inside and on the outside, are quite complicated.

Several methods are available in the cases where it can be assumed that there is a periodically varying temperature upon the outside, and a constant maintained temperature on the inner.

The analysis of such a situation is set out below:-

Let the constant internal temperature be $t\bar{e}i$, and the sol-air temperature to which the element is subjected be denoted by teo(θ). This notation indicates that this value of the sol-air temperature teo is variable in time θ . Let us further assume that the mean value of the sol-air temperature is $t\bar{e}o$. The value of teo(θ) at any instant can now be considered as the instantaneous deviation from its mean value, $t\bar{e}o$, ie.

$$teo(\theta) = t\bar{e}o + \Delta(\theta)$$

where:

$\triangle(\theta)$ = deviation of the sol-air temperature from its mean value (deg.C)

thus $\triangle(\theta)$ may be positive or negative.

The instantaneous heat gain through an element can now be calculated as two components:-

a) the mean sol-air temperature, $\bar{teo}$, and

b) the instantaneous deviation, $\triangle(\theta)$

In the first instance we assume that the element is subject to a constant sol-air temperature equal to $\bar{teo}$. Since in this concept $\bar{teo}$ and the indoor air temperature $\bar{tei}$ are both constant in time, this will result in steady-state heat transfer. Hence the total solar heat gain through the element $\bar{Q}$, is given by the following equation:

$$\bar{Q} = U.A.(\bar{teo} - \bar{tei}) \qquad (10)$$

thus $\bar{Q}$ represents the mean heat flow through the element over one full cycle.

In the second case we include the effect of thermal capacitance, and take into account the time-lag '$\emptyset$' and decrement factor 'f'.

If the value of the sol-air temperature $\emptyset$ hours before θ, be denoted by teo $(\theta-\emptyset)$, the deviation from the average heat flow rate, $\tilde{Q}$, can be expressed as follows:

$$\tilde{Q} = U.A.f\ (teo(\theta-\emptyset)-\bar{teo}) \qquad (11)$$

Equations (10) and (11) can be added to obtain the instantaneous heat flow under periodic conditions. Thus if $(Q)(\emptyset) = \bar{Q} + \tilde{Q}$, the value of $Q(\emptyset)$ is given by:

$$Q(\emptyset) = U.A.\ ((\bar{teo}-\bar{tei}) + f(teo-\bar{teo})) \qquad (12)$$

Equation (10) shows that $\tilde{Q}$ can be positive or negative, depending on whether teo is greater or less than $\bar{teo}$. It is clear that sometimes, (during the night for example), teo must be less than its mean value $\bar{teo}$.

2.6 Transmission of Solar Radiation through Glass

2.6.1 Introduction

The fact that glass and certain other translucent materials have virtually no thermal insulation value, and they transmit shortwave solar radiation with very little attenuation. Energy does not seem to be appreciated by many designers, but by placing careful attention to the potential difficulties associated with the extensive use of glass and other glazing materials, it is still possible to enjoy their advantages - long term durability, almost perfect surface finish, ability to transmit visible light and allow clear vision at the same time - without paying too high a price for thermal comfort.

2.6.2 Thermal Properties

The characterising property of materials such as glass is their ability to transmit radiant energy directly; this mainly involves the range of visible range of the electromagnetic spectrum - roughly 6000 to 9000 Angstrom, although infra-red is also involved.

On impinging onto a transparent of translucent surface, radiant energy is divided into three components:

a) A proportion is reflected, having no thermal effect on the material.

b) A further proportion is absorbed by the material itself, subsequently to raise its temperature or to be dissipated by the processes of conduction, convection or longer wave radiation.

c) The balance is directly transmitted through the material.

The relative proportions of these three components are determined by the angle of incidence of the incoming radiation, (depicted in Figure 2.9 ~~below~~). The unique property of glass, and some transparent plastics, which is responsible for their specific thermal characteristics is the differential transparancy in relation to the radiations wavelength. Thus whilst transmitting most of the radiation in the range of 0.3 to 2.5 microns, which approximately coincides with the range of the visible light in the solar spectrum, glass is completely opaque to radiation of longer wavelengths, around 10 microns.

Thus glass transmits radiation in a selective manner permitting solar radiation to penetrate into the building, and to be absorbed by the internal surfaces and objects and raise their temperatures. Then the heated surfaces emit radiation with a wavelength of about 10 microns which cannot be transmitted outwards through the glass. This process, known as the 'greenhouse effect', can be used to collect and concentrate useful solar energy.

When glass is subjected to solar radiation:

