CRANFIELD INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL ENGINEERING

Ph.D. THESIS

Academic Year 1985-6

M.K. AL-MOTAWAKEL

SOLAR ENERGY APPLICATIONS IN THE YEMEN ARAB REPUBLIC

Supervisors: Dr. B. Norton
Professor S.D. Probert
Dr. J.C. McVeigh
CONTENTS

ACKNOWLEDGEMENTS i - ii

GENERAL SUMMARY iii - v

CHAPTER 1: ENERGY USED DOMESTICALLY IN THE YEMEN ARAB REPUBLIC 1 - 40
  Glossary and Nomenclature 2 - 7
  Survey Aims 8
  Classification Scheme 9 - 14
  Housing Statistics 14 - 17
  Prospects for Passive Solar-Energy Applications with respect to Yemeni Housing 17 - 19
  Energy Balance 19 - 34
  Consumption per Head of Population 34 - 39
  Conclusions and Recommendations 39
  References 40

CHAPTER 2: SOLAR INSOLATION UPON THE YEMEN ARAB REPUBLIC 41 - 58
  Glossary and Nomenclature 42 - 44
  Ambient Energy in the Yemen 45 - 50
  Solar Radiation Modelling 50 - 53
  Efficacy of the Predictions 53 - 55
  Conclusions 55 - 57
  References 58

CHAPTER 3: THERMAL BEHAVIOURS OF VERNACULAR BUILDINGS IN THE YEMEN ARAB REPUBLIC 59 - 102
  Glossary and Nomenclature 60 - 68
  Mathematical Model of the Steady-State Heat transfer behaviour 69 - 74
  Justifications for Employing the Steady-State Approach 74 - 88
  Application of the Model 88 - 91
  How to Use the Model 91 - 94
  Deductions and Recommendations 95 - 99
  Conclusions 99 - 102
  References 102
# CONTENTS (cont)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAPTER 4: SOLAR ENERGY HARNESSING PERFORMANCES OF DIRECT-GAIN AND TROMBE WALLS UNDER YEMENI WEATHER CONDITIONS</td>
<td>103 - 153</td>
</tr>
<tr>
<td>Glossary and Nomenclature</td>
<td>104 - 112</td>
</tr>
<tr>
<td>Introduction</td>
<td>113 - 114</td>
</tr>
<tr>
<td>Utilizability Method</td>
<td>115 - 120</td>
</tr>
<tr>
<td>Mathematical Model</td>
<td>121 - 134</td>
</tr>
<tr>
<td>Physical Meanings of the Dimensionless Parameters Used in the Study and their Relations to the Commensurate Ones of the Utilizability Method</td>
<td>135 - 138</td>
</tr>
<tr>
<td>Applications and Results</td>
<td>139 - 150</td>
</tr>
<tr>
<td>Conclusions</td>
<td>150 - 151</td>
</tr>
<tr>
<td>References</td>
<td>152 - 154</td>
</tr>
<tr>
<td>APPENDIX 1: Arabic-to-English Translation of the 1982 Energy Survey</td>
<td>155 - 171</td>
</tr>
<tr>
<td>APPENDIX 2: Listings of the Computer Programs Used in the Analysis</td>
<td>172 - 233</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

## Chapter 1

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The two considered domestic energy consumption zones for urban houses in the Yemen Arab Republic</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Distribution of the dwellings in the Yemen Arab Republic (according to 1975 census and 1982 energy survey)</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Regional distribution of urban residential houses according to their external walls in the Yemen Arab Republic</td>
<td>16</td>
</tr>
<tr>
<td>4</td>
<td>Analysis of the urban residential housing stock located in the capital cities of the Yemen Arab Republic</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>City dwellers subjective views concerning applying solar-energy for use in the urban and rural residential houses in the Yemen Arab Republic</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>Functional uses of energy in a typical city residential house in the Yemen Arab Republic as percentages of the total house energy load</td>
<td>33</td>
</tr>
<tr>
<td>7</td>
<td>Total energy load per average house according to type of house and geographic location</td>
<td>35</td>
</tr>
<tr>
<td>8</td>
<td>Distribution of the per capita consumption, per capita expenditure and percentage of income according to the type of house and geographic location</td>
<td>37</td>
</tr>
<tr>
<td>9</td>
<td>Domestic energy load as satisfied by indigenous and imported energy resources</td>
<td>38</td>
</tr>
</tbody>
</table>

## Chapter 2

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location and geographical regions of the Yemen Arab Republic</td>
<td>48</td>
</tr>
<tr>
<td>2</td>
<td>Mean monthly diurnal variations of the global insolation in the horizontal plane</td>
<td>49</td>
</tr>
<tr>
<td>3</td>
<td>Correlation between the predicted and measured average daily total global insolutions for one day of each month in Sana'a</td>
<td>54</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>Fig. 1.</td>
<td>Thermal resistance circuit for the steady-state heat leaks through the two-layer boundary elements of a house</td>
<td></td>
</tr>
<tr>
<td>Fig. 2.</td>
<td>Vertical cross-sections of traditionally-employed horizontal roofs on dwellings in the Yemen Arab Republic</td>
<td></td>
</tr>
<tr>
<td>Fig. 3.</td>
<td>Vertical cross-sections of some commonly-employed types of walls in the Yemen Arab Republic</td>
<td></td>
</tr>
<tr>
<td>Fig. 4.</td>
<td>Phase-lags for a thermal signal passing through different thicknesses of the stated wall materials</td>
<td></td>
</tr>
<tr>
<td>Fig. 5.</td>
<td>Experimental observations of the heat-loss reduction factor as a function of time for a typical Yemeni building</td>
<td></td>
</tr>
<tr>
<td>Fig. 6.</td>
<td>Predicted steady-state heat losses for single-storey houses with different roof constructions; the latter being indicated by their type number, as designated in Figure 2</td>
<td></td>
</tr>
<tr>
<td>Fig. 7.</td>
<td>The upper limits of wall area ratio, $R$, as a function of the glazed-to-wall area ratio, $k$</td>
<td></td>
</tr>
<tr>
<td>Fig. 8.</td>
<td>Indications of the rates of heat loss from dwellings in the Yemen Arab Republic: Effects of different vertical layers of materials in the walls.</td>
<td></td>
</tr>
</tbody>
</table>

**Chapter 4**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 1.</td>
<td>Schematic diagram of direct-gain and Trombe wall passive-heating systems</td>
</tr>
<tr>
<td>Fig. 2.</td>
<td>Monthly-average meteorological data for the considered location</td>
</tr>
</tbody>
</table>
LIST OF FIGURES (cont)

Chapter 4

Fig. 3. Correlations of the direct gain ambient-energy recuperation factor, $\eta_{rec,d}$, and of the direct solar-gain factor, $F$, for a single-storey stone house with the thermostat-outdoor temperature difference divided by the total amount of solar radiation transmitted to the considered house. 140

Fig. 4. Correlations of the direct-gain ambient-energy recuperation factor, $\eta_{rec,d}$, and of the direct solar-gain factor, $F$, for a single-storey concrete house with the thermostat-outdoor temperature difference divided by the total amount of solar radiation transmitted to the house 141

Fig. 5. Effect of house mass on the direct-gain ambient-energy recuperation factor 144

Fig. 6. Variations of the monthly-average actual indoor temperature of a single-storey stone house and a single-storey concrete house both incorporating a south-facing direct-gain passive heating system 145

Fig. 7. Correlation of the annual cooling period with the thermostat set temperature and the collector-to-storage floor areas ratio. 147

Fig. 8. Comparison of the auxiliary energy requirements and the solar-heating fraction calculated by the present design method and by the "Un-utilizability" method {4}. 149
ACKNOWLEDGEMENTS

Many have contributed to the growing body of the solar energy literature on which I have drawn. Here I note only a few of the most important of them. The work of J.A. Duffie and his colleagues and students at the University of Wisconsin, Madison, U.S.A. that of S.A. Klein and of B.Y.H. Liu and R.C. Jordan continues to be of basic importance. In passive solar energy applications, the publications of S.A. Klein, Monsen et al., Zarmi and Jordan provide much of the quantitative information we have used in this application.

Individuals who have helped me during the lengthy course of this thesis are many. I would particularly like to mention those friends who received me, travelled with me, and graciously opened the doors of their houses and hearts and did not make me feel an intruder with my indiscreet survey questions. The help of Sana'a University students, the students of the Police Academy in Sana'a and the administrative staff of Sana'a University is acknowledged; the number of errors in the survey questionnaire were lowered substantially as a result of their good-natured criticisms. I am also grateful to the local authorities - the Central Planning Organisation, the Ministry of Municipalities and the Civil Aviation Department - who assisted me in many ways and provided me with useful information which is referenced in the appropriate chapters. I am also grateful to Sana'a University and the British Council for their support of the research programme.

Constructive but critical reviews are imperative, and I am indebted to Professor S.D. Probert, Dr. B. Norton and Dr. J.C. McVeigh for reading and editing this thesis. They have been, and will continue to be, a source of ideas, a sounding board for a wide range of concepts, the authors of many publications and constructive criticism of the best kind. High on any list of acknowledgements must be to GOD-THE SOURCE OF THE ABSOLUTE KNOWLEDGE who granted me the health and inspiration without which this work would not be possible.
Typing and drafting aid was essential and I am pleased to note the help of Mr. Y.Z. Al-shami of the Ministry of Municipalities in Sana'a who provided me with the cross sections of the vernacular walls and roofs used in the Yemeni buildings. I am also grateful to Mrs. A. Walshe who typed the final version of this thesis. Special thanks are due to the members of the drawing office at Cranfield Institute of Technology. Their persistence, skill and good humour have been tremendous.

Not the least, I thank the members of my patient family, particularly my wife, for their forbearance during the lengthy process of putting this thesis together.
GENERAL SUMMARY

It is indeed seldom that a specialised subject can be considered independently. Usually it is allied to and embodied in a systematic sequence of principles, and its field is generally an integral part of a reflection of some broader conception. This is especially true of this thesis, which is concerned with the climatic environmental influences on regional architecture. In the process of evolving the passive solar aspects, theoretical considerations yielded some interesting details and solutions. Examples studied showed a great variety of design principles. Thus as the material grew it suggested an entity - a theme itself.

The intention of this thesis was to clarify some of the underlying principles of passive solar design methods and by doing so, to secure a firm foundation to avoid emotional interpretations. Accordingly, this thesis deals partly with theoretical aspects, and is partly illustrated by architectural examples. The material was divided into four Chapters. In the first, the annual patterns of energy consumption in residential dwellings in the provincial capital cities of the Yemen Arab Republic and their suitability for harnessing solar energy either passively, actively, or both were investigated. Depending upon occupancy and energy-use patterns, as well as according to geographical location, the investigation indicated that the annual fuel consumption per house varied from 16 to 32 GJ. On the assumption that this domestic energy load is satisfied by conventional energy resources, a typical family of five in the Yemen Arab Republic would spend between 29 and 51% of its income on fuel. The prospects for employing passively-gained solar energy appeared promising: in this respect, 70% of all urban residential houses considered have their walls oriented favourably without direct solar radiation being obstructed. Also 80.5% of the flat roofs were free from over-shading at all times, and thus were suitable locations for roof-mounted solar-energy harnessing devices. The second Chapter dealt with solar radiation data, and the processing of these data to arrange them in forms needed for the calculation of process performance.
For this purpose, the diurnal global insolation was measured over a 3-year period with a precision pyranometer at Sana'a University's solar station latitude 15°N; longitude 44°E; and 2210 m above sea level. Comparison has been made with predictions obtained from three different empirical models proposed by earlier investigators. Durations of sunshine hours, in addition to geographical latitude and altitude above mean sea level, were the only model inputs required. The calculated values obtained from a modified version of Exell's empirical formulae gave agreement to within ±6 per cent with the measured data. The predictions from the regression equation of Page and the relation proposed by Barbaro et. al. agreed to within ±10 per cent with the measured solar radiation intensities.

The analysis of the thermal design efficiency of the Yemeni residential dwellings started in Chapter Three, where a simple steady-state mathematical model describing the average daily rate of heat loss through the walls, windows and flat roof of a generalised Yemeni building was developed. From this, a technique was evolved by which designers can predict approximately the transient rate of heat loss via traditionally-employed combinations of indigenous materials, as used in the walls and roof. The principal variable was the ratio of the total glazed area for each storey to the corresponding sum of the surface areas of the solid walls and roof in contact with the ambient environment. The predictions, expressed graphically, enable designers to select the most suitable combination of locally-available indigenous building materials, so that more energy effective dwellings can be built. Because the future of solar-energy applications, in particular the passive applications, depend on the costs of solar energy systems, and the availability of their components at an economic cost, I choose to conclude this thesis with a design method which combined the effects of many design variables as well as the local weather data on the thermal behaviour of buildings incorporating direct-gain or Trombe walls as a south-facing passive heating system. For this purpose, an ambient-energy recuperation factor was developed and correlated with the thermostat-outdoor temperature difference divided by the total amount of solar energy transmitted into the house. This factor was obtained by solving a one-dimensional heat balance equation and it was expressed as a function of the total amount of solar and internal
gains, the overall thermal conductance of the house, and the thermal properties of the local building materials. Practically, the design method presented in the last chapter of this thesis, enables designers to estimate the solar contribution to the building heating requirements, the amount of heat that is in excess of the house load, and the variation of the internal house temperature with respect to time. It also provides a number of graphs by which designers can choose the appropriate passive heating system parameters for tropical climates and thereby design their system to be both cost effective and thermally comfortable.

In short, this thesis begins with an introductory chapter describing the patterns of energy usage in the urban residential houses of the Yemen Arab Republic as well as their suitability for solar energy applications. The remaining chapters deal with the steps of the passive design process. As building designs progress, the amount of required detail increases. This is reflected by the size of the later chapters and the amount of information contained in each. It may, therefore, appear to a person reading through this thesis that the presentation is at times repetitive. However, the difference between one chapter and the next lies in the level of detail presented and not in the subject matter. Finally, it is the wish of the author to see the results of this work translated into physical reality.
CHAPTER ONE

ENERGY USED DOMESTICALLY IN THE YEMEN ARAB REPUBLIC
In the context of the Yemen Arab Republic, a city is typically an urban region with a typical population of approximately 45 thousand people; the urban region being a mixture of residential houses and industrial premises.
### NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Considered room's floor area</td>
<td>m²</td>
</tr>
<tr>
<td>C</td>
<td>Per capita expenditure on fuel, as defined in equation (16)</td>
<td>U.S.$</td>
</tr>
<tr>
<td>Cₚ</td>
<td>Specific heat of water (= 4190 kg⁻¹ °C⁻¹)</td>
<td></td>
</tr>
<tr>
<td>ddₜh</td>
<td>Degree-days for heating, defined by equation (12), with respect to a reference temperature of 18.3°C</td>
<td>°C-day</td>
</tr>
<tr>
<td>fₑₜ</td>
<td>Fraction of the 24-hour day, during which artificial illumination was employed in the considered rooms of the house</td>
<td></td>
</tr>
<tr>
<td>Fₜₜ</td>
<td>Proportion, supplied by natural gas, of the energy used for cooking; deduced from the survey data - see Table 2(iv)</td>
<td></td>
</tr>
<tr>
<td>fₚₚ</td>
<td>Fraction of the 24-hour day, during which hot water was being used by the occupants of the household</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Per capita income of the head of the typical U.S.S. family: deduced from the survey data - see Table 2(v)</td>
<td>U.S.$</td>
</tr>
<tr>
<td>K</td>
<td>Constant characteristic of the type of household; = Nₚ L fₚₚ Cₚ - see Table 2(iii)</td>
<td>J°C⁻¹day⁻¹(person)⁻¹</td>
</tr>
<tr>
<td>L</td>
<td>Average amount of hot water each person used per day</td>
<td>m³day⁻¹</td>
</tr>
<tr>
<td>n₟ₜ₟ₚ</td>
<td>Numbers of fluorescent and tungsten lamps respectively used to illuminate the rooms in the considered house</td>
<td></td>
</tr>
</tbody>
</table>
NOMENCLATURE (cont)

\( n_h \) \hspace{1cm} \text{Total number of houses in a given geographical location}

\( n_j \) \hspace{1cm} \text{Total number of rooms in the considered house with a floor area in the jth category: } j = 1, 2, 3 \text{ or } 4

\( n_{j\ell} \) \hspace{1cm} \text{Number of fluorescent or tungsten lamps used to illuminate the rooms, which, for the considered house, were in the jth category with respect to floor area}

\( N \) \hspace{1cm} \text{Number of days in the considered calendar month}

\( N_p \) \hspace{1cm} \text{Number of occupants in the house: obtained from an analysis of the survey data - see Table 2 (iii)}

\( P_f, P_t \) \hspace{1cm} \text{Rated powers respectively of the most commonly used fluorescent and tungsten lamps in the considered house}

\( P_i \) \hspace{1cm} \text{Rated power of the ith appliance used in the considered house}

\( P_k \) \hspace{1cm} \text{Power provided by a kerosene lamp, when used for illuminating a room in the considered house}

\( P_n \) \hspace{1cm} \text{Total expenditure paid for natural gas by the house owner per calendar month: deduced from an analysis of the survey data - see Table 2(iv)}
NOMENCLATURE (cont)

- \( P_T \) Calculated total power of the lamps used to illuminate the various rooms in the house - see Table 2

- \( P_{TF}, P_{Tt} \) Total powers of the fluorescent or tungsten lamps respectively which are used to illuminate the rooms of all the houses located in the considered geographical region - see equations (4) and (5) respectively

- \( P_{TFt} \) Total power of the fluorescent and tungsten lamps used to illuminate the rooms of all the houses located in the considered geographical region - see equation (6)

- \( Q_c \) Per capita consumption of energy, as defined by equation (15)

- \( \dot{Q}_{ap} \) Energy load due to appliances, as defined by equation (1)

- \( \dot{Q}_{co} \) Cooking load, as defined by equation (9)

- \( \dot{Q}_{hh}, \dot{Q}_{hc} \) Heating and cooling loads respectively for the considered house, as defined by equations (11) and (14)

- \( \dot{Q}_L \) Lighting load, as defined by equation (2)

- \( \dot{Q}_T \) Total energy load of the house - see Fig. 7

- \( \dot{Q}_{wh} \) Water-heating load, as defined by equation (8)

- \( T_a \) Annual average daily ambient temperature, as listed in Table 2(v)
<table>
<thead>
<tr>
<th>NOMENCLATURE (cont)</th>
</tr>
</thead>
<tbody>
<tr>
<td>((UA)_h) Building's overall energy loss coefficient multiplied by the house's external total surface area, as defined by equation (13)</td>
</tr>
<tr>
<td>((UA)_w, (UA)_r, (UA)_g) Heat loss coefficient multiplied by the appropriate area for walls, roof and floor and glazed elements respectively</td>
</tr>
<tr>
<td>(\dot{V}) Volume rate (at atmospheric pressure) of air infiltration into (or ventilation from) the house</td>
</tr>
<tr>
<td>(\Delta t) Average duration per day during which artificial light was switched on in the considered room of the house</td>
</tr>
<tr>
<td>(\Delta t_i) Operating time for the ith appliance</td>
</tr>
<tr>
<td>(\Delta t_s) Theoretical operating period, as defined by equation (3)</td>
</tr>
<tr>
<td>(\eta_o,\eta_i) Efficiencies for the gas oven and the ith appliance respectively</td>
</tr>
<tr>
<td>(\rho) Density of water</td>
</tr>
<tr>
<td>(\phi) Percentage of the household's income spent on fuel: an expression for which is given by equation (17)</td>
</tr>
</tbody>
</table>

**Suffixes**

- **a**: Ambient environment
- **ap**: Appliance
- **c**: Consumption
NOMENCLATURE (cont)

co  Cooking
f  Fluorescent
g  Glazing
h  House
hc  House cooling
hh  House heating
i  Integer, which takes values from unity to n, indicating the types of appliance used in the house
j  Integer, which takes values from unity to 4, so designating the sizes of the floor for the rooms of the considered house
k  Kerosene
L  Artificial light
m  Integer which refers to the way in which the various rooms in the house are illuminated: it is defined, for $j > 2$, by $m = j - 1$, see equation (6)
n  Natural gas
o  Oven
p  Person
r  Roof
t  Tungsten
T  Total
w  water
wh  Water heating
CHAPTER 1

ENERGY USED DOMESTICALLY IN THE YEMEN ARAB REPUBLIC

THE AIMS

Buildings are major consumers of energy in the Yemen Arab Republic (YAR). Approximately 90% of the total electricity generated and 10% of the total imported oil are expended upon heating, lighting and other building services \([1]\). As part of an investigation into 'passive solar gain and housing design', a survey of the annual energy demands from the existing urban detached housing stock, located in the capital cities of the YAR, was carried out during the period April-to-December 1982. The survey's prime aim was to estimate the total number of city houses suitable for harnessing solar energy, either passively, actively or both. Specifically the objectives of the survey can be summarised as follows:-

- To determine the annual consumption patterns for the various fuels in the YAR
- To provide rational criteria for assessing passive solar designs with emphases on:-
  a) choice of appropriate wall and roof materials;
  b) the ratio of glazed area to the total house floor area;
  c) orientation and obstruction with respect to the solar insolation; and
  d) domestic energy-requirements for heating and cooling.
- To rank, according to financial viability, existing and prospective solar-energy applications in the Yemeni domestic sector.
SURVEY METHODOLOGY, SOURCES OF ERRORS AND SAMPLING TECHNIQUE

Classification Scheme

Urban detached houses, which represent 70% of the housing stock in the YAR, were considered in this survey. According to their annual fuel consumptions, i.e. the types and quantities of energy employed for space heating and cooling, water heating, lighting, cooking and for other appliances, the urban houses can be classified into two major energy-consuming categories (see Fig. 1).