a) The energy transmitted through the glass at any given

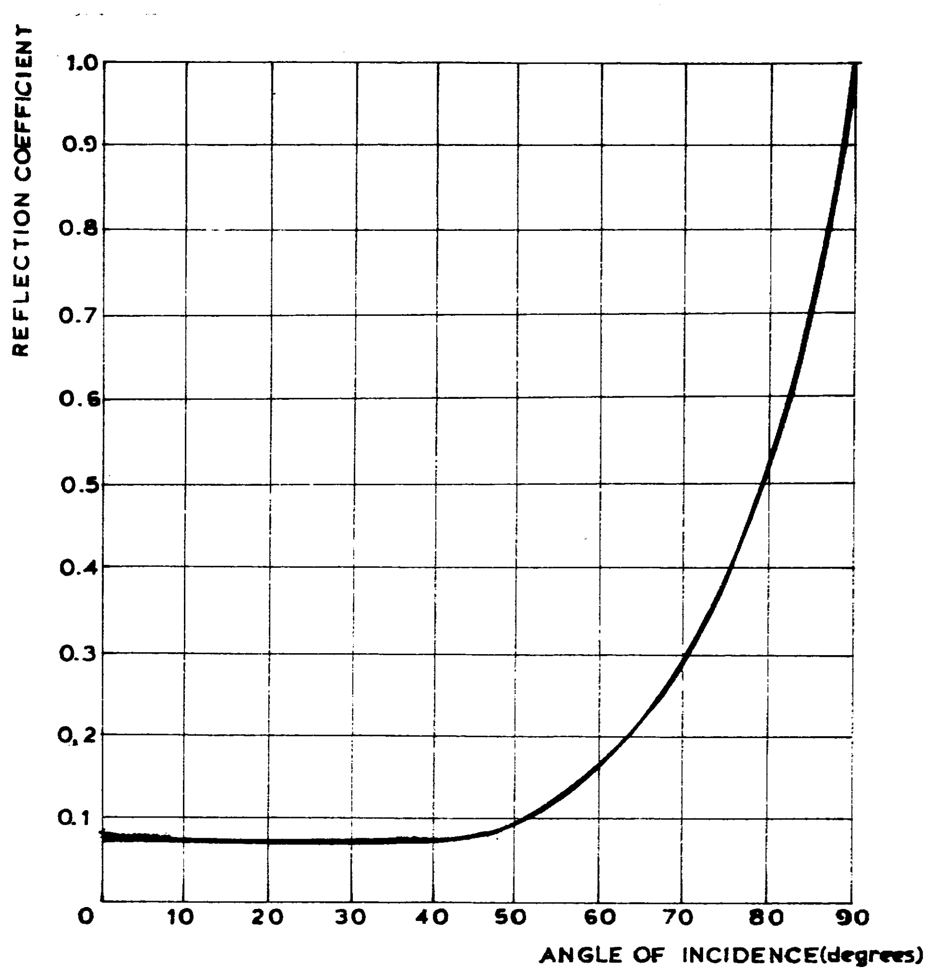


FIG. 2.9–THE CHANGE OF REFLECTION WITH ANGLE OF INCIDENCE–

wavelength is equal to the magnitude of the incident solar radiation, (normal to the glass), multiplied by the corresponding transmission coefficient.

$T = I \times Ct$ (13a)

b) The energy reflected by the glass is equal to the incident solar radiation multiplied by the reflection coefficient.

$R = I \times Cr$ (13b)

c) $Ct + Cr + Ca = 1$ (13c)

where:

Ct = the transmission coefficient

Cr = the reflection coefficient

Ca = the absorption coefficient

I = the incident solar radiation

Incoming radiation is attenuated and refracted by the interference caused by moisture vapour and cloud. Clouds diffuse the radiation, such that the incident radiation is composed of an element of uni-directional direct radiation coming from the cloudless sector of the sky, and an element of diffuse radiation which because of its scattering, is omni-directional.

In order to calculate the total energy being transmitted through glazing, both the direct and diffuse radiation have to be considered. the reason for this is that at any given time the incident direct radiation will strike the glazing at a particular sun-angle with a corresponding transmission coefficient, whilst the diffuse radiation will be the integral of the solid angle subtended by the glazed opening - obviously involving a different coefficient of transmission.

Typical values for different types of glazing are given in Table 2.4 overpage

2.7 Cyclical Heat Inputs

In consideration of the heat flows through the fabric of a building it has been assumed that the difference between the external and internal temperatures did not vary with time, ie. a steady-state condition.

However, due to the fluctuations in the external temperature, solar radiation and internal temperature, the real-life situation is dynamic.

There have been a number of analytic solutions proposed for this type of situation. Loudon (24), Billington (25) and others, have set out simplified approaches which, through approximations, are accurate enough to form the basis for practical decisions. For this analysis a 24 hr period is used, and the energy input into the building is assumed to be of sinusoidal form. The results of such analyses has been that the fluctuations in the internal temperatures in a space can be described by a property of that space terms the "room admittance".

The room admittance is a function of the admittance, (Y), of the sum of the admittances of the component elements enclosing it. Milbank and Harrington-Lynn, (26), define this as the reciprocal of the thermal resistance and impedence of an element to cyclic heat flow from the environmental temperature point, and has the

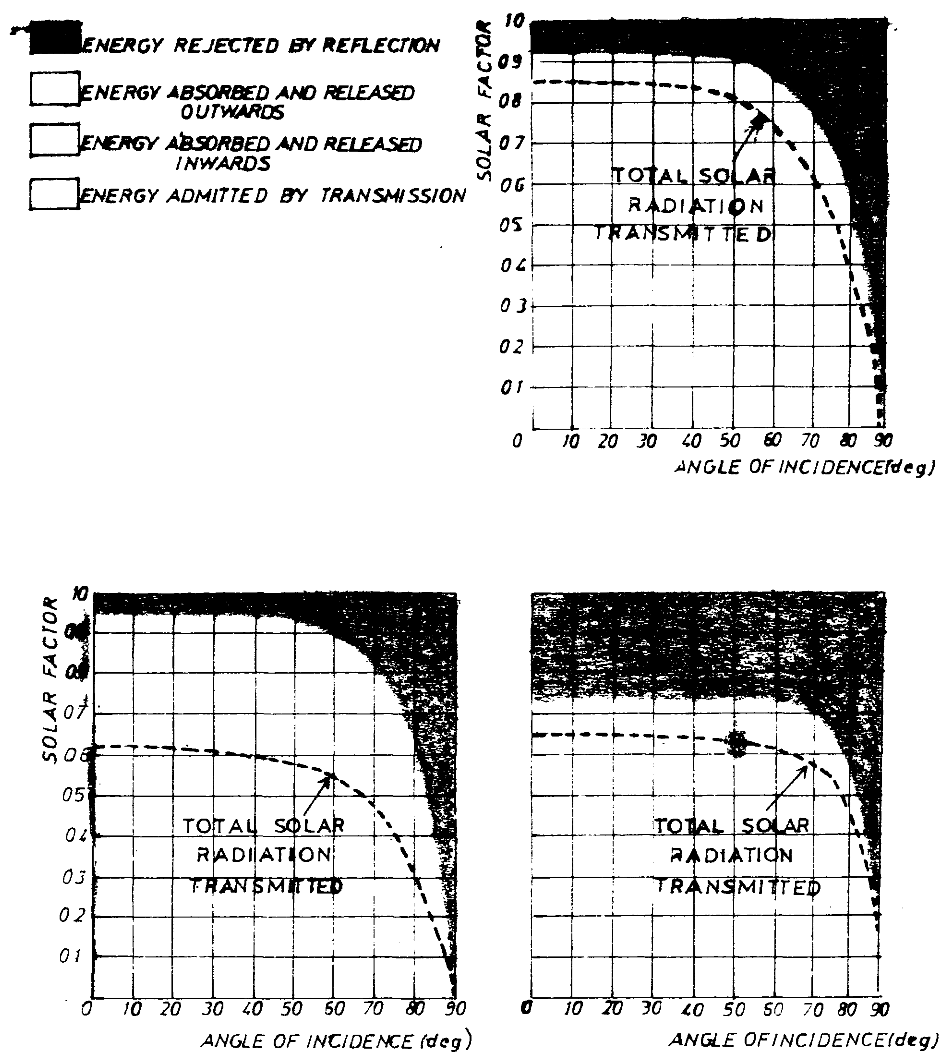


TABLE.2.4 TOTAL SOLAR RADIATION TRANSMITTED FOR A VARIETY OF GLAZING TYPES PLOTTED AGAINST THE ANGLE OF INCIDENCE

(a) FLOAT GLASS

(b) HEAT ABSORBING GLASS

(c) COATED CLEAR GLASS

same units as the 'U-value'. This means that for a given energy input the temperature swing is inversely proportional to its admittance; ie. the greater the admittance, the smaller the temperature swing.