Zone 1: This includes all urban houses, whose annual consumptions range from 16 to 25.6 GJ per house. Geographically, this category includes houses from Maarib and Al-Beida in the east, and from Ibb and Dhamar in the interior Ibb plain to Al-Mahweet and Hajjah in the west.

Zone 11: This comprises houses from Taiz in the south and Sana'a in the interior Ibb plain to Al-Hodiedah in the west. The annual consumption, in this category, ranges from 21 to 32 GJ per house.

For comparison purposes, the corresponding average fuel consumption per house in the United Kingdom was 46.5 GJ.

To permit generalisations to emerge from the gathered data, we grouped the urban houses located in these zones as follows:

Group 1: Those built with external walls for each storey of the same construction material, e.g. stone, mud, or red brick.

Group 11: Those in which each house had different masonry materials for the external walls according to the storey. Two types of vernacular built forms can be discerned in this group. These are: (i) those dwellings with a first storey of stone and all subsequent storeys built of less dense materials, and (ii) those with a concrete first storey, but
FIG. 1  THE TWO CONSIDERED DOMESTIC ENERGY CONSUMPTION ZONES FOR URBAN HOUSES IN THE YEMEN ARAB REPUBLIC.
with upper storeys built of either less or more dense materials. These forms are assigned the designations of vernacular house types (i) and (ii) respectively in the subsequent analysis.

Survey Sample

The distribution of the sample of dwellings surveyed, see Table 1, was dictated by factors such as:

- Population density and size of individual regions.
- Technical complexity of the data to be collected.
- Availability of qualified coordinators for the task. Their functions were to distribute the questionnaires, to explain to the prospective respondents the meanings of the various technical terms used in the survey questions, and to collect the completed forms. The difficulties involved in finding such capable coordinators limited severely the number of the distributed questionnaires.
- Educational level of the people being questioned, i.e. the respondents capabilities with respect to understanding the technical terms, units, dimensions, rated powers of the household electric equipment, as well as the details of the construction and materials of their house walls, roofs, and floors, necessary to complete the answers to the questionnaire properly.

Because of these factors and to guarantee the completion of the survey as required, we limited the random sampling to the capital cities of each region - see Fig. 1.

The Questionnaire

Various preliminary versions of the questionnaire were composed and tested on a small, but representative, sample of respondents with respect to such factors as:
<table>
<thead>
<tr>
<th>REGION'S CAPITAL</th>
<th>NUMBER OF DISTRIBUTED QUESTIONNAIRES</th>
<th>NUMBER OF REPLIES RETURNED WITH AMBIGUOUS OR INSUFFICIENT INFORMATION</th>
<th>NET NUMBER OF PROCESSED REPLIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>SANA'A</td>
<td>1000</td>
<td>60</td>
<td>940</td>
</tr>
<tr>
<td>TAIZ</td>
<td>600</td>
<td>55</td>
<td>545</td>
</tr>
<tr>
<td>AL-HODIEDAH</td>
<td>300</td>
<td>23</td>
<td>277</td>
</tr>
<tr>
<td>IBB</td>
<td>50</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>DHAMAR</td>
<td>50</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>HAJJAH</td>
<td>50</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>AL-BEIDA</td>
<td>50</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>AL-MAHWEET</td>
<td>50</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>MA'A'RIB</td>
<td>50</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2200</td>
<td>183</td>
<td>2017</td>
</tr>
<tr>
<td>PROPORTION OF TOTAL</td>
<td>100%</td>
<td>8%</td>
<td>92%</td>
</tr>
</tbody>
</table>
- Technical complexity. To facilitate understanding, the use of locally-employed (in addition to SI) units was found to be necessary. For example, the "Tankah" (which is equivalent to twenty litres) was employed as the basic unit of measurement for water consumption.

- Availability of the required data, such as the monthly bills for electricity, gas and water consumptions; monthly income; amounts of money paid monthly for purchasing wood, animal waste and agricultural residues; rated powers of the appliances used in the house and other information which related to: the location; floor, wall, and roof areas; number of occupants; and patterns of energy use within the houses.

- Ease of interpretation of the presented questions. Normally this required the use of the standard version of the Arabic language. However, for some questions, it was difficult to express exactly what was needed using standard Arabic, and therefore the local dialect, in addition to standard Arabic, was employed.

- Acceptability of devoting the time required (~30 minutes) for "filling up" the questionnaire.

The finally-devised version of the questionnaire was also based partially on the experiences gained from previous surveys, carried out by the Central Planning Organisation and by Sana'a University (5,6). Eventually, it evolved to comprise a total of twenty-two questions (each consisting of three to six parts), and these were divided into three main sections in the questionnaire. In the first section, the survey sought the geographical location of the house, the number of family members normally living in it and a technical description of the dwelling. In the second section, the questions concerned the types of energy supplies employed in the house and their respective applications, rates of consumption and running costs incurred. The final section was intended to collect information about water - its supply systems, hot and cool water consumption rates, and the daily usage patterns. This section also included a question about the ranking of low-temperature (i.e. < 80°C) solar-energy applications according to their priorities in both cities and villages. In order to reduce the possibilities of misunderstandings, ambiguities and misinterpretations
the questions were chosen as far as feasible to elicit either a 'yes' or 'no' answer, involve completing a sentence, or require the respondent to choose one of the supplied alternative answers.

Sources of Misunderstanding and Difficulty

The most obvious ambiguities and problems concerning the printed questions were remedied and corrected after discussion of the answers with the survey coordinators. However, further difficulties were discovered during the check for reasonableness: these were partially overcome after the data had been analysed by computer. Despite these precautions, some forms were not completed according to the printed instructions or not received in time for the analysis to be undertaken: this reduced the number of processed forms by 8%. The answers from the remaining 92% of the distributed forms were analysed in detail. Errors in data handling arose in the coding of the reports and data punching, but these were reduced by three successive checks.

HOUSING STATISTICS (see Fig. 2)

According to the 1975 census [2] there were, excluding the Sa'adah and Al-Jawf provinces, ~ 664 thousand houses in the YAR distributed as shown in Fig. 2(a): 78.9% of the total housing stock in December 1975 compared with 85% in December 1982 was located in the capital cities considered by this survey. This is because the recent urban development in the YAR occurred predominantly in the provincial capital cities. Fig. 2(b) shows the distribution of the urban houses as compared with that of 1975.

The data summarised in Fig. 3 were derived by interpreting the 1975 figures, adapted for 1982, together with the regional distribution of the building materials as indicated by the answers to the questionnaire.

To apply the gathered data to the whole housing stock located in the capital cities of each province, a weighting procedure was used. The weighting factor for each house was defined as the ratio of the number of houses represented by this particular type of house to the total
Fig. 2  
DISTRIBUTION OF DWELLINGS IN THE YEMEN ARAB REPUBLIC (ACCORDING TO THE 1975 CENSUS)

AS DEC. 1975 AND DEC. 1982:
1. DISTRIBUTION OF HOUSES LOCATED IN THE CAPITAL CITIES
   - Sanaa, Taiz, Aden, Mukalla, Hodeida, Abyan, Marib, Ad-Dhahirah, Ta'izz, Lahij, Salala

1975 CENSUS:
- Sanaa, Taiz, Aden, Mukalla, Hodeida, Abyan, Al-Mahwit, Marib

NUMBER OF URBAN HOUSES
NUMBER OF HOUSES

CAPITAL CITY (1982 SURVEY)
CAPITAL CITY (1975 CENSUS)
NUMBER OF HOUSES IN THE PROVINCE (1975 CENSUS)
NUMBER OF HOUSES IN THE
FIG. 3. REGIONAL DISTRIBUTIONS OF URBAN RESIDENTIAL HOUSES ACCORDING TO THEIR EXTERNAL WALLS IN THE YEMEN ARAB REPUBLIC.

NUMBER OF HOUSES IN 40 is
number of houses in that province. The magnitude of the weighting factor depended on the number of houses of that type, and their geographical location. Fig. 4 shows the results of the weighting procedure adopted here. The representations for mud and red-brick houses were inaccurate due to the failure to return, in time for processing, all the forms sent to S'dadah and Al-Jawf provinces, where these two building materials are extensively used (7). Based on the total number of houses in each group, the results were representative of approximately 80% of the total housing stock. Therefore, it is possible to assume that the conclusions with respect to the prospects for the use of solar energy in urban houses may, with reasonable confidence, be taken as a worthwhile indication of what applies for the whole country.

PROSPECTS FOR PASSIVE SOLAR-ENERGY APPLICATIONS WITH RESPECT TO YEMENI HOUSING

The most important factors influencing the prospects for harnessing solar energy are the house orientation and the blocking of solar energy by obstructions. In this context, an analysis of the answers to the present survey questions showed that 70% of all urban houses assessed have their walls oriented favourably, with no obstructions inhibiting direct solar gains. In the analysis of the effects of obstructions in intercepting the insolation and so preventing it reaching the walls of the surveyed dwellings, all the direct solar energy incident on a particular wall was assumed to be harnessable: that is in effect, the amount, for example reflected away by the considered walls was equal to that received by reflected solar radiation from neighbouring house walls. The detailed analyses indicated that 30% of these well-oriented walls were free from all obstructions: a further 40% suffered from obstructions which caused only a 10% reduction in the intensity of the direct solar energy striking the house walls. The effects of obstructions with respect to insolation that would otherwise be received by the walls were considerable among the remaining 30% of city houses represented in this survey: 16.5% lose more than 20% of the theoretically-available direct solar insolation falling on the house walls.

In the Yemen, all roofs are flat and almost horizontal: 82.5% of all roofs in the sample were free from obstructions to direct solar
FIG. 4.
ANALYSIS OF THE URBAN RESIDENTIAL HOUSING STOCK LOCATED IN THE CAPITAL CITIES
OF THE YEMEN ARAB REPUBLIC.

RELATIVE WEIGHTING FACTOR

GROUP I
STONE
MUD
RED-BACK
GROUP II
VERTICAL
VERNACULAR
Houses
Houses

0
0.5
1.0
insolation. Only 4% of all roofs suffered complete blocking of the Sun's direct rays and so may be considered as unfit for any form of solar collection. The remaining 13.5% of all roofs lost, by shading, more than 50% of the solar radiation that would otherwise fall on these near-horizontal surfaces.

Based on the wall and roof exposures to the Sun, it was found that 30% of all city houses suffered no loss, due to obstructions, of the theoretically-available direct solar insolation falling on the house walls and roof. Approximately 63.5% of all city houses represented in the sample lost between 10 and 20% of the direct solar radiation falling on their walls and horizontal roofs. The remaining 6.5% of all urban houses may be considered as unfit for any type of solar-energy applications. The loss, due to blocking, among the last 6.5% of all urban houses amounted to more than 50%. It is clear that the least obstructive possibility, for the well-oriented houses is some form of roof-mounted collector for solar energy. On that basis, up to 80% of all urban houses, particularly multi-storey houses, were suitable for harnessing solar-energy.

From the responses of city dwellers to the question about low-temperature solar-energy applications for city and village needs, the consensus was that water heating, followed by house electrification (using solar cells) are perceived as the most desired applications in cities. However, irrigation and crop-drying were the most desired applications in the countryside. A summary of the city dwellers subjective views towards the ranking of these applications according to rural and urban uses is shown in Fig. 5.

ENERGY BALANCE

Analysis of this energy survey indicated that 20% of all city houses used electricity for lighting, cooking, water heating, space cooling and heating and for stimulating various other items of household equipment. Natural gas is used mainly for cooking. This applied to 15% of all the city houses investigated via the survey. On the other hand, 55% of all city houses represented in the survey employed wood, agricultural
FIG. 5

CITY DWELLERS SUBJECTIVE VIEWS CONCERNING APPLYING SOLAR-ENERGY FOR
USE IN THE URBAN AND RURAL RESIDENTIAL HOUSES IN THE YEAR.

PERCENTAGE OF CITY DWELLERS

WATER HEATING
WATER PUMPING
HOUSE ELECTRIFICATION
OPERATING HOUSEHOLD EQUIPMENT
WATER DISTILLATION
CROP DRYING
IRRIGATION
HOUSE HEATING
HOUSE COOLING
REFRIGERATION

URBAN USES
RURAL USES
residues, or animal wastes for cooking and water heating. This percentage is lower than that obtained by the Central Planning Organisation's 1977 fertility survey (5). Only 3% of all city houses represented in the present survey employed kerosene for either lighting, cooking or water heating. The remaining 7% of all city houses considered used charcoal for cooking, heating food, as well as for water and space heating.

Energy consumptions in the city houses of the Yemen have been classified as follows:-

**APPLIANCE LOADS**

This arises due to the use of radios, TV sets, washing machines, refrigerators and water pumps: it is satisfied predominantly by electricity. The total magnitude of the load was calculated via

\[
\dot{Q}_{ap} = \sum_{i=1}^{n} P_i \eta_i \Delta t_i
\]  

where \( \eta_i \) is the efficiency of the \( i \)th appliance obtained from the manufacturer's catalogue. Table 2(i) summarises, according to the type of house and its geographical location, the values of \( \dot{Q}_{ap} \) as calculated via Eq. (1).

**LIGHTING LOAD**

The major proportion (\( \sim 96\% \)) of this load is provided by electricity; the remaining 4% by kerosene. It was defined as the energy required to give adequate illuminations in the various rooms, halls etc., of the house. Its magnitude was calculated using

\[
\dot{Q}_L = \bar{P}_T \Delta t
\]  

It was necessary to estimate the actual average total power, \( \bar{P}_T \), used to illuminate the various rooms in the house as well as the actual operating period, \( \Delta t \). The estimation of \( \Delta t \) involved the multiplication of the
### TABLE 2

PARAMETERS USED IN CALCULATING THE ENERGY LOADS
FOR THE TYPICAL CITY HOUSE IN THE YEMEN

#### TABLE 2(i) LOAD $\dot{Q}_{ap}$ DUE TO DOMESTIC APPLIANCES PER TYPICAL HOUSE

<table>
<thead>
<tr>
<th>Region's Capital</th>
<th>Energy-demand Load $\dot{Q}_{ap}$ (Wh/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stone Houses</td>
</tr>
<tr>
<td>Sana'a</td>
<td>1407</td>
</tr>
<tr>
<td>Taiz</td>
<td>1303</td>
</tr>
<tr>
<td>Al-Hodiedah</td>
<td>1616</td>
</tr>
<tr>
<td>Ibb</td>
<td>990</td>
</tr>
<tr>
<td>Dhamar</td>
<td>990</td>
</tr>
<tr>
<td>Hajjah</td>
<td>766</td>
</tr>
<tr>
<td>Al-Mahweet</td>
<td>479</td>
</tr>
<tr>
<td>Al-Beida</td>
<td>719</td>
</tr>
<tr>
<td>Ma'arib</td>
<td>-</td>
</tr>
</tbody>
</table>

(- no information available from the present survey)
maximum period during which the artificial illumination might be 'switched on' (which is explained later) by a "light use factor", i.e. the fraction of the day during which artificial illumination is employed somewhere in the house, i.e.

\[ \Delta t = f_L \Delta t_s \]  

... (3)

where \( \Delta t_s \) is the total number of hours of darkness minus the average period of sleep: this represents the maximum theoretical operating time per day, and \( f_L \) is the light-use factor. The maximum theoretical operating time, \( \Delta t_s \), was determined by subtracting the sum of the annual daily average number of sunshine hours (i.e. 9 hours per day - see reference (8)) and the standard number of sleeping hours (i.e. 8 hours per day) from the 24-hour considered period. Accordingly, \( \Delta t_s \) equals 7 hours per day. It is reasonable to assume that the factor \( f_L \) was unity and 0.1 for the most and the least frequently occupied rooms in the house respectively, and so a representative value for the light-use factor in the house would be 0.55. To allow for the occupant's behaviour with respect to switching the lights on-and-off in the various rooms of the house, and for the seasonal variations with respect to daylight duration, the average value of \( f_L \) was reduced by 0.05 to yield, using equation (3), an actual operating time, \( \Delta t \), of 3.5 hours per day. The next step involved the estimation of the actual average total power used to illuminate the rooms of the house. In each geographical location, the number of rooms were determined from an analysis of the survey data. The rooms were then classified according to floor area, \( A \), into four categories (i.e. \( j=1, 2, 3 \) or 4), namely

1 \( \text{m}^2 \) \( \leq A < 5 \text{ m}^2 \)
5 \( \text{m}^2 \) \( \leq A < 10 \text{ m}^2 \)
10 \( \text{m}^2 \) \( \leq A < 20 \text{ m}^2 \)
20 \( \text{m}^2 \) \( \leq A < 50 \text{ m}^2 \)

The first category includes toilets, kitchens, small halls, stairways, as well as sleeping, sitting, reading and dining rooms. The second category
contains medium-size sleeping, sitting and reading rooms. Large sitting and receiving rooms, as well as large halls, were grouped in the third category. Social gathering rooms and spacious receiving rooms were deemed to be in the fourth category. The aim of such a classification was to establish the number of lamps required to provide various rooms with sufficient illumination. According to local practices, rooms in the first, second, third and fourth categories are illuminated respectively by one, two, three or four lamps. These were either 40W fluorescent lamps, 60W tungsten lamps, or an appropriate combination of both types. Because of these options, it was assumed that the rooms could be illuminated in three different ways. In the first, we assumed that rooms in all the categories were illuminated by 40W fluorescent lamps. Accordingly, the total power, $P_{Tf}$, used to illuminate the various rooms is given by:

$$P_{Tf} = \sum_{j=1}^{4} n_j n_{j\&} P_f$$  \hspace{1cm} \ldots (4)$$

In the second lighting mode, it was assumed that various rooms in all four categories were illuminated by 60W tungsten lamps. Consequently, the total power, $P_{Tt}$, used to illuminate the various rooms, is given by:

$$P_{Tt} = \sum_{j=1}^{4} n_j n_{j\&} P_t$$  \hspace{1cm} \ldots (5)$$

Rooms with floor areas exceeding 10 square meters were usually illuminated by fluorescent as well as tungsten lamps. For example, rooms in the third category were illuminated either by two 40W fluorescent lamps and one 60W tungsten lamp, or vice versa. However, rooms in the fourth category were illuminated using three different arrangements: either by three 40W fluorescent lamps and one 60W tungsten lamp, or vice versa, or two 40W fluorescent and two 60W tungsten lamps. The average power in any of these arrangements used to illuminate various rooms is given by:

$$\bar{P}_{Tft} = \left[ \sum_{j=1}^{2} n_{j\&} \left( \frac{P_f + P_t}{2} \right) + \sum_{j=3}^{4} \frac{n_j}{j-1} \left( n_{fjm} P_f + n_{tjm} P_t \right) \right]$$  \hspace{1cm} \ldots (6)$$

where $n_{fjm}$, $n_{tjm}$ are respectively the number of fluorescent and tungsten lamps used to illuminate the various rooms in the house, and $m(=j - 1)$ is
an integer accounting for the different ways in which the room may be illuminated. The first term of equation (6) gives the average total power used to illuminate the rooms in the first and second room area categories. For these, the rooms were usually illuminated using either 40W fluorescent lamps or 60W tungsten lamps and therefore the total power i.e.

$$\sum_{j=1}^{2} n_j (n_j (P_f + P_t))$$

was taken as the mean of the two alternatives. The second summation term on the right-hand side of equation (6) gives the average total power used to illuminate the rooms in the third and fourth room area categories. These rooms could be illuminated in (j-1) ways and therefore we divided the total power, i.e.

$$(n_j (n_{fjm} P_f + n_{tjm} P_t)),$$

by the number of possibilities in which the room in the third and fourth categories could be illuminated. Thus the actual power provided by electricity and used to illuminate the various rooms in the house lies somewhere between those predicted by equations (4), (5) and (6). In this analysis, it was taken as the average of the three predictions. To account for that portion of the lighting load provided by kerosene, we added to the above average, the appropriate power. Thus the actual total power, $\tilde{P}_T$, used to illuminate the rooms in the house is given by:

$$\tilde{P}_T = \left[ (P_{Tf} + P_{Tt} + \tilde{P}_{Tft})/3 \times n_h \right] + P_k \quad \ldots (7)$$

where $n_h$ is the total number of houses in the given geographical location, and $P_k$ was the power provided by kerosene when used for illumination: $P_k$ was estimated, for each house, by determining from the reported monthly bills paid for kerosene, the corresponding energies (in Whr) and dividing the result by the actual operating time. Once the actual average total power used to illuminate the various rooms in the house was estimated, the weighting procedure shown in Figure 4 of this analysis was employed to obtain $\tilde{P}_T$ for the various types of houses considered in this survey - see Table 2(ii).
<table>
<thead>
<tr>
<th>Region's Capital</th>
<th>Stone Houses</th>
<th>Red-brick Houses</th>
<th>Mud Houses</th>
<th>Type (i) Vernacular Houses</th>
<th>Type (ii) Vernacular Houses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sana'a</td>
<td>104</td>
<td>107</td>
<td>132</td>
<td>104</td>
<td>102</td>
</tr>
<tr>
<td>Taiz</td>
<td>98</td>
<td>-</td>
<td>-</td>
<td>105</td>
<td>101</td>
</tr>
<tr>
<td>Al-Hodiedah</td>
<td>82</td>
<td>94</td>
<td>-</td>
<td>93</td>
<td>68</td>
</tr>
<tr>
<td>Ibb</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>96</td>
<td>84</td>
</tr>
<tr>
<td>Dhamar</td>
<td>112</td>
<td>127</td>
<td>138</td>
<td>101</td>
<td>99</td>
</tr>
<tr>
<td>Hajjah</td>
<td>114</td>
<td>-</td>
<td>-</td>
<td>106</td>
<td>102</td>
</tr>
<tr>
<td>Al-Mahweet</td>
<td>135</td>
<td>151</td>
<td>167</td>
<td>130</td>
<td>125</td>
</tr>
<tr>
<td>Al-Beida</td>
<td>92</td>
<td>106</td>
<td>116</td>
<td>88</td>
<td>84</td>
</tr>
<tr>
<td>Ma'arib</td>
<td>-</td>
<td>-</td>
<td>87</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(- no information available from the present survey)
WATER-HEATING LOAD

This according to the house considered, was provided by electricity, wood, kerosene and/or charcoal. The water heating load, $\dot{Q}_{wh}$, was determined by using an expression from reference [9], modified by the daily use function, that is, the fraction of the day during which hot water was used, i.e.

$$\dot{Q}_{wh} = K(T_h - T_a) \ldots (8)$$

where $T_h$ is the hot-water temperature. In this analysis, $T_h$ is taken to be equal to 60°C [9]. In calculating the numerical values for the parameter $K$ we assumed, in accordance with reference [9], that on average a person would use 100 litres of hot water per day: see Table 2(iii).

COOKING LOAD

Natural gas, wood, charcoal and electricity are used for cooking in the city houses. By estimating, from the monthly bills paid for natural gas (as obtained from an analysis of question 11 in the survey), the rate of energy consumed (in kWh/day), and then dividing the result by the estimated proportion, $F_n$, of the cooking load provided by natural gas, the rate of energy used for cooking can be deduced from:

$$\dot{Q}_{co} = 30.3 \eta_o (P_n / F_n) \ldots (9)$$

where 30.3 is the conversion factor from Rial/month to kWh/day, and $\eta_o$ is the efficiency of the gas oven which, in the YAR, is ordinarily between 0.5 and 0.6 [9] - see Table 2(iv).

SPACE HEATING AND SPACE COOLING LOADS

These loads were satisfied by more than one energy resource, viz

$$\dot{Q}_T = \dot{Q}_{ap} + \dot{Q}_L + \dot{Q}_{wh} + \dot{Q}_{co} + \dot{Q}_{hh} + \dot{Q}_{hc} \ldots (10)$$
<table>
<thead>
<tr>
<th>Region</th>
<th>Houses</th>
<th>Houses</th>
<th>Houses</th>
<th>Houses</th>
<th>Houses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taiz</td>
<td>Stone</td>
<td>Mud</td>
<td>Red-brick</td>
<td>Vernacllar</td>
<td>Vernacllar</td>
</tr>
<tr>
<td>A1-Hod USING</td>
<td>123</td>
<td>4.7</td>
<td>4.4</td>
<td>6.2</td>
<td>6.4</td>
</tr>
<tr>
<td>A1-Hodahad</td>
<td>218</td>
<td>6.1</td>
<td>4.9</td>
<td>7.2</td>
<td>7.8</td>
</tr>
<tr>
<td>A1-Hodahad</td>
<td>77</td>
<td>61</td>
<td>6.1</td>
<td>71</td>
<td>5.5</td>
</tr>
<tr>
<td>A1-Abab</td>
<td>77</td>
<td>61</td>
<td>6.1</td>
<td>74</td>
<td>5.0</td>
</tr>
<tr>
<td>A1-Abab</td>
<td>54</td>
<td>5.3</td>
<td>5.5</td>
<td>71</td>
<td>5.1</td>
</tr>
<tr>
<td>A1-Abab</td>
<td>63</td>
<td>5.9</td>
<td>5.5</td>
<td>76</td>
<td>4.7</td>
</tr>
<tr>
<td>A1-Jebadah</td>
<td>66</td>
<td>4.7</td>
<td>5.7</td>
<td>79</td>
<td>5.1</td>
</tr>
<tr>
<td>Ma'rib</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: (iii) Water-Heating Load Per Typical House
Table 2 (iv) **COOKING LOAD PER TYPICAL HOUSE**

<table>
<thead>
<tr>
<th>Region's Capital</th>
<th>Stone Houses</th>
<th>Red-brick Houses</th>
<th>Mud Houses</th>
<th>Type (i) Vernacular Houses</th>
<th>Type (ii) Vernacular Houses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$P_n$</td>
<td>$F_n$</td>
<td>$P_n$</td>
<td>$F_n$</td>
<td>$P_n$</td>
</tr>
<tr>
<td>Sana'a</td>
<td>94</td>
<td>0.5</td>
<td>71</td>
<td>0.4</td>
<td>71</td>
</tr>
<tr>
<td>Taiz</td>
<td>141</td>
<td>0.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Al-Hodiedah</td>
<td>188</td>
<td>0.85</td>
<td>94</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>Ibb</td>
<td>71</td>
<td>0.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dhamar</td>
<td>71</td>
<td>0.4</td>
<td>71</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>Hajjah</td>
<td>47</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Al-Mahweet</td>
<td>47</td>
<td>0.15</td>
<td>47</td>
<td>0.15</td>
<td>47</td>
</tr>
<tr>
<td>Al-Beida</td>
<td>47</td>
<td>0.20</td>
<td>47</td>
<td>0.2</td>
<td>47</td>
</tr>
<tr>
<td>Ma'arib</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23</td>
</tr>
</tbody>
</table>

(* Conversion factor 1Rial=0.1£ or 0.169 U.S.$ as at June 1985)
(- no information available from the present survey)
For a given type of house in a given geographical location, the space heating load, $\dot{Q}_{hh}$, was calculated in accordance with:

$$\dot{Q}_{hh} = (UA)_h \, dd_h \tag{11}$$

where $dd_h$ was the number of heating degree-days in a month, and $(UA)_h$ was the product the building's overall heat loss coefficient and the total external house area \cite{9}. In this analysis, the number of heating degree-days in a month was calculated using $18.3^\circ C$ as the reference temperature, rather than $22^\circ C$, because the sundry energies released from within the building (as a result of the operation of the oven, lights, appliances, the presence of people and solar gains through the windows) were sufficient to raise the average diurnal indoor temperature from $18.3^\circ C$ to the comfort level of $22^\circ C$. So

$$dd_h = (18.3 - T_a)N \tag{12}$$

where $N$ was the number of days for the selected calendar month, and $T_a$ was the annual daily average ambient air temperature - see Table 2(v). The building's overall heat loss coefficient time the house's overall total external surface area (including that of the floor) product, $(UA)_h$ was determined from the details of the building construction, i.e.,

$$(UA)_h = (UA)_w + (UA)_r + (UA)_g + (1200/3600) \, \dot{V} \tag{13}$$

where $(UA)_w$, $(UA)_r$, and $(UA)_g$ are respectively the heat loss coefficient area products for walls, roof and floor and glazed elements. The last term on the right-hand side of equation (13) represents the rate of heat loss due to ventilation \cite{10}, where $\dot{V}$ is the volume of air (at atmospheric pressure) lost from the house in cubic metres per hour. Solving equation (10) for $\dot{Q}_{hc}$, taking into consideration equations (1) through to (13), we obtain:

$$\dot{Q}_{hc} = \left[ Q_T - 30.3 \, n_o (P_n/F_n) - K(T_h - T_a) - \sum_{i=1}^{n} P_i \, n_i \, \Delta t_i - \dot{Q}_{hh} \right] \tag{14}$$
<table>
<thead>
<tr>
<th>Region's Capital</th>
<th>Houses</th>
<th>House Vermaular (1) Type</th>
<th>Houses Vermacular (1) Type</th>
<th>Houses Brick</th>
<th>Houses Mud</th>
<th>Houses Stone</th>
<th>Houses Head of House</th>
<th>Houses Income of Head of House</th>
<th>G (°C)</th>
<th>Annual Mean Daily Average Ambient Air Temperature</th>
<th>&quot;3&quot; (°C)</th>
<th>Annual Per Capita Income of &quot;Head of House&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ma'rib</td>
<td>-</td>
<td>530</td>
<td>520</td>
<td>369</td>
<td>471</td>
<td>564</td>
<td>594</td>
<td>18.7</td>
<td>16.7</td>
<td>15.1</td>
<td>22.5</td>
<td>21.4</td>
</tr>
<tr>
<td>A1-Beidha</td>
<td>-</td>
<td>511</td>
<td>420</td>
<td>384</td>
<td>459</td>
<td>592</td>
<td>581</td>
<td>16.4</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>A1-Mahweet</td>
<td>-</td>
<td>454</td>
<td>425</td>
<td>465</td>
<td>422</td>
<td>569</td>
<td>567</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>Haflis</td>
<td>-</td>
<td>410</td>
<td>422</td>
<td>420</td>
<td>489</td>
<td>596</td>
<td>568</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>Taiz</td>
<td>-</td>
<td>406</td>
<td>462</td>
<td>477</td>
<td>471</td>
<td>565</td>
<td>541</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>Saban'a</td>
<td>-</td>
<td>564</td>
<td>422</td>
<td>381</td>
<td>459</td>
<td>564</td>
<td>567</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>Annual per Capita Income for a Typical House</td>
<td>(U.S. $/YEAR)</td>
<td>as obtained from the survey data</td>
<td>Table 2 (8)</td>
<td>MEAN AMBIENT TEMPERATURE AND PER CAPITA INCOME FOR A TYPICAL HOUSE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The distributions of the energy load per house, $Q_I$, by cities and daily functional application of energy, are shown in Fig. 6. The cooking load, except for red-brick and type (i) vernacular houses, i.e. houses with first storeys built in stone and the upper storeys of a less dense material - see reference (4), located in Al-Hodiedah city, was the prime consumer of energy. For example, in Hajjah, Al-Beida, Al-Mahweet and Ma'arib cities, the cooking load represented more than 45% of the total domestic energy load. For other capitals, the cooking demand amounted to a little over 30% of the domestic energy load. This variation is attributed to differences of educational, economic and social factors. Although it is traditional for those living in Sana'a, Taiz, Al-Hodiedah, Ibb or Dhamar to use wood for bread making on alternate days, this is not so for the other cities. This local sociological difference reflects the greater awareness concerning energy thrift by the populations of the more developed cities. It is also clear from Table 2(iv) that the contribution of natural gas, in those cities where the cooking load represented more than half the total load, was relatively small ($\sim 20\%$). This implies that wood, which is more expensive than natural gas, satisfies the largest proportion of the cooking energy demand in these cities. Add to this the absence of energy-thrift measures of any kind, then the wide variations of the cooking load, as we go from the cities of zone II to those of zone I, may be appreciated.

Depending on the type of house and its geographical location, water-heating, space-cooling or space heating loads were the second priority with respect to energy consumptions - see Fig. 6. For example, in all houses located in the city of Ma'arib in the east, Al-Mahweet and Hajjah in the west, and Ibb in the interior Ibb plain, the water-heating load was the second largest consumer for energy followed respectively by the space-cooling and the space-heating loads. Appliances, and lighting loads ranked according to their respective consumptions, each contributed the least percentage of the energy load. For example, lighting and appliances loads represented respectively, at most 3% and 10% of the total energy domestic load. On the other hand, the space-heating load represented a negligible percentage of the house energy load in Al-Beida, Ma'arib, and Al-Hodiedah cities. It was negligible in Al-Hodiedah city for all types of houses. Thus the regional distribution of the domestic energy load
FUNCTIONAL USES OF ENERGY IN A TYPICAL CITY RESIDENTIAL HOUSE IN THE YEMEN ARAB REPUBLIC AS PERCENTAGES OF THE TOTAL HOUSE ENERGY LOAD.
showed that the cooking load, except for some types of houses in Al-Hodiedah city, was the principal consumer of energy in the city houses of the Yemen. The variations from one type of house to another were attributed to the differing architectural designs, \((UA)_h\) values and locations of the houses. More specifically, the more important factors which cause the variations of the domestic energy load from one type of house to another were:

- Number of occupants and their daily usage of hot water - see Table 2(iii)
- Visits to the city family by relatives from rural and urban areas: this led to significant increases in cooking loads
- The \((UA)_h\) product, which indicates the thermal design effectiveness of the house and influences the magnitudes of the space-heating or space-cooling loads
- Type and efficiency of the electric equipment used in the house. These had direct influences, see equation 1, on the appliance's load
- Shading obstructions affecting how much solar energy falls on the house walls and 'horizontal' roof.

**CONSUMPTION PER HEAD OF POPULATION**

The per capita energy consumption, \(Q_c\), for a given type of house in a given geographical location is defined by:

\[
Q_c = \frac{Q_T}{N_p} \quad \ldots (15)
\]

where \(Q_T\) is the total energy load, plotted for all types of house in Fig.7; and \(N_p\) is the number of occupants in the house-see Table 2 (iii).

If one kWh costs 1.1 Rial, i.e. 0.169 U.S.$ at June 1985 exchange rates, then the per capita expenditure on fuel, \(C\), is given by:

\[
C = 0.169 P_c \quad \ldots (16)
\]
Fig 7. Total energy load per average house according to type of house and geographic location.

<table>
<thead>
<tr>
<th>Location</th>
<th>Type of House</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Manar</td>
<td>Red Brick Houses</td>
</tr>
<tr>
<td>Al-Manar</td>
<td>Type I Vernacular Houses</td>
</tr>
<tr>
<td>Al-Manar</td>
<td>Stone Houses</td>
</tr>
<tr>
<td>Al-Beida</td>
<td>Red Brick Houses</td>
</tr>
<tr>
<td>Al-Beida</td>
<td>Type I Vernacular Houses</td>
</tr>
<tr>
<td>Al-Beida</td>
<td>Stone Houses</td>
</tr>
<tr>
<td>Hajar</td>
<td>Red Brick Houses</td>
</tr>
<tr>
<td>Hajar</td>
<td>Type I Vernacular Houses</td>
</tr>
<tr>
<td>Hajar</td>
<td>Stone Houses</td>
</tr>
<tr>
<td>Dhahran</td>
<td>Red Brick Houses</td>
</tr>
<tr>
<td>Dhahran</td>
<td>Type I Vernacular Houses</td>
</tr>
<tr>
<td>Dhahran</td>
<td>Stone Houses</td>
</tr>
<tr>
<td>Jubai</td>
<td>Red Brick Houses</td>
</tr>
<tr>
<td>Jubai</td>
<td>Type I Vernacular Houses</td>
</tr>
<tr>
<td>Jubai</td>
<td>Stone Houses</td>
</tr>
<tr>
<td>Al-Hoceima</td>
<td>Red Brick Houses</td>
</tr>
<tr>
<td>Al-Hoceima</td>
<td>Type I Vernacular Houses</td>
</tr>
<tr>
<td>Al-Hoceima</td>
<td>Stone Houses</td>
</tr>
<tr>
<td>Tadz</td>
<td>Red Brick Houses</td>
</tr>
<tr>
<td>Tadz</td>
<td>Type I Vernacular Houses</td>
</tr>
<tr>
<td>Tadz</td>
<td>Stone Houses</td>
</tr>
<tr>
<td>Santa</td>
<td>Red Brick Houses</td>
</tr>
<tr>
<td>Santa</td>
<td>Type I Vernacular Houses</td>
</tr>
<tr>
<td>Santa</td>
<td>Stone Houses</td>
</tr>
</tbody>
</table>
The percentage $\phi$ of income spent on fuel is defined as the ratio of the annual per capita expenditure so incurred to the annual per capita income, i.e.,

$$\phi = \frac{(365C/I) \times 100}{... (17)}$$

where $I =$ per capita income, as listed in Table 2 (v).

The regional distributions of $Q_c$ and $C$ are shown respectively in Figs. 8a and b. Accordingly, and depending on the type of house, the per capita consumption varied from 2.3 kWh/day (i.e. 8.3 MJ/day) to 4.32 kWh/day (i.e. 15.6 MJ/day). The per capita cost ranged from 0.4$/day to 0.75$/day. Thus a family of five would spend between 2 and 3.5 $/day on fuel. Taking the per capita income for the whole country as 500$/year, i.e. 2500$/year for this family (2), then 29 to 51% of the income would be spent on fuel. The regional variation of $\phi$ is plotted, for all types of houses considered by this energy survey, in Fig. 8c.

The variation of the energy consumption and consequently the percentage of the income spent on fuel is explained by Fig. 9: the house energy load, $Q_T$, was split between the imported energy resources, consumed in the forms of electricity and natural gas, and the local energy resources, i.e. wood, animal waste, charcoal, and agricultural residues. More than half of the house energy load is provided by local energy resources in the cities of zone I and in Taiz of zone II. The situation was different in the cities of Al-Hodiedah and Sana'a where, for some types of house, more than half the house energy load was provided by imported energy resources, i.e. electricity and natural gas. It is worthy of note that the cost per kWh provided by the local resources, at least for the time being, is higher than that of electricity or natural gas. This strange phenomenon indicates why the percentage of income spent on fuel in the cities of zone I was higher than that, except for Taiz, of the cities of zone II. It is also interesting to note that red-brick and mud houses use local energy resources more frequently than any other types of houses. In these houses more than half the total energy load, regardless of geographical location, was provided by wood, charcoal, animal waste, and/or agricultural residues. On the other hand, type (ii) followed by type (i) vernacular houses, particularly in Al-Hodiedah city, relied on electricity and natural gas more than any other type of house represented in this energy survey.
FIG. 8. DISTRIBUTION OF THE PER CAPITA CONSUMPTION, PER CAPITA EXPENDITURE, AND PERCENTAGE OF INCOME ACCORDING TO THE TYPE OF HOUSE AND GEOGRAPHIC LOCATION.
ENERGY RESOURCES
DOMESTIC ENERGY LOAD AS SATISFIED BY INDIGENOUS AND IMPORTED

FIG. 9

PERCENTAGE OF THE TOTAL DOMESTIC LOAD

AL-HODIEDAH
SANA'A
TAIZ
HAJJAH
DHAMAR
IBB
AL-MAHWEET
AL-BEIDA

PERCENTAGE OF THE TOTAL DOMESTIC LOAD

AL-HODIEDAH
SANA'A
TAIZ
HAJJAH
DHAMAR
IBB
AL-MAHWEET
AL-BEIDA
Nevertheless, local energy resources still dominate the provision of domestic energy in the whole country. This is in spite of the fact that the recent indigenous oil discovery has not, as yet, had a national impact on the energy-consumption patterns.

CONCLUSIONS AND RECOMMENDATIONS

The presented tables and figures suggest that there are good prospects for passive solar-energy systems in existing urban houses in the Yemen. But there is a need to:

- Develop an awareness and interest amongst architects and builders concerning harnessing and applying solar energy.

- Foster the acceptability of, and desire for, integrating solar energy components within building structures.

- Improve the public's respect for using solar energy, not only as a source of illumination, but also as a source of power.

- Introduce energy-thrift measures, such as government regulations limiting the \((UA)_n\) values for buildings according to international recommendations [10].
REFERENCES


2) Anon, "Statistical Year Book", Department of Statistics, Central Planning Organization, Sana'a, Yemen Arab Public, 1982


5) Anon, "Fertility Survey", Department of Statistics, Central Planning Organization, Sana'a, Yemen Arab Republic, 1977

6) N.A. Aulaqi, "Household Energy and Tree Seedling Demand Survey in the Northern Uplands of the Yemen Arab Republic", Sana'a University Report, Sana'a, Yemen Arab Republic, June 1982


CHAPTER TWO

SOLAR INSOLATION UPON THE YEMEN ARAB REPUBLIC
GLOSSARY

**Actinograph**
A device in which a mechanical linkage is used to record temperature differences between a black-coated bimetallic strip exposed to solar radiation and two similar bimetallic strips either painted white or shielded from solar radiation. Because the response time is slow, this instrument is only suitable for obtaining estimates of total global radiation for a large time interval.

**Pyranometer**
An instrument for the measurement of the solar radiation received from the whole hemisphere. It is suitable for the measurement of the global or sky radiation.