$$Y = \tilde{q}/\tilde{t} \qquad (14)$$

where

$\tilde{q}$ = heat flux per unit area

$\tilde{t}$ = temperature flux

The factors which influence the admittance value of a particular material are the thermal diffusivity and its thickness. The diffusivity, D, is equal to the thermal conductivity divided by the volume and specific heat. This implies that dense materials are likely to have a higher admittance value than lighter materials. In addition, since the temperature swing varies inversely as the admittance, it follows that dense, heavyweight structures will have smaller temperature swings than lightweight.

Some typical admittance values are shown in Table 2.5 below.

Loudon, (20), shows that when the temperatures and rate of input are changing slowly, the ventilation heat flow can be added to that for the fabric, thus giving a simple equation for the environmental temperature swing, ie.

$$\tilde{t}ei = \tilde{Q}/(\Sigma AY + Cv) \qquad (15)$$

Considering the alternative heat input due to solar radiation; if $I'g$ = peak solar irradiance and $\bar{I}g$ = mean solar irradiance over a 24 hr period, then:

$$I''g = I'g - \bar{I}g \qquad (16)$$

where $I''g$ = alternative intensity

In the case of steady-state input. the radiation transmitted by the window was given by:

$$Q = S.\bar{I}gv.Ag \qquad (17)$$

where:

S = mean solar gain factor, (see Table 2.6)

$\bar{I}gv$ = incident solar radiation

Ag = area of glazing

However, for an alternating input, an alternating solar gain factor is necessary, (see Table 2.7). In which case the alternating heat input due to solar radiation transmitted by a window is as equation (17), with the substitution of the alternating solar gain factor.

In order to obtain the peak environmental temperature due to the alternating heat input, it is necessary to calculate the temperature swing, $\tilde{t}ei$, the peak/mean value. (see Figure 2.10 below)

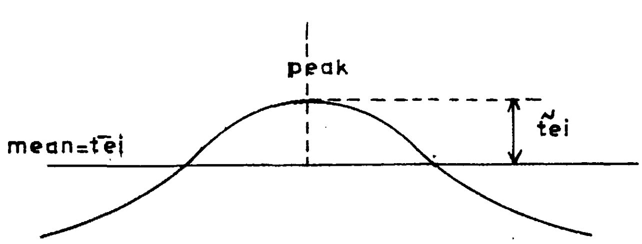


FIG. 2.10

TABLE 2.5 - ADMITTANCE VALUES

ELEMENT	ADMITTANCE Y ($Wm^{-2} K^{-1}$)
WALLS	
Cavity wall, 105mm brick inner and outer leaves. Deuse plaster on inside face	4.3
As above but lightweight plaster on inner face	3.3
Cavity wall brick outer leaf, lightweight concrete block inner leaf. Deuse plaster on inside face	2.9
As above but with 73mm polystyrene in cavity	3.0
ROOF	
Asphalt on 75mm lightweight concrete screed on 150mm dense concrete	5.1
Asphalt on fibre insulation board on hollow asbestos cement decking	1.9
Asphalt on cement/sand screed on woodwool slab on steel framing with plasterboard ceiling	1.45
INTERNAL WALLS	
Lightweight concrete block plastered both sides	2.55
Half brick plastered both sides	4.53
FLOORS	
Cast concrete with screed	5.6
As above with carpet or wood block	3.1
CEILING	
Floor unit: cast concrete with screed	5.6
Floor unit: as above with carpet or wood block	5.8

POSITION OF SHADING AND TYPE OF SUN PROTECTION		Solar gain factors (s) for the following types of glazing	
Shading	Type of Protection	Single	Double
NONE	None	0.76	0.64
	Lightly heat absorbing glass	0.51	0.38
	Densely heat absorbing glass	0.39	0.25
	Lacquer coated glass, gold	0.56	-
	Heat reflecting glass, gold (sealed with when double)	0.26	0.25
INTERNAL	Dark green open weave plastic blind	0.62	0.56
	White venetian blind	0.46	0.46
	White cotton curtain	0.41	0.40
	Cream holland linen blind	0.30	0.33
MID-PANE	White venetian blind	-	0.28
EXTERNAL	Dark green open weave plastic blind	0.22	0.17
	Canvas roller blind	0.14	0.11
	White louvred sunbreaker blades at 45^{o}	0.14	0.11
	Dark green miniature louvred blind	0.13	0.10

TABLE 2.6 - Solar Gain Factors (s) for various types of glazing and shading (strictly accurate for UK only, approximately correct world wide) -

POSITION OF SHADING AND TYPE OF SUN PROTECTION		Alternating solar gain factors (sa) for the following building and window types			
		Heavyweight Building		Lightweight Building	
Shading	Type of sun protection	Single	Double	Single	Double
	None	0.42	0.39	0.65	0.56
	Lightly heat absorbing glass	0.36	0.27	0.47	0.35
	Densely heat absorbing glass	0.32	0.21	0.37	0.24
None	Lacquer coated glass, Gold	0.37	-	0.50	-
	Heat reflecting glass, Gold (sealed unit when doubled)	0.21	0.14	0.25	0.20
	Dark green open weave plastic blind	0.55	0.53	0.61	0.57
Internal	White venetian blind	0.42	0.44	0.45	0.46
	White cotton curtain	0.27	0.31	0.35	0.37
	Cream holland linen blind	0.24	0.30	0.27	0.32
Mid-pane	White venetian blind	-	0.24	-	0.27
	Dark green open weave plastic blind	0.16	0.13	0.22	0.17
External	Canvas roller blind	0.16	0.08	0.13	0.10
	White louvred sunbreaker blades at 45°	0.08	0.06	0.11	0.08
	Dark green miniature louvred blind	0.08	0.06	0.10	0.07

TABLE 2.7 - Alternating solar gain factor (Sa) for various types of glazing and shading for heavyweight and lightweight building -

2.8 Summary

Currently, the most widely applied ways to consider the thermal design of buildings are based upon the concept of steady-state conditions, in which the heat entering a building is totally balanced by the heat loss, and the storage of heat in the fabric is totally ignored. Concepts such as the 'U-value' and the 'mamimum rate of heat loss' are based upon this approach.