**Pyrheliometer**
An instrument for measuring the intensity of direct solar radiation at normal incidence.

**Sky radiation**
Downward diffuse solar radiation as received on a horizontal plane from a hemispherical surface bounded by the horizon with the exception of that part of the surface bounded by the solid angle subtended by the sun's disc.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(i), i=0 to 6</td>
<td>Fourier coefficient in eqn. (12)</td>
</tr>
<tr>
<td>A(2), L=0 to 6</td>
<td>Fourier coefficient in eqn. (11)</td>
</tr>
<tr>
<td>A(r), r=1 to 3</td>
<td>Fourier coefficient in eqn. (7)</td>
</tr>
<tr>
<td>A(s), s=0 to 4</td>
<td>Fourier coefficient in eqn. (7)</td>
</tr>
<tr>
<td>B</td>
<td>Arbitrary constant in eqn. (1)</td>
</tr>
<tr>
<td>C(j), j=1 to 7</td>
<td>Fourier coefficient defined by eqn.(15)</td>
</tr>
<tr>
<td>c(i,j), (i=1 to 4, j=1 to 7)</td>
<td>Matrix used in eqn. (15)</td>
</tr>
<tr>
<td>D</td>
<td>Daily diffuse solar insolation (MJ m⁻²)</td>
</tr>
<tr>
<td>Dc</td>
<td>Diffuse solar radiation flux from a clear sky defined by eqn. (13)</td>
</tr>
<tr>
<td>Fc</td>
<td>Cloud cover factor, see eqn. (17)</td>
</tr>
<tr>
<td>G</td>
<td>Daily global insolation (MJ m⁻²)</td>
</tr>
<tr>
<td>G̅</td>
<td>Average daily global insolation (MJ m⁻²)</td>
</tr>
<tr>
<td>Gc</td>
<td>Global solar radiation flux from a clear sky defined by eqn. (11)</td>
</tr>
<tr>
<td>Ho</td>
<td>Extra-terrestrial radiation on a horizontal surface defined by eqn. (2) (MJ m⁻²)</td>
</tr>
<tr>
<td>H₀</td>
<td>Average daily extra-terrestrial radiation (MJ m⁻²)</td>
</tr>
<tr>
<td>h</td>
<td>Mean relative humidity (per cent) (%)</td>
</tr>
<tr>
<td>K</td>
<td>Zone parameter</td>
</tr>
<tr>
<td>k</td>
<td>Parameter defined by eqn. (19)</td>
</tr>
<tr>
<td>Ic</td>
<td>Direct solar radiation flux from a clear sky W m⁻² defined by eqn. (12)</td>
</tr>
<tr>
<td>Isc</td>
<td>Solar constant (= 1353 W m⁻²)</td>
</tr>
<tr>
<td>L</td>
<td>Number of month (i.e. January = 1, February = 2, etc.)</td>
</tr>
<tr>
<td>m</td>
<td>Number of days in the month</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>$m^*$</td>
<td>Effective air mass, see eqn. (17)</td>
</tr>
<tr>
<td>$N$</td>
<td>Theoretical length of insolation period, hr</td>
</tr>
<tr>
<td>$n$</td>
<td>Actual diurnal duration of sunshine on specified area of Yemen, hr</td>
</tr>
<tr>
<td>$R$</td>
<td>Rayleigh scattering coefficient (= -0.104)</td>
</tr>
<tr>
<td>$S$</td>
<td>$= \frac{n}{N}$</td>
</tr>
<tr>
<td>$T$</td>
<td>Argument of the function defined by eqn. (8)</td>
</tr>
<tr>
<td>$t$</td>
<td>Rain parameter</td>
</tr>
<tr>
<td>$W$</td>
<td>Weighting factor</td>
</tr>
<tr>
<td>$X$</td>
<td>Parameter defined by eqn. (16)</td>
</tr>
<tr>
<td>$x$</td>
<td>Thickness of the ozone layer, m</td>
</tr>
<tr>
<td>$y$</td>
<td>Day of the year</td>
</tr>
<tr>
<td>$Z$</td>
<td>Zenith distance defined by eqn. (10)</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Altitude defined by eqn. (9), degrees</td>
</tr>
<tr>
<td>$\alpha_k$</td>
<td>Noon altitude, see eqn. (6), degrees</td>
</tr>
<tr>
<td>$\alpha_o$</td>
<td>Ozone absorption coefficient (= 0.045), see eqn. (17)</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Latitude, degrees</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Solar declination defined by eqn. (3), degrees</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Hour angle, $= (12.5 - H) \times 15^\circ$; $H = 6$ to 19, degrees</td>
</tr>
<tr>
<td>$\omega_s$</td>
<td>Sunset hour angle defined by eqn. (4), degrees</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Opacity plus albedo effects, see eqn. (17)</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>Latitude factor defined by eqn. (20)</td>
</tr>
<tr>
<td>$\psi_{i,j}$</td>
<td>Seasonal factor ($i = 1$ for inland, $i = 2$ for coastal, $j = 1$ to 12), see eqn. (19)</td>
</tr>
</tbody>
</table>
CHAPTER 2

SOLAR INSOLATION UPON THE YEMEN ARAB REPUBLIC

AMBIENT ENERGY IN THE YEMEN

The average daily solar radiation in Sana'a, the capital city of the Yemen, is 22 MJ m⁻². This is equivalent to an annual energy supply of 8167 MJ m⁻². Some locations in the Yemen have longer hours of sunshine and may have even higher intensities of insolation. The amount of solar energy available throughout the country is so large that its potential as a future energy source deserves exploitation. Thus, harnessing solar energy in the Yemen appears to be a commercially viable proposition.

Energy currently represents more than 25 per cent of the total imports to the Yemen [1] and the demand for energy is increasing rapidly as industrialisation proceeds. It is therefore important that the Yemen, like many other countries, should harness indigenous sources of power, especially wind and solar energy.

INSOLATION MEASUREMENTS

Sana'a University has installed three Eppley pyranometers and a sunshine duration recorder. In particular the following instruments were used:

(1) An Eppley precision spectral pyranometer, for the assessing of solar and sky radiation.
(2) An Eppley Angström pyrheliometer, for determining the magnitudes of direct solar radiation.
(3) An Eppley precision spectral pyranometer, with an iron shade, to measure the diffuse radiation.
(4) An actinograph for hourly observations of the global solar insolation.
In addition, pertinent measurements have been made by the Meteorological Department at Sana'a airport. The experimental data available to date, for the period January, 1977 to September, 1982, are summarised in Table 1.

The Yemen Arab Republic (see Fig. 1) can be divided geographically into three regions:

(i) The coastal zone bordering the Red Sea to the west.
(ii) A mountain range to the north.
(iii) The interior Ibb plain bounded on the east and on the north by a mountain range.

The long-term average climatic conditions for different locations within the interior plain are similar.

For this reason, the Sana'a data are thought to be representative of conditions generally prevailing in the Ibb plain. No solar data are available at present for the mountain area but, because of the distances involved and the difficulties in reaching parts of the mountain regions, it is reasonable, as a first approximation, to use the Sana'a data for predicting conditions there. However, for the mountain region, altitude must also be taken into consideration.

Due to the near-total previous absence of accurate solar radiation data bases for the Yemen {2} and the urgent need there to develop solar-energy systems for rural applications, three theoretical models will be reviewed and analysed.

Typical radiation curves which show the variations of solar intensity as functions of time are given in Fig. 2. Comparisons of the mean hourly values, maximum hourly values and minimum hourly values reveal:

(i) That the mean values per hour, in general, follow a smooth near symmetrical curve with a broad peak of 750 to 942 W m\(^{-2}\) occurring at 12.00 (noon) to 13.00 h.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19.4</td>
<td>20.9</td>
<td>23.4</td>
<td>24.8</td>
<td>24.1</td>
<td>23.8</td>
<td>23.9</td>
<td>23.8</td>
<td>22.3</td>
<td>19.4</td>
<td>9.9</td>
<td>18.4</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
<td>9.9</td>
<td>9.1</td>
<td>9.1</td>
<td>8.8</td>
<td>7.4</td>
<td>7.1</td>
<td>8.7</td>
<td>10.1</td>
<td>18.1</td>
<td>8.1</td>
<td>9.0</td>
</tr>
<tr>
<td>Mean daily global daily sunshine hours (hr)</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>21</td>
<td>23</td>
<td>25</td>
<td>23</td>
<td>23</td>
<td>18</td>
</tr>
<tr>
<td>Maximum value of insolation during the month (Wm⁻²)</td>
<td>831</td>
<td>803</td>
<td>914</td>
<td>903</td>
<td>914</td>
<td>920</td>
<td>720</td>
<td>803</td>
<td>914</td>
<td>914</td>
<td>914</td>
<td>806</td>
</tr>
<tr>
<td>Average monthly value of insolation (Wm⁻²)</td>
<td>0.541</td>
<td>0.725</td>
<td>0.723</td>
<td>0.744</td>
<td>0.769</td>
<td>0.778</td>
<td>0.725</td>
<td>0.725</td>
<td>0.744</td>
<td>0.769</td>
<td>0.725</td>
<td>0.601</td>
</tr>
</tbody>
</table>
FIG. 1. LOCATION AND GEOGRAPHICAL REGIONS OF THE YEMEN ARAB REPUBLIC.
FIG. 2. MEAN MONTHLY DIURNAL VARIATIONS OF THE GLOBAL INSOLATION IN THE HORIZONTAL PLANE.
(ii) That the maximum values per hour follow a smooth curve with a sharp peak of 866 to 1163 W m\(^{-2}\) at noon approximately.

(iii) That minimum values per hour vary from zero in the early morning to a maximum of 694 W m\(^{-2}\) at noon approximately.

A summary of the daily values is given in Table 1.

SOLAR RADIATION MODELLING

There have been many attempts to establish models which can predict the amount of global insolation available at any location (2-9). These models have ranged in complexity from the complete radiative transfer function to some simple models which do not require large-store computers. The mathematical expressions for some of these empirical models are reviewed below.

Page (3) developed an earlier model by Angström (4) that used the sunshine duration as the model input to estimate the average daily solar radiation. It sought a linear relationship between global radiation levels and the number of sunshine hours. The average daily global insolation was predicted from:

\[ \bar{G} = H_o (A + Bn/N) \quad \ldots (1) \]

where:

\[ H_o = \left( \frac{24 I_{sc}/\pi}{1 + 0.033 \cos \left( \frac{360y/365}{\pi} \right)} \right) \times \left[ \cos \delta \cos \phi \sin \omega_s + \left( \frac{2\pi \omega_s/360}{\pi} \right) \sin \delta \sin \phi \right] \quad \ldots (2) \]

\[ \delta = 23.45 \sin \left( \frac{360(y + 284)/365}{\pi} \right) \quad \ldots (3) \]

and:

\[ \cos \omega_s = -\tan \phi \tan \delta \quad \ldots (4) \]
The Liu and Jordan model \cite{5} relates the ratio $D/H_0$ of daily rates of diffuse to extra-terrestrial irradiation, to the ratio $G/H_0$ of daily rates of global to extra-terrestrial irradiation. Although the method is applicable to daily, rather than hourly values, it has frequently been used to estimate hourly rates of diffuse radiation. The equation below, representing the Liu and Jordan correlation, will be used in this study:

$$D/H_0 = 0.294(G/H_0) + 0.1445 \sin (4.97(G/H_0))$$  \ldots \ (5)

Barbaro et al \cite{6} combined the monthly sunshine duration, the noon altitude of the sun on a particular day of the month and a zone parameter to estimate the average monthly global insolation on a horizontal surface. The following mathematical form of this model has been used in this investigation:

$$G = k((mn)^{1.24} (a_k^{0.19})) + 10550(\sin a_k^{2.1}) + 300(\sin a_k)^3$$  \ldots \ (6)

Exell \cite{7} developed a compact first-order random model for simulating daily totals of solar radiation and hourly radiation fluxes. Altitude, declination, zenith distance and latitude were the model inputs. From the day of the year, the Sun's declination was calculated by means of a Fourier series of the form:

$$\delta = \sum_{s=0}^{4} A(s) \cos(sT) + \sum_{r=1}^{3} A(r) \sin(rT)$$  \ldots \ (7)

in which

$$T = (360(y - 80)/365)$$  \ldots \ (8)

The sun's altitude, the zenith distance and the hourly radiation fluxes were calculated by means of eqns. (9) to (13).
Altitude,

\[ \sin \alpha = \cos \omega \cos \delta \cos \phi + \sin \delta \sin \phi \]  

... (9)

Zenith distance,

\[ Z = (1 - \alpha/90) \]  

... (10)

Rate of global insolation,

\[ G_c = W \sum_{\lambda=0}^{6} A(\lambda)Z^{2\lambda} \]  

... (11)

Rate of direct radiation,

\[ I_c = W \sum_{i=0}^{6} A(i)Z^{2i} \]  

... (12)

Rate of diffuse radiation,

\[ D_c = G_c - I_c \sin \alpha \]  

... (13)

The weighting factor, \( W \), allows for changes in the intensity of solar radiation due to variations in the distance of the sun from each particular location on the earth. This factor will be defined later. The model also provides a formula for calculating the average daily global insolation. This formula consists of a Fourier series in which the arguments of the trigonometric terms are functions of the day of the year and the Fourier coefficients are functions of the latitude. Thus:

\[ G = W \left[ \sum_{j=0}^{4} C(j) \cos (jT) + \sum_{j=5}^{7} C(j) \sin((j-4)T) \right] \]  

... (14)

where the \( C(j) \) values are given by:

\[ C(j) = \sum_{i=1}^{4} c(i,j)X^i \]  

... (15)
and:

\[ X = (\phi - 12.5)/7.5 \]  

Goldberg and Klein [8] combined the effective air mass, \( m^* \), for the day, the opacity plus albedo effects and a correction factor for average cloud cover to estimate the daily global insolation. Their equation was:

\[ G = \left( \frac{H_0}{2} \right) \left[ (1 + \exp(-m^*R))\exp(-m^*(\alpha_0 x + \tau)) + 0.1 \right] F_c \]  

... (17)

Reddy [9] introduced a new formula for computing the daily total solar radiation, \( G \), received on the earth's surface;

\[ G = k \left[ (0.8S + 1)(1 - 0.2t)/\sqrt{h} \right] \]  

... (18)

\[ k = 100(\lambda N + \psi_i,j \cos \phi) \]  

... (19)

\[ \lambda = \left[ 0.2/(1 + 0.1\phi) \right] \]  

... (20)

Only predictions from three of the above models, chosen according to the climatological inputs currently available, will be compared in the present investigation with the measured data. The three models are those of Page [3], Barbaro et al [6] and a modified Exell model [7].

**EFFICACY OF THE PREDICTIONS**

Because each of the three chosen models uses similar terms in different ways, or uses different parameters, certain modifications had to be made so that the predictions could be properly compared. For the Page model, the behaviour of the measured data which showed a sinusoidal trend, in-phase with solar declination, dictated the following empirical equations for the regression constants:

\[ A = 0.315 + 0.0335 \sin \left( 30(L - 3) \right) \]  

(21)
FIG. 3. CORRELATION BETWEEN THE PREDICTED AND MEASURED AVERAGE DAILY TOTAL GLOBAL INSOLATIONS FOR ONE DAY OF EACH MONTH IN SANA'A.
and:

\[ B = 0.775 - A \quad \ldots \quad (22) \]

The parameter \( \tilde{H}_0 \) was estimated from eqn. (2) by selecting for each month the day for which \( \tilde{H}_0 \) is nearly the same as the mean monthly value (see Table 1).

For the Barbaro et al model \{6\}, the zone parameter for the latitude range in which the Yemen is located varies sinusoidally according to:

\[ K = 15.3 - 0.095 \sin (30(L - 7)) \quad \ldots \quad (23) \]

The noon altitude was calculated for the same typical day as used to calculate \( \tilde{H}_0 \) in the Page model \{3\}.

When the behaviour of the measured data for Sana'a was analysed, it indicated that the weighting factor \( W \) for the Exell model should be redefined as:

\[ W = 0.845 + 0.0115 \sin \left( \frac{360(y - 196)}{365} \right) \quad \ldots \quad (24) \]

With these modifications and employing the appropriate equations, the correlations between the predicted and the measured values for the three models were evaluated. The results are shown in Fig. 3 for the average daily global insolations for selected days of the year.

**CONCLUSIONS**

As can be seen from Table 2, the percentage deviation reached 9 per cent at maximum for the Page model \{3\}, 10 per cent for the Barbaro et al model \{6\} and only 6 per cent for the modified Exell model \{7\}. Thus the modified Exell empirical formulation (eqn. (4)), gave the best agreement with the measured global insolation data. Equations (7) to (14) with \( W \) defined by eqn. (24), could therefore be used to:

(i) Estimate the solar radiation intensity to within 6 per cent for the Ibb plain.
<table>
<thead>
<tr>
<th>Month</th>
<th>误差 (M)^2</th>
<th>年平均日全球辐射量</th>
<th>误差 (M)^2</th>
<th>年平均日全球辐射量</th>
<th>误差 (M)^2</th>
<th>年平均日全球辐射量</th>
<th>误差 (M)^2</th>
<th>年平均日全球辐射量</th>
<th>误差 (M)^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>15</td>
<td>18.4</td>
<td>4</td>
<td>19.1</td>
<td>4</td>
<td>19.1</td>
<td>4</td>
<td>19.1</td>
<td>4</td>
</tr>
<tr>
<td>Feb.</td>
<td>47</td>
<td>20.9</td>
<td>0</td>
<td>23.0</td>
<td>0</td>
<td>23.0</td>
<td>0</td>
<td>23.0</td>
<td>0</td>
</tr>
<tr>
<td>Mar.</td>
<td>74</td>
<td>23.4</td>
<td>2-</td>
<td>22.7</td>
<td>2-</td>
<td>22.7</td>
<td>2-</td>
<td>22.7</td>
<td>2-</td>
</tr>
<tr>
<td>Apr.</td>
<td>105</td>
<td>24.8</td>
<td>3-</td>
<td>24.8</td>
<td>3-</td>
<td>24.8</td>
<td>3-</td>
<td>24.8</td>
<td>3-</td>
</tr>
<tr>
<td>May</td>
<td>135</td>
<td>24.8</td>
<td>3-</td>
<td>24.8</td>
<td>3-</td>
<td>24.8</td>
<td>3-</td>
<td>24.8</td>
<td>3-</td>
</tr>
<tr>
<td>June</td>
<td>166</td>
<td>24.1</td>
<td>1-</td>
<td>24.1</td>
<td>1-</td>
<td>24.1</td>
<td>1-</td>
<td>24.1</td>
<td>1-</td>
</tr>
<tr>
<td>July</td>
<td>196</td>
<td>21.9</td>
<td>9-</td>
<td>21.9</td>
<td>9-</td>
<td>21.9</td>
<td>9-</td>
<td>21.9</td>
<td>9-</td>
</tr>
<tr>
<td>Aug.</td>
<td>227</td>
<td>23.3</td>
<td>5-</td>
<td>23.3</td>
<td>5-</td>
<td>23.3</td>
<td>5-</td>
<td>23.3</td>
<td>5-</td>
</tr>
<tr>
<td>Sept.</td>
<td>258</td>
<td>23.8</td>
<td>2-</td>
<td>23.8</td>
<td>2-</td>
<td>23.8</td>
<td>2-</td>
<td>23.8</td>
<td>2-</td>
</tr>
<tr>
<td>Oct.</td>
<td>288</td>
<td>22.3</td>
<td>6+</td>
<td>22.3</td>
<td>6+</td>
<td>22.3</td>
<td>6+</td>
<td>22.3</td>
<td>6+</td>
</tr>
<tr>
<td>Nov.</td>
<td>319</td>
<td>19.4</td>
<td>7+</td>
<td>19.4</td>
<td>7+</td>
<td>19.4</td>
<td>7+</td>
<td>19.4</td>
<td>7+</td>
</tr>
<tr>
<td>Dec.</td>
<td>349</td>
<td>18.4</td>
<td>4+</td>
<td>18.4</td>
<td>4+</td>
<td>18.4</td>
<td>4+</td>
<td>18.4</td>
<td>4+</td>
</tr>
</tbody>
</table>

Average daily global insolation, as predicted from the available models, together with the percentage errors relative to the actual observations.

Table 2
(ii) Provide sensible estimates for the missing data in the station records.

(iii) Establish a typical reference year for solar-energy calculations in the Yemen.
REFERENCES


CHAPTER THREE

THERMAL BEHAVIOURS OF VERNACULAR BUILDINGS IN THE YEMEN ARAB REPUBLIC
### NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Vertical area, in contact with the ambient environment, of the solid walls (i.e. excluding windows) of the house</td>
<td>m²</td>
</tr>
<tr>
<td>A_r</td>
<td>External area of the horizontal roof of the considered house</td>
<td>m²</td>
</tr>
<tr>
<td>A_ref</td>
<td>External area of the reference house roof</td>
<td>m²</td>
</tr>
<tr>
<td>A_win</td>
<td>Total glazed area for each storey of the considered house</td>
<td>m²</td>
</tr>
<tr>
<td>C_n(j,k)</td>
<td>Wall-roof matrix, an expression for which is given by eqn. (18)</td>
<td></td>
</tr>
<tr>
<td>C_p,i</td>
<td>Specific heat of the material in the ith layer of the vertical wall (or horizontal roof)</td>
<td>J kg⁻¹K⁻¹</td>
</tr>
<tr>
<td>d_i</td>
<td>Thickness of the ith layer (in the vertical wall or horizontal roof)</td>
<td>m</td>
</tr>
<tr>
<td>f_r,f_w</td>
<td>Ratio of the rate of energy transmitted through a horizontal roof (or vertical wall) to that falling on the horizontal roof (or vertical wall) at a specific time</td>
<td></td>
</tr>
<tr>
<td>F_n</td>
<td>U-value of a specified wall: defined for n&gt;1 by equation (20)</td>
<td>W m⁻²K⁻¹</td>
</tr>
<tr>
<td>F_n,I(j,k),F_n,II(j,k)</td>
<td>Dimensionless quantities as given by eqns. (65) and (71) respectively</td>
<td></td>
</tr>
</tbody>
</table>
NOMENCLATURE (cont)

\( g(k), g_n(k) \)  
Dimensionless quantities defined by eqns. (49) and (51) respectively

\( g_1, I(j,k), g_2, II(j,k) \)  
Dimensionless quantities as defined by eqns. (56) and (58) respectively

\( g_n, I(j,k), g_n, II(j,k) \)  
Dimensionless quantities, as given by eqn. (60)

\( h \)  
Overall (i.e. including radiation contribution) heat loss coefficient \( \text{W m}^{-2}\text{K}^{-1} \)

\( h_i \)  
Air-film heat-transfer coefficient \( \text{W m}^{-2}\text{K}^{-1} \) for the inside wall of the considered house as defined in Table 1

\( h_o \)  
Air-film heat-transfer coefficient \( \text{W m}^{-2}\text{K}^{-1} \) for the outside surface of the considered house evaluated under respectively sheltered, normal, or severe wind conditions (see Table 1)

\( h_{o,1}, h_{o,n} \)  
Outside air-film heat-transfer coefficients for \( n=1 \) and \( n>1 \) respectively \( \text{W m}^{-2}\text{K}^{-1} \)

\( H \)  
Long-wave rate of thermal radiation \( \text{W m}^{-2} \) from a black surface at the environmental air temperature: average values for typical vertical and horizontal surfaces in the Yemen are given by eqn. (21a)

\( j \)  
Integer, referring to the design of the chosen roof and its combination of constructional materials; \( j=1, 2, 3, \ldots \) or 9 as designated in Fig. 2.
NOMENCLATURE (cont)

\( k \)  
Integer, such that \( 1 \leq k \leq 10 \): it refers to the glazed-to-wall area ratio, see eqns. (14) and (15)

\( \ell \)  
Integer indicating direction for east, west, north or south, for which \( \ell \) equals 1, 2, 3 or 4 respectively