Unfortunately, such steady-state concepts are unable to answer a number of questions that are being asked in the quest for energy conservation, where there is a need to improve our knowledge and understanding of the way in which buildings respond to fluctuating external conditions, and intermittent heat supply.

Although there are a number of ways in which the limitations of steady-state heat analysis are bypassed, for example, bv the Introduction of correction factors, many of these correction factors are based upon empiracal studies. Indeed, field studies are demonstrations, and are used to investigate both a wide range of energy conservation techniques, and to validate the efficacy of existing performance prediction methods. Nevertheless, field studies have often suffered from the absence of a comprehensive model to guide designers. Such a model, fully validated, would obviate the need for many of the expensive and time-consuming investigations that must otherwise be done.

APPENDIX 3

ANALYTICAL METHODS

3.1 Standardisation

Some methods are good tools for design purposes; other more complex, offer greater possibilities for research. There is however, little concensus on which is the best method, or on what the most desirable level of analysis should be.

Nevertheless, in 1981 the EEC assigned the task of 'standardisation' to the Passive Solar Modelling Group, created for the purpose. Their objectives were to co-ordinate European research into computer based thermal models. Comparative studies using 'bench-test' data have highlighted the variability of the different simulation models.

All simulation models have to account for solar input, and this presents two areas of difficulty. Firstly, the geometric aspects: Solar gain is delivered to different parts of the interior at different times of the day and season. Furthermore, obstructions both internal and external, effect the amount of incident solar radiation.

Secondly, solar radiation data is often available only for total quantities, ie. the sum total of direct and diffuse falling from all directions. Conversion to reliable figures for directional solar radiation is inherently difficult. The preceding problems do not of themselves explain the variance between models, but does illustrate some of the fundemental problems which can lead to such a situation.

It is accepted that there is a variance between the accuracy which can be expected and that which is required, (27). It is therefore, very important that model predictions are analysed and compared with experimental measurements in order that the validity of the model and its bounds of accuracy can be identified.

It is not our aim to analyse all mathematical simulation models currently available, but to briefly present a few in order to illustrate a certain range of problems. The seven models mentioned range from manual to dynamic simulation methods.

3.1.1 Method 5000

This is a manual method which has also been coded for micro-computer implementation.

Recognised by the Passive Solar Modelling Group of the EEC, it is well constructed and very comprehensive. It is oriented towards passive solar features, especially direct gain, sun-spaces, Trombe and mass storage walls.

It generates a monthly 'recuperation factor' taking all gains into account. This provides a useful initial indication of overheating risk. It accounts for overshadowing and site obstructions, and allows for the inclusion of ventilation pre-heating by drawing fresh air through a sunspace. (see section 3.6.1 for fuller description).

3.1.2 Casano

This is a computer program.

This presents a complete range of passive solar features, allowing for the possible simulation of all of the common range of passive solar devices. It comprises of two basic modules: the first of which is PASSIF, in which the monthly heating loads of the building is computed. The second module, COMFORT, predicts indoor air temperature swings due to direct solar gains, using built-in meteorological data. The program was developed for design purposes and not for research.

3.1.3 Spiel

Spiel is a sub-suite of a more comprehensive program called BRIEF. The graphic module calculates all surface areas, lengths and volumes necessary as input to the thermal module. This appears to currently be the only microcomputer program with a graphics interface and geometric building description, although it will accept manually compiled input files.

3.1.4 Seri-Res

This is a thermal simulation model intended for use in the design and evaluation of small buildings. It was created by the Ecotype Group, Seattle, Washington State, USA, funded by the US Solar Energy Research Institute. It models a building as a thermal network which is driven by hourly weather data. The building may be subdivided into climatic zones, and each zone may have its own heating and usage regime. Internal temperature, casual gains, ground temperature and shading may be scheduled both hourly and seasonally. Thermostatically controlled fans, rock bin thermal storage and vented Trombe walls are explicitly provided for in the input to the model.

3.1.5 ESP

ESP is a major finite difference model for implementation on mini or mainframe computers. It was developed at the ABACUS Unit, University of Strathclyde, Glasgow, and has been accepted as a modelling method by the EEC Passive Solar Modelling Group. There is very little simplification of the required input data, and consequently it is of more use as a research than a design tool. It reflects the state-of-the-art in machine representation of the physical phenomena involved in energy flows through buildings. It consists of several modules which specify the geometric description, the climate, shading, occupancy regime and the desired input data. (see section 3.6.2 for fuller description).

3.1.6 Suncode

Suncode is a very convenient package which can be mounted upon minicomputer. For the smaller offices it probably represents the optimal model available. However, because it is designed to fit on a minicomputer it suffers restrictions.

3.1 .7 Blast 3

This program has a framework which accommodates all of the necessary routines, but being based upon response factors with a 'time-history', it does not cope well with rapid changes, such as the deployment of moveable insulation. This model is research oriented.

Tables 3.1 overpage compares some of the simplified models, whilst Table 3.2 indicates those features handled by the four dynamic models.

The comparison of the simplified models is based upon a bench test using the data for both the Liege and Los Alamos cells. The respective specifications are set out in Table 3.3 below.

Table 3.3 Specifications for the Test Cells

Characteristics		Liege Cell		Los Alamos Cell	
Length (m)	(m)	1	External	2.3	Internal
Height (m)	(m)	1		2.8	
Width (m)	(m)	1		1.4	
Glazed area (m^2)	(m^2)	0.36		4.1	
U-value Wall (North)	w/m^2k	0.76		0.34	
(East/West)	w/m^2k	0.76		0.34	
(South Opaque)	w/m^2k	0.76		0.39	
Floor	w/m^2k	0.31		0.21	
Roof	w/m^2k	0.76		0.27	
South Window	w/m^2k	5.6		5.6	
Specification		Raised off Ground		All in contact with ground	
Thermal Mass	Wh/k	Restricted to plasterboard 50		1230	

Table 31 COMPARISON OF SOMME SIMPLIFIED MODELS

		TYPE OF HARDWARE	MANUAL		MICRO COMPUTERS	
		NAME OF THE METHOD OR PROGRAM (Country)	METHOD 5000 (F)	LOS ALAMOS (USA)	CASAMO (F)	SPIEL (UK)
		BUILDING DESCRIPTION				
		_BUILDING DESCRIPTION	Numeric	Numeric	Numeric or graphic	Numeric
		_DATA ALTERATION	Complete new input	Complete new input	Interactive	Interactiv
INPUTS		CLIMATIC DATA				
INPUTS		_HOURLY/DAILY MONTHLY	Monthly	Monthly	Monthly	Monthly Dai (generated by the pg itself)
INPUTS		_SUPPORT OF CLIMATIC DATA	Tables	Tables	Disk	Disk
INPUTS		HUMAN DATA				
INPUTS		_OCCUPANCY PATTERNS	YES	YES	YES	YES
INPUTS		_COMFORT CONTROLING DATA	NO	NO	NO	YES
PASSIVE SOLAR CHARACTERISTICS		SOLAR HANDLING				
PASSIVE SOLAR CHARACTERISTICS		_SEPARE DIFFUSE SOLAR HANDLING	YES	YES	YES	YES
PASSIVE SOLAR CHARACTERISTICS		_GROUND REFLECTION IN ADDITION TO WEATHER DATA	YES	YES	YES	YES
PASSIVE SOLAR CHARACTERISTICS		PASSIVE SYSTEMS MODELLING CAPABILITIES				
PASSIVE SOLAR CHARACTERISTICS		_DIRECT GAIN	YES	YES	YES	YES
PASSIVE SOLAR CHARACTERISTICS		_SUNSPACES	YES	YES	YES	YES
PASSIVE SOLAR CHARACTERISTICS		_TROMBE WALL	YES	YES	YES	YES
PASSIVE SOLAR CHARACTERISTICS		_MASSE WALL	YES	YES	YES	YES
PASSIVE SOLAR CHARACTERISTICS		_ROOF POND	NO	NO	NO	YES
PASSIVE SOLAR CHARACTERISTICS		_THERMOSIPHON	NO	NO	NO	YES
PASSIVE SOLAR CHARACTERISTICS		_WATER WALL	NO	YES	YES	YES
PASSIVE SOLAR CHARACTERISTICS		MOVABLE SHADING				
PASSIVE SOLAR CHARACTERISTICS		_OUTDOOR	YES(not mov)	YES (not mov)	YES(not mov)	YES(not m
PASSIVE SOLAR CHARACTERISTICS		_INDOOR	NO	NO	NO	NO
CALCULATION METHODS	BUILDING	NUMBER OF SPACES WITH INTERACTION BETWEEN SPACES	1 heated any nbr of unheated spaces	1 heated + any nbr of buffer zones	1 heated + up to 4 unheated zones	10 nodes maxim (ie less than 10 n
CALCULATION METHODS	BUILDING	AUXILIARY SYSTEM				
CALCULATION METHODS	BUILDING	_ EFFICIENCY	NO	NO	NO	YES
CALCULATION METHODS	BUILDING	_SYSTEM INERTIA	NO	NO	NO	YES
CALCULATION METHODS	CLIMATE	SHADING EFFECT +	YES	YES	YES	YES
CALCULATION METHODS	CLIMATE	HOW SCHEDULED?	Monthly	Monthly	Monthly	Daily
CALCULATION METHODS	CLIMATE	MOVABLE INSULATION +	YES	YES	YES	YES
CALCULATION METHODS	CLIMATE	HOW SCHEDULED?	Day/Night	Day/Night	Day/Night	Day/Nigh
CALCULATION METHODS	CLIMATE	MIN/MAX TIME STEP OF CALCULATIONS	Month	Month	Month	Hour Mon
CALCULATION METHODS	COMFORT	MEAN RADIANT TEMPERATURE	NO	NO	NO	YES
CALCULATION METHODS	COMFORT	STRATIFICATION OF ROOM AIR TEMPERATURE	NO	NO	NO	YES
CALCULATION METHODS	COMFORT	MOVEMENT OF AIR BETWEEN ZONES	YES	NO	YES	YES
OUTPUTS		TYPE OF INFORMATION				
OUTPUTS		_ROOM AIR TEMPERATURE	YES	NO	NO	YES
OUTPUTS		_HEATING/COOLING LOAD	YES/NO	YES/NO	YES/NO	YES/YES
OUTPUTS		_ENERGY REQUIREMENT	YES	YES	YES	YES
OUTPUTS		_DAILY/MONTHLY/ANNUAL	M A	M A	M A	M
OUTPUTS		FORMAT				
OUTPUTS		_NUMERIC	YES	YES	YES	YES
OUTPUTS		_GRAPHIC	NO	YES(graph)	YES	YES
COMPUTER	MAND	TYPE OF HARDWARE (MINI MICRO)			MICRO	MICRC
COMPUTER	MAND	SIZE TO RUN THE PROGRAM (K WORDS)	MANUAL	MANUAL	60K	48 K
COMPUTER	MAND	LANGUAGE OF PROGRAM			BASIC	BASI

TABLE 3.2 - FEATURES HANDLED BY THE FOUR DYNAMIC MODELS

Topic Handle Machine Type		ESP Dec 10/ Prime 450 Honeywell 6060 HP 3000	BLAST CDC	DEROB4 CDC	SUNCODE Dec 10 and VAX
DESIGNS	Direct Gain	√	√	√	√
	Attached Sunspace	√	√	√	√
	Thermosiphon	-	√	√	√
	Roof Space Collector	√	√	√	√
	Double Envelope	difficult	x	difficult	x
	Mass Wall Vented	√	√	√	√
	Mass Wall Unvented	√	√	√	√
	Under Floor Rock Beds	√	√	√	√
PHYSICAL PROBLEMS	Air/Heat movement by convection/by fans	√	√	√	√
	Infiltration	schedule	schedule	schedule	schedule
	Variable glass emissivity	x	x	√	√
	Variable room colour	√	√	√	√
	Effect of furnishing	difficult	difficult	difficult	x
	Air/temperature/ stratification	x	x	√	x
	Movable window insulation	schedule	schedule	schedule	schedule
	Isothermal and non-isothermal storage	√	√	√	√
	Phase change walls	x	√	x	√
	Isolated storage	√	x	√	√
	Adequate handing of beam radiation	√	√	√	√
	Adequate treatment of sky temperature	x	x	x	x
Weather input - Complete 'set'		√	√	√	√
	Daylighting	√	√	√	x
Surface temperature for providing comfort temperatures		√	difficult	√	√
Documentation		very good	poor	good	very good
Graphics output		excellent	x	excellent	x
Building input via digitising tablet		√	x	in principle	-
Building input format		Cartesian	Cartesian	Assemble stand and shapes	-
Internal tables of construction parameters such as infiltration values		√	√	x	√
Is it continuing to be improved		√	√	√	√

The test runs have been used to emphasise the differences between the models, and to determine whether the 'advice' they give the designer is consistent. However, these studies didn't give any validation of the models which could have been done by comparing the outputs obtained with a program (with the theoretical hypothesis and simplifications) with parameters measured on the field by the use of measurement tools.