\( l, l_r \)  
Wall length for the n-storey and m reference houses respectively

\( L \)  
Insolation period: normally \( hr \) \( L = 8 \) hours

\( M_n(j,k) \)  
The n-storey house coupling matrix - see eqn. (17)

\( n \)  
Number of storeys in the considered building

\( \dot{q}(t) \)  
Instantaneous value of the total heat flux entering a house or (emerging from the house, if its value is of negative sign) as defined by equation (22) \( W \)

\( \dot{q}_{cg}(t) \)  
Transient rate of thermal flux \( W \) conducted, through the glazed elements, into the house, as defined by eqn. (25)

\( \dot{q}_{dir}(t), \dot{q}_{indr}(t) \)  
The direct and indirect heat transfer \( W \) components of the flux entering the house: these are evaluated respectively at time \( t \) in eqns. (23) and (30)

\( \dot{q}_{fe}(t) \)  
Transient rate of heat gain from the "free" energy sources within the house
\[ q_g(t), q_v(t) \] Rates of thermal loss from the house via the ground and ventilation respectively

\[ q_{indr} \] 24 hour average of the instantaneous rate of heat transfer through the building structure, as defined by eqn. (31)

\[ \dot{q}_{indr}(t') \] Swing of the heat flow about the daily average of the rate of heat being transferred, through the building structure, to or from the house, as defined by eqn. (34)

\[ q_{njk, I}(t), q_{njk, II}(t) \] Transient rates of heat loss from a house of \( n \) storeys in groups I and II respectively, as defined by eqns. (39) and (40)

\[ q_T(t) \] Transient rate of solar energy transmitted through the glazed area into the house, as defined by eqn. (24)

\[ Q_1 \] Average steady-state (i.e. in practice the mean value over 24 hours) rate of heat loss from the ground storey as indicated by eqn. (11)

\[ \sum_{x=1}^{4} Q_x(t) \] Transient rate of solar energy falling per unit area on the differently oriented (i.e. east, west, north or south facing) house walls
### NOMENCLATURE (cont)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{n,I}(j,k), Q_{n,II}(j,k)$</td>
<td>Steady-state rates of heat loss $W$ from a house of $n$ storeys in groups I and II respectively, as defined by eqns. (16) and (17)</td>
</tr>
<tr>
<td>$Q_r, Q_w, Q_{win}$</td>
<td>Rates of steady-state heat loss $W$ through the roof (and ceiling), walls, and windows respectively: expressions for which are given by eqns. (7), (6), and (8)</td>
</tr>
<tr>
<td>$Q_{ref,I}(j,k), Q_{ref,II}(j,k)$</td>
<td>Steady-state rates of heat loss $W$ from the reference house of groups I and II respectively, as defined by eqns. (55), and (57)</td>
</tr>
<tr>
<td>$R$</td>
<td>Ratio of wall length of the $n$-storey house relative to that of the reference house, as defined by eqn. (53)</td>
</tr>
<tr>
<td>$R_{njk,I}(t), R_{njk,II}(t)$</td>
<td>Heat loss reduction factors, expressions for which are given by eqns. (42) and (43) respectively</td>
</tr>
<tr>
<td>$R_t$</td>
<td>Total thermal resistance of a wall $W^{-1}m^2 K$ or roof - see eqn. (4)</td>
</tr>
<tr>
<td>$S$</td>
<td>Sum of the vertical outside surface $m^2$ areas of the external solid homogeneous walls for the considered storey</td>
</tr>
<tr>
<td>$S_r$</td>
<td>Solid homogeneous wall area for the considered storey of the reference house</td>
</tr>
<tr>
<td>$t, t'$</td>
<td>Time periods: $t' = t + \phi$ hr</td>
</tr>
</tbody>
</table>
NOMENCLATURE (cont)

$T_e, T_i$  
The average daily temperatures of the ambient environment and of the air inside the house respectively

$T_0, T_0(t)$  
Ambient environmental air temperatures in the steady-state and transient-state representations respectively

$T_{sa}(t)$  
Sol-air temperature appropriate to the direction and surface of a wall or roof, as defined by eqn. (21)

$T_{sa,r}, T_{sa,w}$  
24 hour average of the sol-air temperatures appropriate to the direction and surface of the roof and house walls respectively

$T_{sa,r}(t), T_{sa,w}(t)$  
Instantaneous sol-air temperatures appropriate to the direction and surface of the horizontal roof and house walls respectively

$T_{sa,r}(t'), T_{sa,w}(t')$  
Sol-air temperature, evaluated at $t' = t + \phi$, appropriate to the direction and surface of the roof and house walls respectively

$U$  
Composite wall heat transfer coefficient, see eqn. (2)

$U_{cr}$  
Composite roof heat transfer coefficient, see eqn. (7)
NOMENCLATURE (cont)

\( U_{cr,j} \) Heat transfer coefficient for the jth type of roof construction (see Fig. 2) \( \text{W m}^{-2}\text{K}^{-1} \)

\( U_1, U_2 \) Heat transfer coefficients for the first and the second storeys respectively of groups I and II houses \( \text{W m}^{-2}\text{K}^{-1} \)

\( U_{n,I}, U_{n,II} \) Heat transfer coefficients for the nth storey houses in groups I and II respectively, expressions for which are given by eqns. (12) and (13) \( \text{W m}^{-2}\text{K}^{-1} \)

\( U_{n,I}(j,k), U_{n,II}(j,k) \) Heat transfer coefficients for groups I and II houses respectively, as defined by eqns. (61) and (62) \( \text{W m}^{-2}\text{K}^{-1} \)

\( v \) Mean wind speed to which the external wall is exposed (see Table 1) \( \text{m s}^{-1} \)

\( x_i \) Thickness of the ith vertical structural layer in the wall \( \text{m} \)

\( z \) Integer, \( z=1 \) to 8; refers to the type of wall construction as designated in Fig. 3

\( \alpha \) Absorption coefficient of the materials of the outer wall or roof surfaces respectively for short-wave radiation - see references 1 and 2

\( \alpha_g \) Absorption coefficient for glass; for the present numerical predictions, it is assumed that \( \alpha_g = 0.2 \)
NOMENCLATURE (cont)

\( c \)  
Emissivity of the outer surface considered - see Table 1

\( \eta \)  
Dimensionless constructional parameter defined by equation (54)

\( \eta_g(t) \)  
Dimensionless parameter as defined by eqn. (38)

\( \eta_r(t), \eta_w(t) \)  
Dimensionless parameters, as defined for the roof and walls by eqns. (37) and (36) respectively

\( \theta_0 \)  
Initial temperature of the outer surface of the external wall

\( \theta(t) \)  
Temperature at a general point in the external wall, as given by eqn. (27)

\( \lambda_i \)  
Thermal conductivity of the \( i \)th layer in the vertical wall (or horizontal roof)

\( \nu_i(x) \)  
Attenuation factor for the \( i \)th vertical structural layer in the wall: see eqn. (28)

\( \rho_i \)  
Density of the \( i \)th layer in the vertical wall (or horizontal roof)

\( \tau \)  
Glass transmission coefficient: for the numerical predictions, it is assumed that \( \tau = 0.85 \)
NOMENCLATURE (cont)

\( \phi \)  
Phase lag of the temperature \( \text{hr} \) signal dependent on the wall (or roof) thickness - see Fig. 4

\( \phi_i(x) \)  
Phase lag imposed upon the temperature \( \text{hr} \) signal due to its passage through the \( i \)th vertical structural layer of the wall: see eqn. (29)

Suffixes

\( r \)  
of the roof

\( w \)  
of the wall
CHAPTER 3

THERMAL BEHAVIOURS OF VERNACULAR BUILDINGS IN THE YEMEN ARAB REPUBLIC

Mathematical Model of the Steady-State Heat Transfer Behaviour

The walls, any insulant that is present and the air boundary-layer films associated with a building structure, each offer resistances to heat flows. The steady-state heat transfer equation for the double layer wall (or roof), as represented in Figure 1, is given by the well-known equation:

\[
(T_i - T_o) = \dot{Q} \left( \frac{1}{A h_i} + \frac{1}{A h_o} + \frac{1}{A} \sum_{i=1}^{2} \frac{d_i}{\lambda_i} \right) \quad \ldots (1)
\]

However, the overall steady-state heat-transfer coefficient is defined by:

\[
\dot{Q} = U A \Delta T \quad \ldots (2)
\]

where \( \Delta T = T_i - T_o \)

So

\[
U^{-1} = \left( h_i^{-1} + h_o^{-1} + \sum_{i} \frac{d_i}{\lambda_i} \right) \quad \ldots (3)
\]

Thus for a vertical wall (or horizontal roof) of \( i \) parallel vertical (or horizontal respectively) layers, the overall thermal resistance, \( R_t \), can be calculated via

\[
R_t = \left( h_i^{-1} + h_o^{-1} + \sum_{i} \frac{d_i}{\lambda_i} \right) \quad \ldots (4)
\]

The total rate of heat loss from a house is the net result of the simultaneous contributions through its walls, roof, floors and windows, and via ventilation.

Houses in the Yemen can be categorised as follows:

**Group I:** Those with all their external walls of the same material, irrespective of the number of storeys.
FIG. 1

THERMAL RESISTANCE CIRCUIT FOR THE STEADY-STATE HEAT LEAKS THROUGH THE TWO-LAYER BOUNDARY ELEMENTS OF A HOUSE.
Group II: Those built with external walls of different materials for each storey.

In order to obtain a first approximate description of the thermal performance of a house, it is assumed that:

i) its internal temperature can be assigned a single value $T_i$;

ii) the heat losses via ventilation and to the ground are balanced by heat gains from its occupants, solar energy and/or interior lighting;

iii) the heat capacity of the building structure has no effect on the thermal performance, i.e. steady-state behaviour is considered.

Thus the total rate of heat loss from the building is given by:

$$\dot{Q} = \dot{Q}_w + \dot{Q}_r + \dot{Q}_{\text{win}} ... \ (5)$$

where

$$\dot{Q}_w = (S_1 U_1 + S_2 U_2 + \ldots + S_n U_n) \Delta T \ldots \ (6)$$

$$\dot{Q}_r = A_r U_{cr} \Delta T \ldots \ (7)$$

and

$$\dot{Q}_{\text{win}} = n A_{\text{win}} U_{\text{win}} \Delta T \ldots \ (8)$$

For Group I houses

$$\dot{Q}_w = n U_1 S \Delta T \ldots \ (9)$$

where $n$ is the number of storeys in the considered house.

Combining equations 7, 8 and 9, and substituting into an equation corresponding to (5), gives
where $\dot{Q}_1$ is the steady-state rate of heat loss through the walls of the first storey, defined in terms of the corresponding heat transfer coefficient by:

$$\dot{Q}_1 = S U_1 T$$  

... (11)

There will be a greater effect of wind assault on the rate of heat loss from the upper storeys than from the lower ones. The overall heat transfer coefficient for the $n$th storey can be expressed in terms of that for the first storey. These two heat transfer coefficients differ in the value of $h'_0$ for Group I houses and in the values of $h'_0$ and thermal conductivity-thickness ratio for Group II houses. Accounting for the exposure of the external walls and roof to the wind, see Table 1, and using eqn. (3) we can deduce that:

For Group I houses

$$U_{n,I} = \left( \frac{h'_0,n}{h'_0,1} \right) \left( \frac{h'_1 + h'_0,1 + h'_1 h'_0,1 \sum d_i/\lambda_i}{h'_1 + h'_0,n + h'_1 h'_0,n \sum (d_i/\lambda_i)} \right) U_1$$  

... (12)

For Group II houses

$$U_{n,II} = \left( \frac{h'_0,n}{h'_0,1} \right) \left( \frac{h'_1 + h'_0,1 + h'_1 h'_0,1 \sum (d_i/\lambda_i)_{n=1}}{h'_1 + h'_0,n + h'_1 h'_0,n \sum (d_i/\lambda_i)_{n>1}} \right) U_1$$  

... (13)

Traditionally, Yemenis tend to occupy dwellings with the following design ratios \{3\}:

$$A_r/S = 0.05k (K + 0.5)$$  

... (14)

$$A_{win}/S = 0.05k$$  

... (15)

where $k = \text{an integer, such that } 1 \leq k \leq 10$
<table>
<thead>
<tr>
<th>Winds</th>
<th>73.7</th>
<th>47.9</th>
<th>30.9</th>
<th>34.94</th>
<th>h</th>
<th>9.43</th>
<th>9</th>
<th>3.29</th>
<th>8.13</th>
<th>h</th>
<th>0.05</th>
<th>0.05</th>
<th>0.05</th>
<th>0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root/Cellings</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>M411S</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 1**

Heat Transfer Coefficient

For ambient environment surface:

$\alpha = \begin{cases} \alpha_m & (T_m < T_{amb}) \\ \alpha_{s-1} & (T_m > T_{amb}) \end{cases}$

For internal surface (e.g., facing human):

$\alpha = \begin{cases} \alpha_{int} & (T_{int} < T_{amb}) \\ \alpha_{s-1} & (T_{int} > T_{amb}) \end{cases}$

$T$ is the temperature of the surface in question.
For the jth type of roof (as defined in Fig. 2), and using equations (10), (14) and (15), it can be deduced that

\[ \dot{Q}_{nj}(j,k) = \left[ n + 0.5k(k + 0.5)(U_{cr,j}/U_1) + 0.05kn(U_{win}/U_1) \right] \dot{Q}_1 \]

or

\[ \dot{Q}_{nj}(j,k) = M_{nj}(j,k) \dot{Q}_1 \quad \text{... (16)} \]

where the matrix \( M_{nj}(j,k) \) indicates the influence of the wall-roof combination on the total steady-state rate of heat loss from the house, and is given by

\[ M_{nj}(j,k) = n + C_{nj}(j,k) \quad \text{... (17)} \]

where

\[ C_{nj}(j,k) = \left[ 0.05k\left(k + 0.5\right)(U_{cr,j}/U_1) + 0.05kn\left(U_{win}/U_1\right) \right] \quad \text{... (18)} \]

A similar procedure can be used for Group II houses, i.e.

\[ \dot{Q}_{ni}(j,k) = \left[ M_{nj}(j,k) + \left(F_n/U_1\right) + (1 - n) \right] \dot{Q}_1 \quad \text{... (19)} \]

where \( F_n \) is the sum of the U-factors for the different walls, i.e.

\[ F_n = \sum_{z=2}^{n} U_z \quad \text{... (20)} \]

Justification for Employing the Steady-State Approach

The diurnal variations of the ambient environment's temperature and the insolation upon house walls are not accounted for in equations (16) and (19). A more rigorous approach would allow for the transient behaviour taking into account the thermal inertia of the walls and roof, and the variations of the ambient temperature and the energy inputs as functions of time. The usual practice \{1,5\} under such conditions, is to express the rate of heat transfer, i.e. the amount of flux entering (or emerging
FIG. 2. VERTICAL CROSS-SECTIONS OF TRADITIONALLY-EMPLOYED HORIZONTAL ROOFS ON DWELLINGS IN THE YEMEN ARAB REPUBLIC.
from the house, in terms of the differences between the artificial environmental and the sol-air temperatures rather than on the inside-outside air temperature difference. This tactic \{1\} simplifies certain calculations, and moreover the artificial environmental temperature, \(T_e\), is a better index for human comfort assessment purposes than the inside air temperature, \(T_i(t)\). In this analysis, we fix \(T_e\) at the comfort level of 22°C, and calculate the sol-air temperature, \(T_{sa}(t)\), appropriate to the direction and surface of the house walls and roof according to:

\[
T_{sa}(t) = \left( T_o(t) + (\alpha \dot{Q}_x(t) - \varepsilon H)/h \right)
\]

The parameter \(H\) in equation (21) accounts for the long-wave radiation from a black surface at the environmental air temperature. For vertical and horizontal surfaces in the Yemen it is assumed that \{1\}:

\[
H = \begin{cases} 
100 \text{ W m}^{-2} & \text{for a horizontal roof} \\
0 & \text{for vertical walls} 
\end{cases} \quad \text{... (21a)}
\]

The total heat flux entering the house, can be described by the following general equation:

\[
\dot{q}(t) = \dot{q}_{\text{dir}}(t) + \dot{q}_{\text{indr}}(t) \quad \text{... (22)}
\]

where \(\dot{q}_{\text{dir}}(t)\) and \(\dot{q}_{\text{indr}}(t)\) represent respectively the contributions of the direct and indirect heat transfer components to the flux.

The value of \(\dot{q}_{\text{dir}}(t)\) results from contributions due to the:

- transient rate of solar energy transmitted through the glazed area into the house, \(\dot{q}_T(t)\);
- transient rate of thermal fluxes conducted, through the glazed area, into the house, \(\dot{q}_{cg}(t)\);
- rate of ventilation heat losses, resulting from the changes of the inside air, \(\dot{q}_v(t)\);
rate of heat gains from the free energy sources within the house, \( \dot{q}_{fe}(t) \); and

rate of thermal losses through the floor, \( \dot{q}_g(t) \).

Accordingly \( \dot{q}_{dir}(t) \) is the appropriate sum of all these terms, i.e.

\[
\dot{q}_{dir}(t) = \dot{q}_T(t) + \dot{q}_{fe}(t) + \dot{q}_{cg}(t) - \dot{q}_v(t) - \dot{q}_g(t) \tag{23}
\]

Assuming that the heat losses to the ground and due to ventilation are balanced by the rate of heat gains from the "free" energy sources including those within the house, then equation (23) can be rewritten in the form:

\[
\dot{q}_{dir}(t) = \dot{q}_T(t) + \dot{q}_{cg}(t)
\]

where

\[
\dot{q}_T(t) = -4 \sum_{\lambda=1}^4 A_{win} \dot{Q}_\lambda(t) \tag{24}
\]

and

\[
\dot{q}_{cg}(t) = U_{win} A_{win} (T_{sa}(t) - T_e) \tag{25}
\]

On the other hand, the contribution of the indirect components, \( \dot{q}_{indr}(t) \), instantaneous at a time, to the flux entering or emerging from the house occurs at some later time, \( t' = t + \phi \).

This delay depends on the thickness and density of the boundary walls and roof.

Let us consider the response of the indoor temperature to any incident solar heat gains. The general equation for the one-dimensional heat flow through a wall is

\[
\frac{\partial^2 \theta(t)}{\partial x^2} = \left( \frac{\rho \ C_p}{\lambda} \right) \frac{\partial \theta(t)}{\partial t} \tag{26}
\]
During the insolation period, L, the temperature at a general point, of co-ordinate x, in the wall can be written (4) as:

\[ \theta(t) = (\mu(x) \theta_0) \sin \left[ \frac{2\pi(t - \phi(x))}{24} \right] \] ...

(27)

where \( \mu(x) \) and \( \phi(x) \) are respectively the attenuation factor and time delay for a heat pulse propagating through the wall.

On substituting from equation (27) into equation (26), the following expressions can be deduced for the effects of ith vertical layer of the considered wall:

\[ \mu_i(x) = \exp \left\{ - \sqrt{\frac{\rho_i C_{p,i} \lambda_i}{L}} \right\} \] ...

(28)

and

\[ \phi_i(x) = \left( \frac{L}{120} \right) \sqrt{\frac{\rho_i C_{p,i} \lambda_i}{\pi L}} \] ...

(29)

Wall types 6, 7 and 8 (see Fig. 3) are used only as the walls of ground storeys in the modern multi-storey houses. A vernacular multi-storey house can be built wholly using any of types 1 to 5. However, if dissimilar types are used for each storey, they are constructed traditionally with stone (type 1) for the ground-floor walls, followed by concrete (type 3), brick (type 2), or mud (type 4) for successively higher storeys in decreasing order of popularity. Reinforced concrete walls (type 5) are used for the top storeys in buildings of up to three storeys in height, for which the lower storeys have concrete or stone walls.

It can be deduced (via equations 28 and 29 and using the data presented in Table 2) for buildings with vernacular walls (of types 1 or 4), that thermal comfort is maintained better within the structure during the summer months than is achieved with commonly-adopted modern structures (of type 3 for example).

Such predictions are corroborated by experience. The plot of \( \phi_i(x) \) as a function of x, is shown in Fig. 4. The phase lags between the attainment of maximum temperatures at the outer and inner surfaces of a wall will
FIG. 3 VERTICAL CROSS-SECTIONS OF SOME COMMONLY-EMPLOYED TYPES OF WALLS IN THE YEMEN ARAB REPUBLIC.
### TABLE 2

**PHYSICAL PROPERTIES OF SOME COMMONLY-USED WALLS OF BUILDINGS IN THE YEMEN**

<table>
<thead>
<tr>
<th>Wall type</th>
<th>$\rho_i$ (Mg m$^{-3}$)</th>
<th>$d_i$ (m)</th>
<th>$C_{p,i}$ (J kg$^{-1}$ K$^{-1}$)</th>
<th>$\lambda_i$ (W m$^{-1}$ K$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.72</td>
<td>0.52</td>
<td>877</td>
<td>0.872</td>
</tr>
<tr>
<td>2</td>
<td>2.24</td>
<td>0.42</td>
<td>836</td>
<td>0.601</td>
</tr>
<tr>
<td>3</td>
<td>2.21</td>
<td>0.45</td>
<td>897</td>
<td>1.745</td>
</tr>
<tr>
<td>4</td>
<td>1.84</td>
<td>0.62</td>
<td>753</td>
<td>0.465</td>
</tr>
</tbody>
</table>
FIG. 4
PHASE LAGS FOR A THERMAL SIGNAL PASSING THROUGH DIFFERENT THICKNESS OF THE STATED WALL MATERIALS
be approximately 15 hours for types 1 and 4 walls, and between 9 and 14 hours for all other types considered here. Because the phase lag, \( \phi \), evaluated at \( x > 0.4m \), for all the materials considered except concrete is greater than the eight hour insolation period, the contribution of the stored solar gains, (i.e. the indirect heat transfer components \( q_{\text{indr}}(t) \)), is negligible during that period for almost all the walls considered.

Several methods have been used to estimate the contribution of the indirect heat transfer components to the flux entering or emerging from the house. The method followed here expresses such contributions as the sum of the daily average of the instantaneous rate of heat transfer through the solid elements of the house and the swing of the heat flow, evaluated at time \( t' = t + \phi \), where \( \phi \) is the phase lag. Thus:

\[
q_{\text{indr}}(t) = \bar{q}_{\text{indr}} + \dot{q}_{\text{indr}}(t') \quad \text{(30)}
\]

The average daily rate of heat transfer \( \{5\} \) through the solid elements of a house is given by:

\[
\bar{q}_{\text{indr}} = U S (\bar{T}_{sa,w} - T_e) + U_{cr} A_r (\bar{T}_{sa,r} - T_e) \quad \text{(31)}
\]

where \( \bar{T}_{sa,w} \), \( \bar{T}_{sa,r} \), and \( T_e \) are respectively the 24 hour average values of the sol-air temperatures, appropriate to the direction and surface of the house walls and roof, and the constant indoor environmental temperature.

If the thermal capacity of the roof or the wall were infinite and there were no fluctuations of temperature but simply a steady temperature-difference existed, then the rate of heat transfer to the house walls would be given by equation (31). However, if the thermal capacity were zero, the rate of heat transfer at time \( t \) would be:

\[
\dot{q}_{\text{indr}}(t) = U S (T_{sa,w}(t) - T_e) + U_{cr} A_r (T_{sa,r}(t) - T_e) \quad \text{(32)}
\]

The actual rate of heat transfer into the house, \( \dot{q}_{\text{indr}}(t) \), lies somewhere between the extreme values shown by equations (31) and (32), and this occurs at some later time, \( t' = t + \phi \). This rate is calculated by adding to the expression given by equation (31) the swing of the heat flow about the
mean evaluated at time $t' = t + \phi$. Thus

$$
\dot{q}_{\text{indr}}(t) = \ddot{q}_{\text{indr}} + \ddot{q}_{\text{indr}}(t')
$$

... (33)

where

$$
\ddot{q}_{\text{indr}} \text{ is given by equation (31) and } \ddot{q}_{\text{indr}}(t') \text{ is given by (1)}:
$$

$$
\ddot{q}_{\text{indr}}(t') = f_w U S \left( T_{sa,w}(t') - T_e \right) + f_r U_{cr} A_r \left( T_{sa,r}(t') - T_e \right)
$$

... (34)

where $f_w$ and $f_r$ are the decrement factors respectively of the house walls and roof, and dependent on their respective thicknesses; and $T_{sa,w}(t')$ and $T_{sa,r}(t')$ are respectively the sol-air temperatures at $t' = t + \phi$, appropriate to the direction and surface of the house walls and roof.

The overall rate of heat transfer, $\dot{q}(t)$, can be obtained as the sum of components described by equations (33) and (23), i.e.,

$$
\dot{q}(t) = U S \left( T_e - T_o(t) \right) \left( \eta_w(t) + \left( \frac{U_{cr} A_r}{U S} \right) \eta_r(t) - \left( \frac{U_{win} A_{win}}{U S} \right) \eta_g(t) \right)
$$

... (35)

where $\eta_w(t)$, $\eta_r(t)$ are dimensionless parameters expressing the ratio of the temperature difference, as evaluated at times $t'$ and $t$, between the indoor environmental temperature and the ambient sol-air temperature, and $\eta_g(t)$ is a dimensionless parameter expressing the instantaneous effect of the direct heat transfer components on the indoor climate. Expressions for these are:-

$$
\eta_w(t) = \left( \frac{T_{sa,w} + f_w T_{sa,w}(t') - (1 + f_w) T_e}{T_e - T_o(t)} \right)
$$

... (36)

$$
\eta_r(t) = \left( \frac{T_{sa,r} + f_r T_{sa,r}(t') - (1 + f_r) T_e}{T_e - T_o(t)} \right)
$$

... (37)

$$
\eta_g(t) = \left( 1 - \frac{\sum_{n=1}^{n=4} \frac{\dot{q}_n(t)}{h}}{h \frac{U_{win}(T_e - T_o(t))}{} \right)
$$

... (38)
Equation (35) can be generalised to permit one to obtain descriptions of the behaviours of all walls and roofs employed in the Yemeni houses as follows:

For a n-storey house in Group I:

$$\dot{q}_{njk, I}(t) = U_1 S \left( T_e - T_0(t) \right) \left( n \eta_w(t) + (U_{cr,j} A_r/U_1 S) \eta_r(t) - n(U_{win}A_{win}/U_1 S)\eta_g(t) \right)$$

...(39)

For a n-storey house in Group II:

$$\dot{q}_{njk, II}(t) = U_1 S \left( T_e - T_0(t) \right) \left( (1+(F_n/U_1)) \eta_w(t) + (U_{cr,j} A_r/U_1 S)\eta_r(t) - n(U_{win}A_{win}/U_1 S)\eta_g(t) \right)$$

...(40)

Using equations (16), (19), (39) and (40), we can devise the following general expressions

$$\dot{q}_{njk, I}(t) = R_{njk, I}(t) \dot{Q}_{n, I}(j, k)$$

and

$$\dot{q}_{njk, II}(t) = R_{njk, II}(t) \dot{Q}_{n, II}(j, k)$$

...(41)

where

$$R_{njk, I}(t) = \frac{\eta \left( 1 - \eta_w(t) \right) + 0.05k(k+0.5)(1-\eta_r(t)) \left( U_{cr,j}/U_1 \right) + 0.05k\eta_g(t) \left( U_{win}/U_1 \right)}{M_n(j, k)}$$

...(42)
The heat reduction factor \( R_{njk} \), depending on the time of the day, can be positive, i.e. when heat flows from the house inside to the ambient environment \( T_i(t) > T_o(t) \), or negative, i.e. when heat flows in the reverse direction as \( T_o(t) > T_i(t) \). In general, according to equations (42) and (43):

\[
\text{for } T_o(t) < T_i(t) \quad R_{njk, I(t)} > 0
\]

\[
R_{njk, II(t)} > 0
\]

and

\[
\text{for } T_o(t) > T_i(t) \quad R_{njk, I(t)} < 0
\]

\[
R_{njk, II(t)} < 0
\]

Thus the steady-state equations proposed in this model can be used to predict the transient state of heat loss for that period of the day during which the heat flow is from the inside to the outside, i.e. for which \( T_o(t) < T_i(t) \). For the period when \( T_o(t) > T_i(t) \), which amounts to about 4 hours per day in the summer and to about 2 hours per day in the winter, (see Fig. 5), the temperature...
FIG. 5

EXPERIMENTAL OBSERVATIONS OF THE HEAT-LOSS REDUCTION FACTOR AS A FUNCTION OF TIME FOR A TYPICAL VENETIAN BUILDING.

VALUE OF $R_{\text{fin}}(\text{h}) = 0.79$

VALUE OF $R_{\text{fin}}(\text{h}) = 0.71$

OVER 24 HOUR PERIOD. THE AVERAGE

TIME (h) 24 0 16 22 12 8 4

WINTER

MONTH

24 0 16 22 12 8 4

SUMMER
distribution in the external wall is affected by the rates of absorption at the external surfaces (6) and consequently the contribution of the stored heat to the increase of the internal house temperature should be included. The experimental observations of the heat loss reduction factor, \( R_{njk,l}(t) \), as a function of time for a typical Yemeni house is shown for representative summer and winter days in Fig. 5. The plot is for a single-storey stone house with the following design characteristics: a glazed-to-solid wall area ratio of 0.25, a roof U-value of 2.26 W/m\(^2\)K and a window U-value of 4.3 W/m\(^2\)K for the temperature conditions \( \Delta T = 6^\circ\text{C} \) in winter and 2\(^\circ\text{C} \) in summer, and \( \Delta T(t) = 22 - T_0(t) \). As shown in Fig. 5, the steady-state and transient rates of heat loss, see equation (41), are equal during the off-sunshine hours. The same agreement was also obtained during the early morning sunshine hours (i.e. 6.00 to 8.00 a.m. in the summer and 7.00 to 8.00 a.m. in the winter), and the late afternoon hours (i.e. 4.00 p.m. to 6.00 p.m. in the summer and 2.00 to 5.00 p.m. in the winter). Thus the total number of hours during which the predictions of the steady-state model agree with those of a transient-state model is, see Fig. 5, 17 hours in the summer and 19 hours in the winter. In other words, the ratio of the shaded area in Fig. 5, i.e. for periods during which the model fails to predict the thermal behaviour of the house, to the unshaded area (i.e. for the periods during which the model is able to predict the thermal behaviour of the house), equals approximately 0.79 for winter and 0.71 for summer. This means that the transient rates of heat loss can be expressed approximately in terms of the steady-state rates of heat loss for both summer and winter as follows:

\[
\begin{align*}
\dot{Q}_{njk,l}(t) & = R_{njk,l}(t) \dot{Q}_{n,l}(j,k) \\
\dot{Q}_{njk,l}(t) & = R_{njk,l}(t) \dot{Q}_{n,l}(j,k)
\end{align*}
\] ...

\( \text{For Summer} \)
For Winter:

\[
\begin{pmatrix}
q_{nk,1}(t) \\
q_{nk,2}(t)
\end{pmatrix}
= 0.79
\begin{pmatrix}
Q_{n,1}(j,k) \\
Q_{n,2}(j,k)
\end{pmatrix}
\quad \ldots (46)
\]

**APPLICATION OF THE MODEL**

The performances of different houses have been assessed relative to a reference house. For Group I houses (i.e. those built of a single material), the reference house has only a single storey. However, for Group II houses (i.e. those built of more than one material), the reference house is two storeys high. The selection of a two-storey house as the "base" system for Group II allows for a change in materials of construction for each storey. Two cases are of practical interest.

The first is that in which the design of each storey of the nth storey house is an exact duplicate of that of the chosen reference house, i.e. the design as well as the building materials are the same for both houses. For such a case:

\[
\begin{align*}
\dot{Q}_{\text{ref,1}}(j,k) &= \dot{Q}_{1,1}(j,k) \\
\dot{Q}_{\text{ref,2}}(j,k) &= \dot{Q}_{2,1}(j,k)
\end{align*}
\]

From equations (16) and (19) it can be shown that:

\[
\dot{Q}_{n,1}(j,k) - \dot{Q}_{1,1}(j,k) = (n - 1) \dot{Q}_1 g(k)
\]

where

\[
g(k) = \left(1 + 0.05k \left(\frac{U_{\text{win}}}{U_1}\right)\right)
\]

\ldots (49)
and

\[ \dot{Q}_{n,II}(j,k) - \dot{Q}_{2,II}(j,k) = g_n(k) \dot{Q}_1 \]  \hspace{1cm} (50)

where

\[ g_n(k) = \left( n - 2 \right) (g(k) - 1) + \left[ \left( F_n - U_2 \right)/U_1 \right] \]  \hspace{1cm} (51)

For the second case, the design of the n-storey house differs from that of the reference house. For example, the roof area of the n-storey house, assuming the same roof area for each storey, is greater than that of the reference house. To evaluate the contribution which such a change will have upon the rate of heat loss using the present model, it is necessary to relate the wall/roof area of the nth-storey house to that of the reference house. In Yemeni buildings the roof width is usually fixed, but the length does vary according to the size of the available plot of land. The solid wall's vertical area as well as the roof's horizontal area, of the n-storey house can be related to the corresponding values for the reference house as follows:

\[ S_r = (\eta/R) \] and \[ A_{ref} = (A_r/R) \]  \hspace{1cm} (52)

where \( R \) and \( \eta \) are the appropriate ratios of the length of the wall or roof of each storey of the house of n-storeys to those of the reference house, i.e.

\[ R = (1/l_r) \]  \hspace{1cm} (53)

and

\[ \eta = 1 + 0.05k (1-R) \]  \hspace{1cm} (54)

Therefore, the steady-state rates of heat loss from the chosen reference houses for Groups I and II are respectively given by:

\[ \dot{Q}_{ref,I}(j,k) = g_{1,I}(j,k) \dot{Q}_1 \]  \hspace{1cm} (55)
where
\[
g_{1,1}(j,k) = \left( \frac{n}{R} + \frac{(0.05k)(K + 0.5)}{R} \left( \frac{U_{cr,j}}{U_1} \right) + 0.05k \left( \frac{U_{win}}{U_1} \right) \right)
\]

... (56)

and
\[
\dot{Q}_{ref,1}(j,k) = g_{2,1}(j,k) \dot{Q}_1
\]

... (57)

where
\[
g_{2,1}(j,k) = \left( \frac{n}{R} \left( \frac{U_1 + U_2}{U_1} \right) + \frac{(0.05k)(K + 0.5)}{R} \left( \frac{U_{cr,j}}{U_1} \right) + 0.05k \left( \frac{U_{win}}{U_1} \right) \right)
\]

... (58)

From equations (16), (19), (55) and (57), it can be proved that:
\[
\begin{align*}
\dot{Q}_{n,1}(j,k) - \dot{Q}_{ref,1}(j,k) &= g_{n,1}(j,k) \dot{Q}_1 \\
\dot{Q}_{n,2}(j,k) - \dot{Q}_{ref,2}(j,k) &= g_{n,2}(j,k) \dot{Q}_1
\end{align*}
\]

... (59)

where
\[
g_{n,1}(j,k) = \left( (n-1)g(k) - \frac{1-R}{R U_1} \left( U_1(1 + 0.05k) + 0.05k(k + 0.5) U_{cr,j} \right) \right)
\]

and
\[
g_{n,2}(j,k) = \left( (n-2)(g(k)-1) + \frac{F_{n,U_2}}{U_1} - \frac{1-R}{R U_1} \left( (U_1+U_2)(1+0.5k)+0.05k(k+0.5)U_{cr,j} \right) \right)
\]

It can be deduced, using equations (16), (19) and (47) through to (60), and taking into consideration equation (12), that:

For \( R = 1 \):-
\[ U_{n, I}(j, k) - (1/n)U_{1, I}(j, k) = \]
\[
\left( \frac{(n - 1)}{n} g(k) + \left( \begin{array}{c}
\frac{h_{o, n}}{h_{o, 1}} \\
\frac{h_{i} + h_{o, 1} + h_{i}h_{o, 1}}{h_{i} + h_{o, n} + h_{i}h_{o, n}} \sum_{i=1}^{\infty} \frac{d_{i}/\lambda_{i}}{d_{i}/\lambda_{i}}
\end{array} \right) \right) U_{1}
\]

\[ U_{n, II}(j, k) - (2/n)U_{2, II}(j, k) = \]
\[
\left( \frac{1}{n} g_{n}(k) + \left( \begin{array}{c}
\frac{h_{o, n}}{h_{o, 1}} \\
\frac{h_{i} + h_{o, 1} + h_{i}h_{o, 1}}{h_{i} + h_{o, n} + h_{i}h_{o, n}} \sum_{i=1}^{\infty} \frac{d_{i}/\lambda_{i}}{d_{i}/\lambda_{i}}
\end{array} \right) \right) U_{1}
\]

For \( R < 1 \):

\[ U_{n, I}(j, k) - \frac{n}{nR} U_{1, I}(j, k) = \]
\[
\left( \frac{1}{n} g_{n, I}(j, k) + \left( \begin{array}{c}
\frac{h_{o, n}}{h_{o, 1}} \\
\frac{h_{i} + h_{o, 1} + h_{i}h_{o, 1}}{h_{i} + h_{o, n} + h_{i}h_{o, n}} \sum_{i=1}^{\infty} \frac{d_{i}/\lambda_{i}}{d_{i}/\lambda_{i}}
\end{array} \right) \right) U_{1}
\]

\[ U_{n, II}(j, k) - \frac{2n}{nR} U_{2, II}(j, k) = \]
\[
\left( \frac{1}{n} g_{n, II}(j, k) + \left( \begin{array}{c}
\frac{h_{o, n}}{h_{o, 1}} \\
\frac{h_{i} + h_{o, 1} + h_{i}h_{o, 1}}{h_{i} + h_{o, n} + h_{i}h_{o, n}} \sum_{i=1}^{\infty} \frac{d_{i}/\lambda_{i}}{d_{i}/\lambda_{i}}
\end{array} \right) \right) U_{1}
\]

The predictions for (i) a single-storey mud house, (ii) a single-storey house with a concrete internal leaf and stone external cladding, and (iii) a single-storey concrete house, are illustrated in Figure 6a, b and c.

How to Use the Model

The thermal behaviours of buildings throughout a complete year can be predicted by means of computer based simulations. However, the use of such computer programs frequently requires a full year's record of hourly observations of weather conditions for each building's location. Thus, in order to evaluate the thermal response to an annual cycle of conditions...
THEIR TYPE NUMBERS AS DESIGNATED IN FIGURE 2 WITH DIFFERENT ROOF CONSTRUCTIONS. THE LATTER BEING INDICATED BY
PREDICTED STEADY-STATE HEAT LOSSES FOR SINGLE-STORY HOUSES

(a) SINGLE-STORY HOUSE WITH TYPE 1 WALLS AS IN FIG 1.

(b) SINGLE-STORY HOUSE WALLS OF TYPE 7 AS IN FIG 1.

(c) SINGLE-STORY HOUSE WITH TYPE 4 WALLS AS IN FIG 1.

\[ U_{ij,k}(W/m^2K) \]

\[ A_{ij,k}(W/m^2) \]
the program must perform at least 8760 separate calculations. As a result such programs involve excessive computer times and are thus often too expensive to use. They are probably also inappropriate methods for designers in developing countries.

In an ideal design-process for a building, a thermal analysis would be performed in order to evaluate the thermal consequences of each major design option.

The architect may then select the most effective option for that building and intended occupancy pattern. To achieve this, the simplified approach described has been evolved. Using it and knowing the available choices in the house specification (such as the number of storeys, type and materials of the external walls, design and materials for the roof, and the ratio of glazed-to-wall areas), the designer can from the presented equations and graphs evaluate each option. The thermal performance of each house design is characterised by two factors, namely

i) the U-factor for the house and this can be deduced from equations (12), (61) and (62)

and

ii) the steady-state heat leak Q, obtained via equations (16) and (19).

Example: To illustrate the application of the presented mathematical model we will consider a 3-storey mud house with the specifications given in Table 3.

<table>
<thead>
<tr>
<th>Roof type (see Fig. 2)</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside wall plaster wall type (see Fig. 3)</td>
<td>4</td>
</tr>
<tr>
<td>$A_{\text{win}}/S$</td>
<td>0.25</td>
</tr>
<tr>
<td>$S(\text{in m}^2)$</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3 Specifications for the walls and roof of the considered house.

Steps in the calculation:
From Fig. 3, \( U_1 = 0.72 \text{ W m}^{-2}\text{K}^{-1} \)
Assume a fixed internal house temperature, \( T_i \), of 22°C and use the seasonal average ambient temperature, i.e. 16°C in winter and 20°C in summer.

From equation (11):
During the winter, \( Q_1 = U_1 S \Delta T = (0.72)(100)(22 - 16) = 432 \text{ W} \)
and during the summer, \( Q_1 = U_1 S \Delta T = (0.72)(100)(22 - 20) = 144 \text{ W} \)

Evaluate the following parameters for \( A_{\text{win}}/S = 0.25:\)
From equation (18), \( C_3(j,k) = 4.616 \)
From equation (17), \( M_3(j,k) = 7.616 \)

Use equation (16) to evaluate \( \dot{Q}_{n,j}(j,k) \)

Use equations (12) and (61) and Table 1 to evaluate \( U_{n,j}(j,k) \)

Use equations (45) and (46) to determine the steady-state and transient-state rates of heat loss from the house.

The results are presented in Table 4.