3.2 Review of Method 5000 and ESP.

3.2.1 Method 5000

The method 5000 is a simplified method of calculation which gives an evaluated annual and monthly heat load to be provided by a conventional heating system, (28). The method was devised in order to assess the entries for a competition for the design of 5000 solar-aided houses in Jan 1980. The current version keeps the general principles of the competitions method:

i) Monthly calculation,
ii) computation of heat losses,
iii) 'G-value',
iv) Calculation of the 'utilisation factor' as a function of climatic data and building losses.

The improvements in the current version over its predecessors include a finer evaluation of solar gains, the taking into account of collector systems such as air collectors and mass walls. It has also a better definition of the casual gains, (occupancy), and the thermal inertia of the building than previous versions.

The method may appear lengthy to users. This is due as it was intended to be as explicit as possible, and also to handle many passive solar configurations without assuming fixed values for their characteristics.

The comupation is done with the assumption that the dwelling is heated by a perfectly regulated system. The heating load found is then an "optimal performance" of the heating system. This definition has the merit of depending only on the buildings characteristics and not of those of the heating system. The thermal performance of a building is very sensitive to the care with which it has been constructed on site, and the assumption of air infiltration rates, and thermal conductivity coefficients taken from tables of physical data will seldom reflect those present in the actual building, irrespective of the care devoted to the execution of the calculations. Thus the running performance of the building will have a closer correlation to the actual weather rather than on the long term average used in analysis. (Whether this is critical to the accuracy of the pronostications is debatable). The usage regime of the building will be the strongest influence on its performance.

The following presentation describes the general principles and sequence of the method of calculation.

The necessary terms for the calculation are divided into three 'types':

i) Those concerning the ENVIRONMENT, essentially climatic data; external temperature and solar insolation. These are long-term mean monthly values. The solar insolation can be modified by cloud cover, overshadowing - both current and future etc.

ii) Those concerning the casual gains, (occupancy regime). They are taken as a daily mean value which is proportional to the occupied volume, and

iii) Those concerning the building envelope. They are all the physical and geometric values of the envelope in terms of physical composition of walls, surface absorptivities and emissivities etc. Some of these parameters may be variable such as the opening and closing of windows, shutters etc. Others are related to the form and disposition of the collectors, which can effect the amount of solar energy transmitted through the structure - particularly relevent where the building form causes self obscuration to sunlight.

The heat requirement is thus calculated monthly, and is divided into three areas of energy flux labelled A to C: These are:

A. The heat loss through the fabric of the envelope, including for ventilation losses (allowing for heat recovery devices), and air reheated by buffer spaces.

B. Calculation of the solar energy collected by the passive solar devices; external glazing, open loop air collectors (coupled or not to a heat exchanger on exhausted air), sun-space with or without preheated air, mass wall, and Trombe wall (thermosiphon or not).

C. Calculation of the useful solar and internal gains. The crux of the method is the utilisation factor taken from correlation curves. It is represented as a function of 'raw' solar and internal gains and the mean monthly outdoor temperature, the G-value of the house (heat loss - $W/m^{3o}C$) and the thermal mass of the house.

This is followed by the calculation of the 'B-value': in accordance with the 1982 Regulations (29).

Corresponding documentation is included with the Method which steers the user through the calculation system if it is carried out manually. These forms give intermediate results that might guide the user, or allow him to change variables as the design proceeds through the calculation process.

3.2.2 ESP (Energy Simulation Program)

ESP dynamically models the energy transfers between a number of climatic zones which together comprise a building.

Its objective is to make possible a rigorous appraisal of any proposed or existing building design, either as an essential aid to an economic selection of installed plant and associated control regines, or to suggest appropriate energy design strategies. Because of the large amount of information required for input, building proposals have to be in an advanced state of detailed design, and is thus an expensive and time consuming process.

ESP departs from the CIBS methods (as described in Section 3.5) of calculating the thermal performance of buildings, and employs instead an implicit numerical technique of balanced heat flows by conduction, convection and radiation through the building structure.

The system is suitable for investigating traditional or advanced technological features, (attria for example), and has been structured to focus attention at the buildings energy performance.

It's output facilities enable the user to get answers to questions such as:

the time of peak loads,
the magnitude of casual energy contributions,
the environmental conditions existent during extreme climatic influences, or restricted or no plant operation,

the energy requirement over any desired period,
the effects of physical design changes,
the interzone energy transfer,

as well as getting useful information in the attempt to 'optimise' performance. This allows the designer to identify potential problem areas, appropriate design modifications, best-fit plant operational strategies, comfort levels, fabric performance, condensation risks, and most importantly, the inter-relationship between design and performance parameters which can be carried forward to influence the starting point of future projects. Figure 3.8 illustrates the relationship between ESP's disperate models.

3.3 Summary

Mathematical simulation models are invaluable design aids for studying the performance of solar heating systems at comparatively low cost. There are however, a number of considerations that will limit their utility.

1. Simulation models should be adequately validated in order to establish their accuracy. Validation exercises are currently advanced for active but less so for passive systems. Knowing the bounds of accuracy of the models and the ranges over which they may be used is more important than achieving highly precise results. This is particularly true with simplified models.

2. A simulation model is of little use to anyone other than its author unless it has a comprehensive user guide and is very well documented. This is often neglected because the models are being continuously upgraded, and because effective documentation is extremely expensive, painstaking and time consuming to produce.

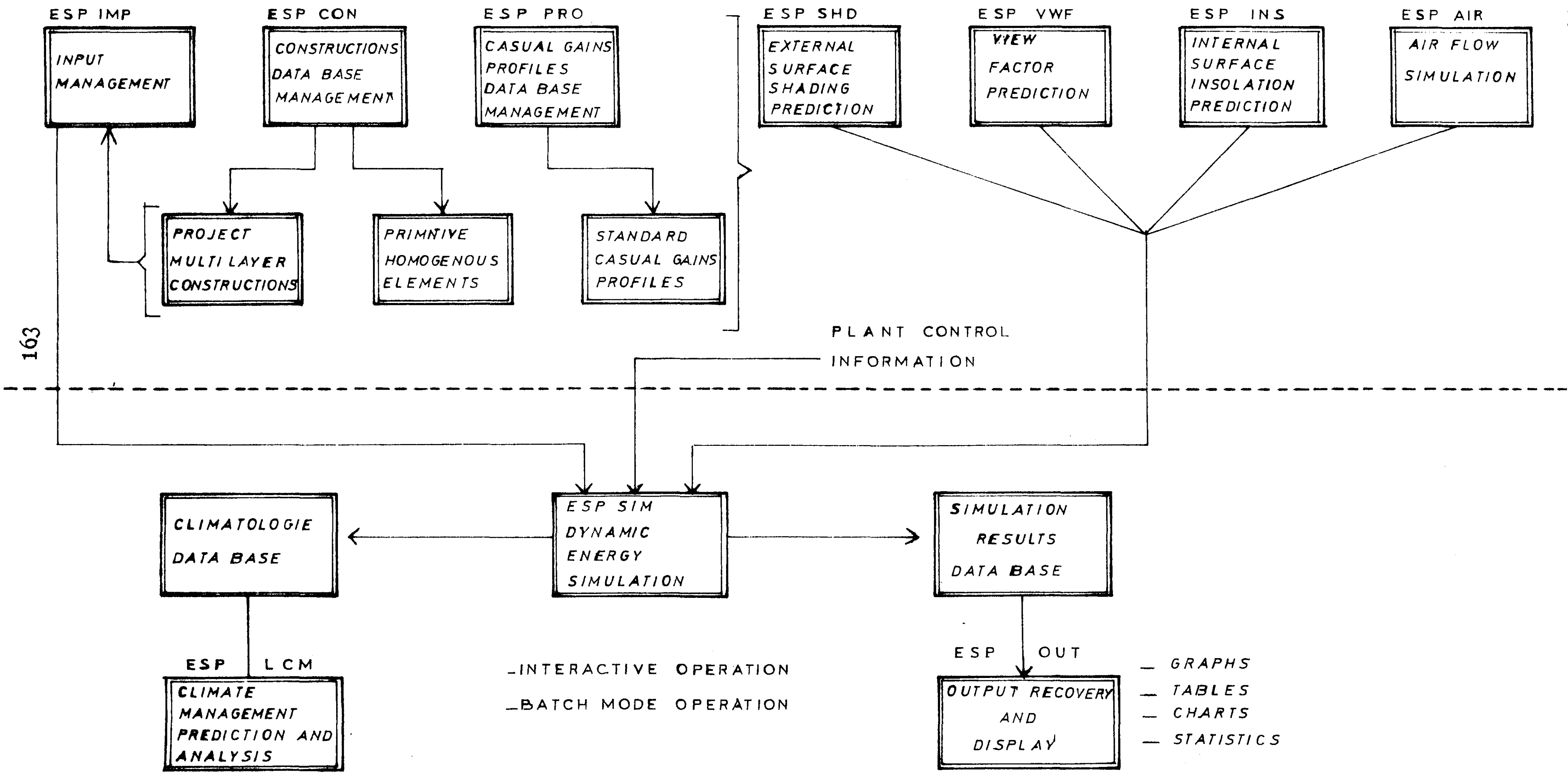


FIG-3.1_THE ESP LOGIC_

Lack of documentation is possibly the most serious handicap restricting their more general use.

3.4 Simulation models will be of most use if they were more readily available to building designers. This is being achieved slowly by the steadily decreasing cost and increasing power of mini and microcomputers. However, simplified and more approachable simulation models should be created with machine portability in mind.

REFERENCES

1. J.K. Page - 'The Optimisation of Building Shape to Conserve Energy ' - Journal of Architecture Research No. 3, 1974

2. Olgyay and Olgyay and Assoc. - Application of Climate Data to House Design - Housing and Home Finance Agency Edition, Washington, 1953

3. B. Givoni - 'Man, Climate and Architecture' - (2nd Ed) Applied Science Publishers Ltd, 1976

4. Edited by H.F.C. Sherat - London, New York, E & F.N. Spon - Applications of Ambient Energy in Buildings.

5. Digest of U.K. Energy Statistics, 1984 D.O.E. H.M.S.O.

6. The Watt Committee on Energy - 'The Rational Use of Energy ' - Report No. 3 Feb, 1978

7. G. Leach, C. Lewis, A Van Burren, F. Romig, G. Foley, ' A Low Energy Strategy for the United Kingdom ' - The International Institute for Environment and Development - Science Reviews, 1979

8. Final Report F137/84/89 - 'Low Energy Houses in the City of Manchester' - Manchester City Council

9. Building Services - 'Insulation' - Mar 1985, p.45 49 and 'Does it pay to Save it ,' - Apr 1985, p46 and 48.

10. Architecture Journal - 'Energy Savings in Domestic Buildings' - 10 Apr, 1985, p 61 - 72.

11. R. Van Chi Bonnardel - The Atlas of Africa - Prepared and Published by 'Jeune Afrique' - Africana Publishing Co.

12. A Mekkideche - Le Secteur Des Hydrocarbures - Office des Publications Universitaires, 1981

13. M. Boudiaf, M. Capderou, M. Janowski - Village Solaire Integre - Etudes Techniques des Trois Prototypes du Solaire Integre - CRAW - Mar 1983.

14. Hassen Fathy - 'Construire Pour Le Peuple' - La Bibliotheque Arabe - Sindbad.

15. Process Architecture No. 6, 1978

16. D. Balcomb, J.C. Hedstrom, R.D. McFarland - Passive Solar Heating of Buildings - Los Alamos Scientific Laboratory, LA 7433 - Ms. Oct 1978.

17. I HVE Guide

18. D. Jacob & H. Lotz - 'Estimation de l'Energie Solaire Disponible en Algerie - Communication au 2 eme Seminaire franco - Algerien (Cmrs - Prides/ Onrs) sur l'energie solaire - Gif. sur - Yuette. July, 1979.