**TABLE 4**

**CONCLUSIONS FOR THE 3-STOREY HOUSE SPECIFIED IN TABLE 3**

<table>
<thead>
<tr>
<th>Exterior wall material</th>
<th>U-factor (Wm(^{-2}\text{K}^{-1}))</th>
<th>Heat loss (GJ/day) from the house</th>
</tr>
</thead>
<tbody>
<tr>
<td>First storey</td>
<td>Second storey</td>
<td>Third storey</td>
</tr>
<tr>
<td>Mud</td>
<td>Mud</td>
<td>Mud</td>
</tr>
</tbody>
</table>

It must be emphasised that, despite contrary conventional practice, because of its low structural strength, it is **not** recommended that mud should be employed as the building material for multi-storey structures.
Deductions

For houses built of similar exterior wall materials, the difference between the rate of heat loss from the n-storey house and that from the reference house is given by:

\[ \dot{Q}_{n,i}(j,k) - \dot{Q}_{\text{ref},i}(j,k) = g_{n,i}(j,k) \dot{Q}_1 \quad \ldots (63) \]

According to equation (63), the smallest difference between \( \dot{Q}_{n,i}(j,k) \) and \( \dot{Q}_{\text{ref},i}(j,k) \) occurs when \( g_{n,i}(j,k) < 1 \). Thus, to reduce the rate of heat loss relative to that of the reference house under similar circumstances, it is recommended that the wall/roof length ratio be such that:

\[ R \leq \left( 1 + F_{n,i}(j,k) \right)^{-1} \quad \text{for } n > 1 \quad \ldots (64) \]

where

\[ F_{n,i}(j,k) = \left( \frac{(n-1)g(k)}{1 + 0.05k} \right) \left( 1 + (k + 0.5)(U_{cr,j}/U_1) \right) \quad (65) \]

However, if the n-storey house is an exact duplicate of the chosen reference house, i.e. \( R = 1 \), this difference becomes an integral multiple of the rate of heat loss from the walls of the house of n-storeys, i.e.

\[ \dot{Q}_{n,i}(j,k) - \dot{Q}_{1,i}(j,k) = (n - 1) g(k) \dot{Q}_1 \quad \ldots (66) \]

On the other hand, the difference between \( \dot{Q}_{n,II}(j,k) \) and \( \dot{Q}_{\text{ref},II}(j,k) \) depends upon the number of storeys as well as upon the U-factors for the individual walls and roof, i.e.

\[ \dot{Q}_{n,II}(j,k) - \dot{Q}_{\text{ref},II}(j,k) = g_n(k) Q_1, \quad \text{for } n > 2 \text{ and } R = 1 \ldots (67) \]

\[ \dot{Q}_{n,II}(j,k) - \dot{Q}_{\text{ref},II}(j,k) = g_{n,II}(j,k) \dot{Q}_1, \quad \text{for } n > 2 \text{ and } R < 1 \]

\[ \ldots (68) \]

For each specified value of \( R \), the smallest difference between \( \dot{Q}_{n,II}(j,k) \) and \( \dot{Q}_{\text{ref},II}(j,k) \) occurs when \( g_n(k) \leq 1 \) or \( g_{n,II}(j,k) \leq 1 \).
Thus, to reduce the heat leaks through the material of an \( n \)-storey house, we recommend choosing the \( n \)-th-storey material and the ratio of wall length respectively such that:

\[
\frac{U_{\text{win}}}{(U_1 - (F_n - U_2))} \leq \frac{1}{((n - 2)(0.05k))}, \text{ for } n > 2 \text{ and } R = 1 \quad \ldots (69)
\]

and

\[
R < \left( F_{n,II}(j,k) + 1 \right)^{-1}, \text{ for } n > 2 \text{ and } R < 1 \quad \ldots (70)
\]

where

\[
F_{n,II}(j,k) = \frac{(F_n - U_2 - U_1 + (n-2)(g(k)-1)U_1)}{(1 + 0.05k)(U_1 + 0.05k(k + 0.5)U_{cr,j})} \quad \ldots (71)
\]

The length ratio, \( R \), of a wall of the reference house to that of the \( n \)-storey house, for which the difference between \( Q_{n,I}(j,k), Q_{\text{ref},I}(j,k) \) and \( Q_{n,II}(j,k), Q_{\text{ref},II}(j,k) \) are minimal can be calculated, using equations (64) and (65) for Group I houses and equations (70) and (71) for Group II houses, from the following expressions:

For Group I houses

\[
R \leq \left( 1 + \frac{(n - 1)(U_1 + 0.05k U_{\text{win}})}{(1 + 0.05k)U_1 + 0.05k(k + 0.5)U_{cr,j}} \right)^{-1} \quad \ldots (72)
\]

For Group II houses

\[
R \leq \left( 1 + \frac{(n - 2)(0.05k U_{\text{win}} + (F_n - U_1 - U_2)/(n - 2))}{(1 + 0.05k)(U_1 + U_2) + 0.05k(k + 0.5)U_{cr,j}} \right)^{-1}
\]

Using equations 72 and 73, the dependence of the upper limits for the value of \( R \) on the glazed-to-solid wall area ratio, \( k \), is illustrated for \( n = 4 \) in Figure 7, for the following particular external walls:
RATIO R OF THE AREA OF THE WALL OF THE
n th - STOREY HOUSE TO THAT OF THE REFERENCE HOUSE

FIG. 7.
THE UPPER LIMITS OF WALL AREA RATIO R, AS A FUNCTION
OF THE GLAZED-TO-WALL AREA RATIO K.
(i) stone (i.e. type 1 in Fig. 3) for the first storey and red brick (i.e. type 2 in Fig. 3) for all the higher storeys;

(ii) same as case (i) but the second, third and fourth storeys are built from concrete (i.e. type 3 in Fig. 3);

and (iii) stone (i.e. type 1 in Fig. 3) for all four storeys.

The choice of these particular arrangements is justified by their popularity in the Yemen, where case (i) is most commonly used followed, for economic reasons, by cases (ii) and (iii). In all cases, the upper limits for R plotted in Figure 7 are for buildings with the same roof type 1 construction (see Fig. 2) which has a U-value of 2.26 W m⁻²K⁻¹. It was also assumed that all windows are single glazed and here a U-value of 4.3 W m⁻²K⁻¹ is used.

The difference between the rate of heat loss from a Group I house and that from a Group II house illustrates the effect of the type of external wall constructional material on the steady-state rate of heat loss. From equations (16) and (19) it can be deduced that:

\[
\dot{Q}_{n,II}(j,k) - \dot{Q}_{n,I}(j,k) = \left(\frac{n}{U_1(n - 1)} - 1\right)(n - 1) \dot{Q}_1 \quad \ldots \quad (74)
\]

This equation implies, for \( n > 2 \), that

- if \( F_n/U_1(n - 1) < 1 \), then \( \dot{Q}_{n,II}(j,k) < \dot{Q}_{n,I}(j,k) \);
- if \( F_n/U_1(n - 1) > 1 \), then \( \dot{Q}_{n,II}(j,k) > \dot{Q}_{n,I}(j,k) \);
- or if \( F_n/U_1(n - 1) = 1 \), then \( \dot{Q}_{n,II}(j,k) = \dot{Q}_{n,I}(j,k) \).

The ratio \( F_n/U_1(n - 1) \) is plotted for \( n = 2, 3 \) and 4 in Figure 8. According to this figure, the condition \( \dot{Q}_{n,II}(j,k) < \dot{Q}_{n,I}(j,k) \) is satisfied when a multi-storey house is built of the vernacular arrangement of walls constructed from stone and red brick, or stone and mud. Thus if the same design of multi-storey house is to be built wholly in either stone, red brick or mud rather than in a storey-by-storey sequence of these materials
i.e. stone for the first storey and red brick or mud for all the successive higher storeys, the steady-state rate of heat loss from the house will be greater.

On the other hand, the Yemeni vernacular arrangements of stone for the first storey and concrete or reinforced concrete for all the higher storeys (see Fig. 8), satisfy the condition \( \dot{Q}_{n,II}(j,k) > \dot{Q}_{n,I}(j,k) \). The steady-state rate of heat loss from a multi-storey house built wholly in stone, concrete or reinforced concrete is less compared with that of a multi-storey house with stone for the first storey and concrete or reinforced concrete for all the higher storeys.

The third condition i.e. when \( \dot{Q}_{n,II}(j,k) = \dot{Q}_{n,I}(j,k) \), does not occur for the storey-by-storey sequences of wall types used at present in the Yemen (see Fig. 8).

The application of the model was extended to buildings with selected particular storey-by-storey sequences of wall types which are not presently constructed in the Yemen. Some of these different arrangements result from reversing the order of some of the conventionally-employed sequences. The deductions can be seen as dotted lines in Figure 8. These arrangements satisfy the same condition, i.e. \( \dot{Q}_{n,II}(j,k) < \dot{Q}_{n,I}(j,k) \), as those of stone and red brick or stone and mud.

CONCLUSIONS

A simple mathematical model for predicting the steady-state total rate of heat loss from a building has been developed. On comparing the steady-state predictions obtained by using it with those from a more realistic, but more complicated, transient model, it was found that the steady-state equations can be used to deduce the daily average rate of heat loss from a Yemeni house by employing reduction factor of 0.71 in the summer and 0.79 in winter. By substituting the likely inaccuracies in the input data to the presented mathematical model, it is deduced that the predicted rates of heat leak will not be error by more than 10%. The advantage of the steady-state formulation to designers is that it uses readily-available data and only requires straightforward calculations.
FIG. 8. INDICATIONS OF THE RATES OF HEAT LOSS FROM DWELLINGS IN THE YEMEN ARAB REPUBLIC: EFFECTS OF DIFFERENT VERTICAL LAYERS OF MATERIALS IN THE WALLS.
and relatively short computational times. It is compatible with the level of the generally-available computational technology in the Yemen and thus should find ready application there.

Finally it should be noted that the modern wall types (namely 3 and 5 to 8 walls as shown in Figure 3) give larger steady-state rates of heat loss when compared with the traditional vernacular wall types (namely 1, 2 and 4 in Fig. 3).
REFERENCES


CHAPTER 4

SOLAR-ENERGY HARNESING PERFORMANCES OF DIRECT-GAIN AND TROMBE WALLS UNDER YEMENI WEATHER CONDITIONS
GLOSSARY

Direct-gain house: In the northern hemisphere, essentially a house whose south-facing wall is of single-glazed glass.

House heating load: The amount of energy required for space-heating.

Un-vented Trombe Wall: A south-facing thermal storage wall with its glazed, blackened surface facing towards the ambient environment. In this analysis, the area of the heat storage wall facing south equals that of its glazing.

Utilizability function: That fraction of the incident solar radiation penetrating into the house, which exceeds the house's heating load.
### NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Constant, as defined by equation (7a)</td>
</tr>
<tr>
<td>$A_C$</td>
<td>Area of the south-facing passive heating element $\text{m}^2$</td>
</tr>
<tr>
<td>$A_F$</td>
<td>Floor area of the considered house $\text{m}^2$</td>
</tr>
<tr>
<td>$A_S$</td>
<td>Area of the direct-gain storage floor or the Trombe heat-storage wall $\text{m}^2$</td>
</tr>
<tr>
<td>$A_{\text{win},i}$</td>
<td>Total window area in the $i$th direction, where $i=1, 2$ or $3$ indicates east, west, or north respectively $\text{m}^2$</td>
</tr>
<tr>
<td>b</td>
<td>Constant, as defined by equation (7b)</td>
</tr>
<tr>
<td>B</td>
<td>Thermal efficiency function of the considered house, as defined by equation (63) $\text{W m}^{-2}\text{K}^{-1}$</td>
</tr>
<tr>
<td>c</td>
<td>Constant, as defined by equation (7c)</td>
</tr>
<tr>
<td>$C_a$</td>
<td>Specific heat of air ($= 1200 \text{ J kg}^{-1}\text{K}^{-1}$)</td>
</tr>
<tr>
<td>$C_s$</td>
<td>Specific heat of the direct-gain storage floor or the Trombe heat-storage wall - see Table 1 $\text{J kg}^{-1}\text{K}^{-1}$</td>
</tr>
<tr>
<td>d</td>
<td>Thickness of the storage element - see Table 1 $\text{m}$</td>
</tr>
<tr>
<td>$f(t_d), \tilde{F}$</td>
<td>Hourly and daily average values of the direct-solar gain factor respectively, as defined by equations (18) and (24)</td>
</tr>
<tr>
<td>$g(t_d), \tilde{g}$</td>
<td>Dimensionless parameters, as defined respectively by equations (11) and (25)</td>
</tr>
<tr>
<td>$g_{sd}, g_{sw}$</td>
<td>Dimensionless storage parameters, as defined respectively for direct solar-gain and Trombe wall systems by equations (55) and (56)</td>
</tr>
</tbody>
</table>
NOMENCLATURE (cont)

\( \tilde{H}_T \) Monthly average of the daily amounts of solar radiation falling per unit area on the south-facing vertical wall - see Fig. 1. \( \text{MJ m}^{-2}\text{day}^{-1} \)

\( \tilde{H}_{T,i} \) Monthly average of the daily amounts of solar radiation falling per unit area on the vertical walls facing east \((i=1)\), west \((i=2)\), and north \((i=3)\) \( \text{MJ m}^{-2}\text{day}^{-1} \)

\( \tilde{H}_t \) Monthly average of the daily amounts of solar radiation transmitted to the living space, as defined by equation \((62)\) \( \text{MJ m}^{-2}\text{day}^{-1} \)

\( i \) Integer, which takes the values 1, 2 or 3 so designating respectively the easterly, westerly, or northerly directions

\( I_c \) Critical radiation intensity, as defined by equation \((2)\) \( \text{W m}^{-2} \)

\( I_{t,\theta} \) Hourly rate of radiation falling per unit area on a surface inclined at an angle \(\theta\) to the horizontal: average values calculated over several days \( \text{W m}^{-2} \)

\( I_{t,\theta} \) Hourly average solar radiation falling per unit area on a surface inclined at an angle \(\theta\) to the horizontal \( \text{W m}^{-2} \)

\( k \) Thermal conductivity of the storage floor or wall - see Table 1 \( \text{W m}^{-1}\text{K}^{-1} \)

\( K_T \) Monthly average clearness index for the ambient environmental atmosphere - see reference \((6)\) \( \text{W m}^{-1}\text{K}^{-1} \)

\( m \) Mass per unit area of the storage element \( \text{Kg m}^{-2} \)

\( (m C)_{sd},(m C)_{sw} \) Heat capacities respectively of the direct-gain storage floor and the Trombe heat-storage wall \( \text{J m}^{-2}\text{K}^{-1} \)
NOMENCLATURE (cont)

\( n_d, n_n \)  
Day-time and night-time durations  
see Fig. 2.  
sec

\( N \)  
Number of days per calendar month

\( p \)  
Dimensionless parameter, as defined  
by equation (64)

\( \dot{q}_{cs}(t_d), \dot{q}_{cs}(t_n) \)  
Transient rates of heat being conducted  
from the storage element to the living  
space, as defined respectively during  
the day or night by equations (14)  
and (15)  
W

\( \dot{q}_{int}(t_d), \dot{q}_{int}(t_n) \)  
Day-time and night-time transient  
rates of heat contributions to the  
internal energy sources  
W

\( \dot{q}_{t,i}(t_d) \)  
Rate of solar radiation falling on the  
house's vertical wall facing in the ith  
direction  
W m\(^{-2}\)

\( \dot{q}_{\text{Lost}}(t_d), \dot{q}_{\text{Lost}}(t_n) \)  
Day and night-time transient rates of  
heat being lost from the considered  
passively heated house to the ambient  
environment, as defined respectively  
by equations (12) and (13)  
W

\( \dot{q}_{Lw}(t_d), \dot{q}_{Lw}(t_n) \)  
Day and night-time transient rates of  
heat being lost from the heat store wall  
to the ambient environment, as defined  
respectively by equations (32) and (33)  
W

\( \dot{q}_{\text{solar}}(t_d) \)  
Transient rate of solar energy transmitted  
through the glazed elements of the consid- 
ered direct-gain house, as defined by  
equation (10)  
W

\( \bar{Q}_{\text{aux}} \)  
Monthly average of the daily amounts of  
auxiliary energy required by the consid- 
ered passively-heated house, as defined  
by equation (57)  
MJ day\(^{-1}\)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{Q}<em>{dd}, \bar{Q}</em>{dw}$</td>
<td>Monthly average of the daily amounts of heat transferred to the room air during the day-time as defined respectively for direct-gain and Trombe wall passive-heating systems by equations (37) and (39)</td>
<td>MJ day$^{-1}$</td>
</tr>
<tr>
<td>$\bar{Q}_{int}$</td>
<td>Monthly average of the daily amounts of heat contributed from the internal energy resources, as defined by equation (17)</td>
<td>MJ day$^{-1}$</td>
</tr>
<tr>
<td>$\bar{Q}_{Load}$</td>
<td>Monthly average of the daily loads of the considered passively-heated house</td>
<td>MJ day$^{-1}$</td>
</tr>
<tr>
<td>$\bar{Q}_{Lost}$</td>
<td>Steady-state rate of heat lost from the considered house to the ambient environment, as defined by equation (23)</td>
<td>W</td>
</tr>
<tr>
<td>$\bar{Q}<em>{nd}, \bar{Q}</em>{nw}$</td>
<td>Monthly average of the daily amounts of heat transferred to the room air during night-time, as defined for direct-gain and Trombe wall systems by equations (38) and (40) respectively</td>
<td>MJ day$^{-1}$</td>
</tr>
<tr>
<td>$\bar{Q}_{solar}$</td>
<td>Monthly average of the daily amounts of solar radiation transmitted through the glazed elements of the considered house, as defined by equation (22)</td>
<td>MJ day$^{-1}$</td>
</tr>
<tr>
<td>$\bar{Q}_{R}$</td>
<td>Monthly average of the daily amounts of residual energy, as defined for direct-gain and Trombe wall systems by equations (45) and (46) respectively</td>
<td>MJ day$^{-1}$</td>
</tr>
<tr>
<td>$\bar{Q}<em>{udd}, \bar{Q}</em>{udw}$</td>
<td>Monthly average of the daily amounts of day-time useful solar gains, as defined for direct-gain and Trombe wall systems by equations (47) and (49) respectively</td>
<td>MJ day$^{-1}$</td>
</tr>
</tbody>
</table>
NOMENCLATURE

\( \bar{Q}_{und}, \bar{Q}_{unw} \) Monthly average of the daily amounts of night-time useful solar gains, as defined for direct-gain and Trombe wall systems by equations (48) and (50) respectively \( \text{MJ day}^{-1} \)

\( \bar{R} \) Average, over a 24-hour continuous period of the heat-loss reduction factor \( \text{MJ day}^{-1} \)

\( R_b \) Ratio of the daily direct solar radiation falling on a surface, at inclination \( \theta \), to that on a horizontal surface \( \text{MJ day}^{-1} \)

\( R_n \) Ratio of the total solar radiation falling on a surface, at inclination \( \theta \), to that on a horizontal surface both at noon at the same location \( \text{MJ day}^{-1} \)

\( \bar{R}_t \) Monthly average ratio of the global solar radiation falling on a surface inclined at \( \theta \) to the horizontal to that falling on a horizontal surface at that same location \( \text{MJ day}^{-1} \)

\( t_d, t_n \) Elapsed time for day and night respectively \( \text{sec} \)

\( T_a(t_d), T_a(t_n) \) Mean day-time and night-time outside ambient environment's air temperature respectively, i.e. evaluated over the periods \( t_d \) and \( t_n \) respectively \( \text{K} \)

\( T_c \) Fixed thermostat set temperature \( \text{K} \)

\( T_i(t_d), T_i(t_n) \) Mean day-time and night-time indoor air temperatures evaluated over the periods \( t_d \) and \( t_n \) respectively \( \text{K} \)

\( T_s(t_d), T_s(t_n) \) Mean day-time and night-time storage element temperatures, evaluated respectively over the periods \( t_d \) and \( t_n \) - see equations (8) and (9) \( \text{K} \)
NOMENCLATURE (cont)

\( T_{sd}(t_d), T_{sd}(t_n) \) Mean day-time and night-time storage temperatures evaluated for the direct-gain house over the periods \( t_d \) and \( t_n \) respectively - see equations (27) and (28) K

\( T_{sd}(0), T_{sd}(n_d) \) Storage temperatures for the direct-gain house evaluated respectively at \( t_d \) equal to zero and \( n_d \) K

\( T_{sw}(t_d), T_{sw}(t_n) \) Mean day and night times storage temperatures for a Trombe wall system evaluated respectively over the periods \( t_d \) and \( t_n \) by equations (34) and (35) K

\( T_{sw}(0), T_{sw}(n_d) \) Storage temperatures of a Trombe wall system evaluated respectively at \( t_d=0 \) and \( n_d \) respectively K

\( \bar{T}_a \) Monthly average outside ambient air temperature - see Fig. 2 K

\( \bar{T}_i \) Actual monthly average indoor temperature as defined by equation (58) K

\( \bar{T}_r \) Monthly average reference indoor temperature, as defined by equation (26) K

\( U_{equiv} \) An equivalent heat-transfer coefficient for the considered house, as defined by equation (4) W m\(^{-2}\)K\(^{-1}\)

\( (UA)_{h} \) Overall thermal conductance of the considered house, as defined by equation (3) W K\(^{-1}\)

\( U_i \) Heat-transfer coefficient for the inner surface of the storage element relative to the air in the room - see Table 1 W m\(^{-2}\)K\(^{-1}\)

\( U_L \) Average heat-transfer coefficient from the outer surface of the heat store through the south-facing glazing to the ambient environment - See Table 1. W m\(^{-2}\)K\(^{-1}\)
N O M E N C L A T U R E (cont)

\( U_s \)  Heat-transfer coefficient from the store to the living space, as defined by equation (16) \( \text{W m}^{-2}\text{K}^{-1} \)

\( U_{sd} U_{sw} \)  Heat-transfer coefficients from the storage floor of the direct-gain system and the heat-storage wall of the Trombe wall system respectively to the air in the room \( \text{W m}^{-2}\text{K}^{-1} \)

\( \dot{V} \)  Rate of ventilation (in this analysis taken as 1 m\(^3\) hr\(^{-1}\)) \( \text{m}^3\text{ hr}^{-1} \)

\( X_c \)  Ratio of the critical radiation intensity to the average hourly radiation intensity falling on the inclined collector surface

\( \bar{X}_c \)  Monthly-average critical radiation ratio, as defined by equation (5)

\( Y, Y_1 \)  Dimensionless constants, as defined respectively by equations (66) and (71)

\( \Delta t \)  Duration of a day (i.e., \( \Delta t = 86400 \text{ sec} \)) \( \text{sec} \)

\( \Delta T \)  Temperature difference between the thermostat set temperature and the monthly average outside ambient air temperature \( ^\circ\text{C} \)

\( \phi \)  Utilizability function - see the glossary

\( \bar{\phi} \)  Monthly average daily utilizability function, as defined by equation (1)

\( n_{rec,d}, n_{rec,w} \)  Ambient-energy recuperation factors, as defined for the direct-gain and Trombe wall systems respectively, by equations (53) and (54)
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho_a$</td>
<td>Density of air: it is assumed for present analysis that $\rho_a = 1 \text{ kg m}^{-3}$</td>
<td>kg m$^{-3}$</td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>Density of the storage elements - see Table 1</td>
<td>kg m$^{-3}$</td>
</tr>
<tr>
<td>$(\bar{\tau} \alpha)$</td>
<td>Monthly average glass transmittance-storage element absorptance product - see Table 1</td>
<td></td>
</tr>
<tr>
<td>$\tau_{sd}, \tau_{sw}$</td>
<td>Thermal time constants, as defined for the direct-gain and Trombe-wall systems by equations (29) and (36) respectively</td>
<td>sec</td>
</tr>
</tbody>
</table>
CHAPTER FOUR

SOLAR-ENERGY HARNESSING PERFORMANCES OF DIRECT-GAIN AND TROMBE WALLS UNDER YEMENI WEATHER CONDITIONS

INTRODUCTION

Space heating and cooling requires approximately 40% of the total house energy loads in typical Yemeni residential buildings (1). Thus accurate means for predicting such energy demands are desirable when considering rival designs of space heating and cooling systems. It is generally accepted that a building can be designed to be more energy effective if its thermal insulation is increased; window size optimised, air leakage and lighting levels decreased; shading devices properly installed; heating and cooling systems better designed, installed and maintained and the building structure's storage capacity more fully utilized. However these energy-saving features must be considered with reference to numerous constraints, such as (i) the added costs for materials, construction and maintenance which would be increased, (ii) conformation with the local building practices and life styles of the occupants, and (iii) availability of suitable heating and cooling equipment at an economic cost.