19. J.W. Weller; A. Joule - 'Thermal Energy Conservation - Building and Services Design - Applied Science Publishers Ltd 1981

20. S.V. Szokolay - World Solar Architecture - The Architectural Press London, Halsted Press Division - John Wiley & Sons, New York, 1980

21. E.L. Harkness, M.L. Mehta - 'Solar Radiation, Control in Buildings' - Applied Science Publishers Ltd, 1978

22. J. Crowley, L.Z. Zimmerman - 'Practical Passive Solar Design ' - A Guide to Home building and Land Development - An Energy Learning Systems Book McGraw -Hill Book Co, 1984

23. J.F. Van Straaten - 'Thermal Performance of Buildings' - Elsevier Publishing Co. 1967

24. A.G. Louolon - 'Summertime Temperature in Buildings' - Building Research Station Current Paper 47/68, 1968

25. N.S. Billington - Building Physics: Heat - Pergamon Press, Oxford, 1967

26. N.O. Milbank, J. Harrington - Lynn - 'Thermal Response and the Admittance Procedure' - Building Research Establishment Current Paper 61/74, 1974

27. Modelling Sub-Group Report - Research Programme in the European Communities

28. Methode 5000

29. Regles Th. B 32 : Calcul du Coefficient Volumique Des Besoins de Chauffage des Logements - Centre Scientifique et Technique du Batiment, Avril 1982

30. N. Cherouati - Climates and Passive Solar Systems - Thesis for Msc. Strathclyde University, 1984.

- '5000 Maisons Solaires' - Ministere de l'Urbanisme et du Logement - Agence Française pour la maitrise de l'Énergie Editions du Moniteur - Paris 1983

- 'Regional Guidelines For Building' - By the AIA Research Corporation - Washington DC - Passive Energy Conserving Homes - US Department of Housing & Urban Development - Office of Policy Development & Research in Cooperation with the US Department of Energy - 1980

- 'Passive Solar Architecture in Europe 2' - The Commission of the European Communities - Edited by R. M. Lebens - The Architectural Press LTD. London.

- 'Development of National Resources in the Provision of Energy in the United Kingdom. 1975 - 2025 -' The Watt Committee on Energy - Report N: 2. August 1977

- 'Energy Simulation in Building Design' - J.A. Clark Adam Hilger Ltd - Bristol & Boston - 1985

- 'Environmental Science in Buildings' - *R. Mc Mullan - The Mc Millan Press Ltd 1983.*

FURTHER READING - BIBLIOGRAPHY

A. Journal 1. 11 May 1983: Atria and Conservation -1-
2. 18 May 1983: Atria and Conservation -2-
3. 25 May 1983: Atria and Conservation -3-

4. Applications of Solar Energy for Heating and Cooling of Buildings
ASHRAE F.

5. ASHRAE Handbook of Fundamentals, Published by American Society of Heating, Refrigerating and air-conditioning Engineers, 1972

6. Building Science (Special Supplement,) Pergamon Press 1975.

7. Building Services - Dec 1984 (P. 34-38)

8. Climatic Design L. Watson, FAIA and Kenneth Labs. McGraw Hill Book Company - 1983

9. Combining Energy Efficiency with Architectural Design - RIBA Journal Oct 1984

10. Computing Method in Solar Heating Design, J.R Simonson Mac Millan Press, London

11. Designing and Building a Solar House. D. Watson

12. Design Methods for Passive Solar Buildings U.K. Section of the International Solar Energy Society (U.K. Ises) Conference Proceeding (C.34) Oct 1984

13. Design with Climate N. Olgyay (1963) Princeton University Press

14. Design with Energy. The Conservation and Use of Energy in Buildings. J. Littler and R. Thomas, Cambridge University Press

15. Energy - Efficient Buildings - W.R. Wagner Jr. The Editors of Architectural Records Magazine.

Energy File. A. Journal

16. 24 Oct 1979 - Predictions of Thermal Performance -1-
17. 31 Oct 1979 - Predictions of Thermal Performance -2- Peak Summertime Temperatures
18. 7 Nov 1979 - Predictions of Thermal Performance -3- Degree Day Method
19. 14 Nov 1979 - Predictions - Case Studies -4-

Energy Primer - A. Journal

20.	12 May 1982	:	Issues
21.	19 May 1982	:	Strategic Design
22.	26 May 1982	:	Detailed Design
23.	9 June 1982	:	Design Methodology
24.	16 June 1982	:	Principles
25.	16 June 1982	:	Thermal Techniques
26.	23 June 1982	:	Economic Techniques
27.	30 June 1982	:	Micro-Computer Aids

Energy Management - Oct 1984

28. Low Energy Houses in Manchester
29. External Wall Insulation can reduce
Condensation
Maintenance and Costs

30. Low Energy Houses in the City of Manchester.
Energy Conservation

31. A Low Strategy for the U.K. - G. Leach, C. Lewis, A Van Baren

32. Modelling and Monitoring Solar Thermal Systems - Conference (C23) at the Geological Society, London Oct 1980 U.K. Section of ISES

33. Monitoring Solar Heating Systems - A Practical Handbook Commission of the European Communities - Pergamon Press.

34. Natural Solar Architecture - A Passive Primer - D. Wright, Cia Environmental Architect

35. Passive Solar Architecture in Europe -2- R. Lebens

36. The Passive Solar Energy Book E. Marzia

37. Passive Solar Heating Design. R. Levens

38. Passive Solar Housing in the U.K. D. Turrent

39. Passive Solar in Milton Keynes. R. Everett Research Report ERG 031.

40. Proceeding of the 3rd National Passive Solar Conference San Jose - California - January 1979 Vol 3.

41. Regional Guidelines for Building Passive Energy Conserving Houses. U.S. Development of Housing and Urban Development.

42. RIBA Journal Oct 1983 : Studies for Low Energy Housing.

43. Second U.K. Passive Solar Conference U.K. ISES Nov 1981

44. Solar Architecture - Proceedings of the Aspen Energy Forum 1977 - GIE Frantu, KR Dison

45. Solar Energy Building. S.Y. Stokolay. The Architectural Press Ltd, London

46. Solar Energy in the 80's Edited by Costia - Stambolis Pergamon Press

47. The Solar Heating Design Process. J.F. Kreider

48. Solar House in Europe - How they have worked - edited by W. Pale and T.C. Steemers.

49. Solar Thermal Energy in Europe - Solar Energy R & D in the European Community Series A - Vol 3 - D. Turrent

50. Solar Radiation, Control in Buildings. E.L. Mackus & M.L. Mehta. Applied Science Pub. Ltd 1978