One way to deduce the required optimal heating and cooling systems (i.e. those leading to minimum total energy consumption), is to study the buildings thermal performance by using mathematical simulations which describe the buildings thermal behaviour. To this end, simplified methods (2-11) have been developed. The initial aim of such research was to estimate or maximise energy savings achievable. Now the aim is shifting more towards the improvement of comfort and convenience for the occupants of the house.

The object of this study is to balance the heat losses with heat gains both being described by functions of the climate and building design parameters. The advantage of this method compared with the solar-load ratio method (3) is that the latter is limited in terms of design variables which are considered. For example, the latter does not allow the designer to investigate the effects of varying the solar absorptance, the building's
heat storage capacity as well as high and low thermostat set temperatures. Although the correlations of the "un-utilizability" method {4,5} are useful in that they provide designers with a value for the solar heating fraction resulting from adopting a particular design, they do not provide information concerning the cooling auxiliary requirements and the variations of the house temperature with respect to time. However, these are often of more importance, particularly in hot climates, than the solar contribution to the building's heating requirements. Thus the advantage of the present design method, compared with the "un-utilizability" method, lies in its ability to provide an estimate, in addition to the auxiliary requirements for heating, those for cooling as well as the variation of the temperature within the house with respect to time. In other words, the present method is appropriate for positive as well as negative differences between the thermostat set temperature and the variable ambient environment's air temperature.

There is an analogy between the physical meanings of the dimensionless parameters introduced in this analysis and the corresponding ones of the utilizability method {4-6}. Thus in Section 1 of this paper, the utilizability concept, and its applications to direct-gain and un-vented Trombe wall systems are reviewed. The development of the ambient-energy recuperation factor along with the fundamental physical considerations upon which the formalism was based are presented in Section 2. In the third section we link the physical meanings of the dimensionless parameters used in this analysis to those of the utilizability method. In the final section of the paper, the formalism is applied to direct-gain and un-vented Trombe wall systems and the results compared, as far as auxiliary heating requirements are concerned, with those of Monsen et al {4,5}. In the same section the annual thermal performances of direct-gain and un-vented Trombe walls systems are compared.
SECTION 1: The Utilizability Method (4-11)

This is a valuable technique for calculating the long-term thermal performances of solar systems designed for heating applications. The concept of utilizability was developed originally from the Hottel-Whiller-Bliss equation (12-15), which relates the rate of the useful-energy collection to the design parameters and operating conditions of a flat-plate solar-energy collector experiencing a constant fluid-flow rate. The utilizability, $\phi$, of insolation is defined as the fraction of the average hourly radiation, $I_{t,\theta}$, which is above a specified critical radiation level $I_C$. The critical radiation ratio, $X_C$, is defined as the ratio of the critical radiation intensity $I_C$ (the solar radiation intensity at which the solar input equals the house load) to the average hourly radiation intensity, $\bar{I}_{t,\theta}$, falling on the inclined collector surface. The $\phi$-curves, i.e. the plot of $\phi$ as a function of $X_C$, are independent of the hour but dependent on the month, location and orientation. Liu and Jordan (12,16) generalised Whillier's $\phi$-curve method by introducing the monthly average clearness index, $K_T$, i.e. the ratio of the monthly average of the daily amounts of radiation falling on a horizontal surface to the extra-terrestrial radiation falling on the same surface. They showed that, over a long period such as a year, the distribution of daily total radiation corresponding to a given value of $K_T$ is unique, and independent of location or time of the year. As a result they constructed the generalised $\phi$-curves for daily clearness indices ranging from 0.3 to 0.7: these curves were independent of the month or the location. They also incorporated the effect of inclination on the $\phi$-curves for surfaces facing south and constructed $\phi$-curves for a range of values of $R_b$ (the ratio of daily direct radiation on a tilted surface to that on a horizontal surface at the same location). These curves are good for calculations undertaken with input data corresponding to ambient-conditions at one-hour intervals. This means 3 to 6 such calculations each day of a month must be performed in order to obtain the total useful output energy for that month. This led Klein (6) to develop the concept of the monthly average of the daily utilizability function, $\bar{\phi}$. This function is defined as the sum for a month, over all hours, of the average hourly radiation intensities, which are above a critical radiation level, falling on an inclined surface divided by
the average value over a month of the radiation intensity, $\bar{H}_T$. In equation form, the average over a month of the daily utilizability $\bar{\phi}$, is given by:

$$\bar{\phi} = \sum_{\text{hour}} \frac{(I_{t,b} - I_c)}{N H_T} \quad \ldots \ (1)$$

where $I_c$ is the critical radiation level, i.e. the level of solar radiation at which the solar input equals the house load. It has been defined $^{4,5}$ for passive solar-energy applications purposes by:

$$I_c = (UA)_h \left( \frac{(\bar{T}_r - \bar{T}_a)}{(\bar{\tau}_\alpha) A_C} \right) \quad \ldots \ (2)$$

where $(UA)_h$ is the overall thermal conductance of the outer fabric of the house, $\bar{T}_r$ is the monthly average reference indoor temperature, which equals the thermostat set temperature minus the increase in the internal temperature caused by the internal gains; $\bar{T}_a$ is the monthly average of the daily outdoor ambient air temperature - see Fig. 1; $(\bar{\tau}_\alpha)$ is the monthly average product of the transmittance of the glass and absorptance of the storage element's outer facing surface - see Table 1; and $A_C$ is the effective area of the vertical south-facing passive collector. The overall thermal conductance of the house is defined here as the sum of the heat losses via the fabric, ground and ventilation, i.e.

$$(UA)_h = U_{\text{eqv}} A_F \quad \ldots \ (3)$$

where $A_F$ is the floor area of the considered house and $U_{\text{eqv}}$ is an "equivalent" heat-transfer coefficient defined in terms of the solid outer walls, roof, ground, ventilation and glazing heat-transfer coefficients by

$$U_{\text{eqv}} = (1/A_F) \begin{bmatrix} (UA)_{\text{south-facing collector}} + (UA)_{\text{solid}} + (UA)_{\text{windows}} + (UA)_{\text{roof walls}} \\ + (UA)_{\text{ground}} + \rho_a C_a \dot{V} \end{bmatrix} \quad \ldots \ (4)$$

where $\dot{V}$ is the rate of ventilation in cubic metres per hour and $\rho_a C_a = 0.34 \ W \ hr/m^2{}^\circ C$ for air.
Fig 1: Monthly Average Meteorological Data for the Considered Location

MONTHLY AVERAGE DAILY SOLAR RADIATION (MJ m^{-2} day^{-1})

MONTHLY AVERAGE DAILY AMBIENT AIR TEMPERATURE, \( T_a \) °C

MONTHLY AVERAGE DAILY NUMBER OF SUNSHINE HOURS, \( n_s \) (hr)

Legend:
1) North-facing vertical surfaces
2) East or west-facing vertical surfaces
3) South-facing vertical surfaces (e.g., walls)
4) Horizontal surface (e.g., roof)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall house thermal conductance ((UA)_h)</td>
<td>158 to 1400 W/°C</td>
</tr>
<tr>
<td>House floor area (A_F)</td>
<td>132 to 200 m²</td>
</tr>
<tr>
<td>Area of south-facing glazing (A_C)</td>
<td>5 to 50 m²</td>
</tr>
<tr>
<td>Product of the density and specific heat for storage element (\rho_s C_s)</td>
<td>1.39 to 2.39 MJ/m³°C</td>
</tr>
<tr>
<td>Thickness of the storage wall or floor (d)</td>
<td>0.05 to 0.4 m</td>
</tr>
<tr>
<td>Thermal conductivity of the storage wall or floor (k)</td>
<td>0.465 to 1.745 W/m °C</td>
</tr>
<tr>
<td>Heat transfer coefficients (U_L) and (U_1)</td>
<td>3.7 and 8.3 W/m²°C</td>
</tr>
<tr>
<td>Heat transfer coefficient of the glazed elements (U_g)</td>
<td>4.3 W/m²°C</td>
</tr>
<tr>
<td>Heat capacity of the storage elements (((mC_s)/A_s))</td>
<td>120 to 506 kJ/m²°C</td>
</tr>
<tr>
<td>Thermostat set temperature (T_C)</td>
<td>18 to 27 °C</td>
</tr>
<tr>
<td>Monthly average product of the glass transmittance and the absorptance of the storage elements ((\tau\alpha))</td>
<td>0.6 to 0.85</td>
</tr>
</tbody>
</table>
Correlations have been developed (6) for \( \hat{\phi} \) as a function of \( K_T \) and two dimensionless variables namely a geometric factor, \( \bar{R}_t/R_n \), and the monthly average critical radiation ratio \( \bar{X}_C \). The geometric factor is the ratio of \( \bar{R}_t \), the monthly ratio of the global radiation falling on the inclined surface considered to that falling on a horizontal surface, to \( R_n \), the ratio of the total solar radiation falling on the inclined surface to that falling on the horizontal one both evaluated at solar noon for an average day of a month. The monthly average critical radiation ratio, \( \bar{X}_C \), is the critical radiation intensity, \( I_C \), divided by the total radiation intensity for that day of the month in which the total daily radiation is the same as the monthly average. In equation form, \( \bar{X}_C \) is given by (6):

\[
\bar{X}_C = \left( \frac{I_C}{r_{tn} R_n K_T \bar{H}_o} \right) \quad \ldots (5)
\]

where \( r_{tn} \) is the ratio of the radiation at noon to the daily total radiation. \( \hat{\phi} \)-curves can be represented (6) by

\[
\hat{\phi} = \exp \left( a + b \left( \frac{R_n}{R_t} \right) (\bar{X}_C + c(\bar{X}_C)^2) \right) \quad \ldots (6)
\]

where \( a, b \) and \( c \) are constant expressed in terms of \( K_T \) as follows (17):

\[
a = 2.943 - 9.271 K_T + 4.031(K_T)^2 \quad \ldots (7a)
\]

\[
b = -4.345 + 8.853 K_T - 3.602(K_T)^2 \quad \ldots (7b)
\]

and \( c = -0.170 - 0.306 K_T + 2.936(K_T)^2 \quad \ldots (7c)\]

Theilacker (18) proposed simplifications to Klein's correlations, which improve the overall accuracy. Collares-Pereira and Rabl (8) have developed monthly average daily utilizability correlations for five collector types. However they defined the monthly average value of the daily utilizability as the fraction of the radiation incident on the collector surface while it is operating. In recent years, the utilizability concept has been used for evaluating the thermal performances of a wide range of solar-energy applications, from active solar collector systems, to photo-voltatic system designs, and to passively
heated direct-gain and Trombe walls systems. The interpretation of the critical radiation level depends on the type of solar-energy application. For flat-plate and concentrating collectors, the radiation below the critical radiation level represents the absorbed radiation that is necessary to overcome the collector losses. The radiation above the critical level is then the "utilizable" portion of the absorbed radiation. On the other hand, for a passively-heated direct-gain house, the critical radiation level represents the building losses. The transmitted solar radiation below that level is used to warm the building, while the solar radiation above it is in excess of the load and must be removed by ventilation, cooling or drawing a shade, or stored for later use.

In all these applications the utilizability concept requires that the critical radiation level be constant over the period considered. This represents a limitation on the method when applied to solar-energy system performance calculations. The actual critical radiation level in most solar-energy systems, particularly those with a storage system, varies from hour-to-hour. The yearly utilizability correlations of Rabl {8} and Gordon and Zarmi {10,11} require the critical radiation level to be invariant over the whole year. Daily correlations require the critical radiation level to be constant for every hour in the month, but it may vary from one month to another.

Similarly, the hourly correlations require the critical radiation level to be a constant for each hourly period but it may differ from that for other hourly periods as well as for each month. These requirements limit the application of the utilizability method to those calculations which involve upper and lower bound limits on the system's performance.
SECTION TWO: Mathematical Model

Consider a building having either a direct-gain or un-vented Trombe wall passive heating system as shown in Figures (2a) and (2b) respectively. The house in both cases is assumed to have the same design details with respect to the areas of the differently oriented walls and windows, floors and roof. For the un-vented Trombe wall system, Fig. 2b, the area of the south-facing heat-storage wall is taken to be equal to the area of its glazing. It is also assumed that the house, in both cases, has a back-up system which ensures that the air temperature within the house never falls below that fixed by the thermostat-set temperature, $T_c$. In those situations when the internal air temperature exceeds $T_c$, it is assumed that the excess energy can be dumped by ventilation or stored in the building structure for use later.

Assuming that the total thermal mass of the solid walls and roof of the considered house is negligible relative to that of the storage element (19-20), then the heat balance equation for the system shown in Figure 2 can be written during the day-time as:

$$ (mC)_s \left( \frac{dT_s(t_d)}{dt_d} \right) = q_{\text{Solar}}(t_d) - q_{\text{Lost}}(t_d) - q_{\text{CS}}(t_d) + q_{\text{Int}}(t_d) \quad \ldots (8) $$

During the night-time, equation (8) reduces to:

$$ (mC)_s \left( \frac{dT_s(t_n)}{dt_n} \right) = - q_{\text{CS}}(t_n) - q_{\text{Lost}}(t_n) + q_{\text{Int}}(t_n) \quad \ldots (9) $$

where $(mC)_s$ is the heat capacity of the storage element; $T_s(t_d)$ and $T_s(t_n)$ are respectively the storage temperatures during day and night times. The physical relations for the various rates of equations (8) and (9) are defined as follows.
The rate of solar energy transmitted to the living space, $\dot{q}_{\text{solar}}(t_d)$, is defined by

$$\dot{q}_{\text{solar}}(t_d) = A_C (\bar{\tau}_a) \dot{q}_t(t_d) g(t_d)$$ \hspace{1cm} (10)

where $A_C$ is the area of the south-facing glazing, $(\bar{\tau}_a)$ is the monthly average glass transmittance-storage element absorptance product, and $\dot{q}_t(t_d)$ is the rate of solar-energy falling per unit area on the vertical south-facing glazing. The dimensionless parameter, $g(t_d)$, used in equation (10) expresses the ratio of the solar energy transmitted through the east, west, and north-facing windows in terms of that transmitted through the south-facing glazing, i.e.,

$$g(t_d) = \left(1 + \frac{\sum_{i=1}^{3} A_{\text{win},i} \dot{q}_{t,i}(t_d)}{A_C \dot{q}_t(t_d)} \right)$$ \hspace{1cm} (11)

where $A_{\text{win},i}$ is the total window area in the $i$th direction (for which $i=1, 2$ or 3 for east, west, or north respectively); and $\dot{q}_{t,i}(t_d)$ is the corresponding rate of solar energy falling on the vertical house walls. The dimensionless parameter, as defined by equation (11), is unity for a simple direct-gain house, i.e., glazed on the south-facing wall only.

The rates of heat loss during the day time, $\dot{q}_{\text{Lost}}(t_d)$ and during the night time, $\dot{q}_{\text{Lost}}(t_n)$ respectively account for the fabric, the ground and ventilation heat losses: the fabric heat losses being through the walls, roof and floors, and windows (including the south-facing glazing). In general the day-time and the night-time rates of heat loss are defined by:

$$\dot{q}_{\text{Lost}}(t_d) = (UA)_h \left( T_i(t_d) - T_a(t_d) \right)$$ \hspace{1cm} (12)

$$\dot{q}_{\text{Lost}}(t_n) = (UA)_h \left( T_i(t_n) - T_a(t_n) \right)$$ \hspace{1cm} (13)

where $T_i(t_d)$ and $T_i(t_n)$ are respectively the day-time and night-time indoor air temperatures.
\( T_a(t_d) \) and \( T_a(t_n) \) are respectively the day-time and night-time outdoor ambient environment air temperatures and \( (UA)_h \) is the overall thermal conductance of the considered house defined by equation (3).

The rates of energy conduction during the day-time, \( \dot{q}_{CS}(t_d) \), and during the night-time, \( \dot{q}_{CS}(t_n) \), are defined as the product of the thermal conductance of the storage, \( U_S A_S \), and the difference between the storage and the thermostat-set temperatures (20-22), i.e.

\[
\dot{q}_{CS}(t_d) = (U_S A_S) \left( T_S(t_d) - T_c \right) 
\]

\[
\dot{q}_{CS}(t_n) = (U_S A_S) \left( T_S(t_n) - T_c \right) 
\]

where \( A_S \) is the effective area of the storage element; \( T_S(t_d) \) and \( T_S(t_n) \) are respectively representative of the day-time and night-time storage temperatures.

The heat-transfer coefficient from the store to the room air, \( U_S \), is defined by (17)

\[
U_S = \left( \frac{U_i k}{k + d U_i} \right) 
\]

where \( U_i \) is the heat-transfer coefficient between the inner surface of the storage element and the indoor space. A typical value for \( U_i \) is 8.3 W m\(^{-2}\)C\(^{-1}\) (22). The parameters \( k \) and \( d \) are respectively the thermal conductivity and thickness of the storage element; values for these are listed for the storage floor and walls used in the Yemeni buildings in Table 1.

The last terms on the right hand sides of equations (8) and (9) represent respectively the contributions of the internal energy sources during day-time and night-time. They arose from the operation of lights, stoves, appliances and the presence of occupants and can be expressed (23) on a daily basis, in MJ/day, in terms of storage floor area as

\[
\int_{day} \dot{q}_{int}(t_d) \, dt_d + \int_{day} \dot{q}_{int}(t_n) \, dt_n = (0.13 \times 3.6)A_F \ldots (17)
\]
AVERAGE DIURNAL PERFORMANCE

Equation (8) and consequently equation (9) cannot be solved analytically because $\dot{q}_{\text{solar}}(t_d)$, $\dot{q}_{\text{Lost}}(t_d)$, and $c_{\text{Lost}}(t_d)$ are complicated functions of both the design characteristics of the house and the weather variables. However, an analytical solution is possible if the difference between the rates of the energy input, $\dot{q}_{\text{solar}}(t_d)$, and the energy output, $\dot{q}_{\text{Lost}}(t_d)$, is assumed to be related to the amount of solar energy input via the dimensionless parameter, $f(t_d)$, i.e.

$$f(t_d) \dot{q}_{\text{solar}}(t_d) = \dot{q}_{\text{solar}}(t_d) - \dot{q}_{\text{Lost}}(t_d) \quad \ldots \quad (18)$$

where $f(t_d)$ is a dimensionless parameter which indicates the net amount of direct gain that is actually used in reducing the house energy load. It will be established, in Section 3, that the average daily value of $f(t_d)$, namely $\overline{F}$, is related to the daily average critical radiation ratio, $\overline{X_c}$, defined by equation (5).

The next step in finding an analytical solution for equation (8) assumes that:

i) the solar insolation falling on any south-facing passive collector can be treated as invariant throughout the day; and

ii) the day-time plus the night-time transient rates of heat losses can be expressed in terms of the 24-hour average steady-state rate of heat losses.

The replacement of the time-dependent insolation by a constant daily rate ($\overline{Q_{\text{solar}}/n_d}$), will not influence the amount of heat conducted from the storage during day-time [19-21]. For low values of the thermal time constant,

$$\tau_s = \frac{(mc)_s}{U_s} ,$$

the effect of the above assumption on the amount of heat collected by room air during the night is within the allowed limits of error (i.e. 6% - see reference [19]). Better agreements were found by increasing the values
of $\tau_s$ and at large values, i.e. $\tau_s > 5$ hours, the effect of the first assumption is negligible. Accordingly, by using storage elements with $\tau_s > 5$ hours, the replacement of the time-dependent insolation by a constant daily rate will not affect the predictions of the analysis. The transient rates of heat loss from the structure and the glazed elements of the residential buildings in the Yemen can be expressed in terms of the corresponding steady-state rates of heat loss by employing a heat-loss reduction factor of 0.71 in the summer and 0.79 in the winter {24}. Consequently the transient rate of heat loss,

$$\dot{q}_{\text{Lost}}(t) = \dot{q}_{\text{Lost}}(t_d) + \dot{q}_{\text{Lost}}(t_n),$$

can be expressed in terms of the corresponding steady-state rate of heat loss, $\dot{q}_{\text{Lost}}$, via the equation

$$\dot{q}_{\text{Lost}}(t) = \bar{R} \, \dot{q}_{\text{Lost}} ... (19)$$

where $\bar{R}$ is the 24-hour average of the heat-loss reduction factor, $R(t)$ - see reference {24}. Thus the effect of substituting for the transient rate of heat loss by the corresponding steady-state one can be eliminated by multiplying the steady-state rate of heat loss, $\dot{q}_{\text{Lost}}$ by the 24-hour average of the heat loss reduction factor. With these justifications, equations (8) and (9) can respectively be rewritten as:

$$\left(mC\right)_s \left(\frac{dT_s(t_d)}{dt_d}\right) = \bar{F} \left(\bar{Q}_{\text{solar}}/n_d\right) - \dot{q}_{\text{cs}}(t_d) ... (20)$$

$$\left(mC\right)_s \left(\frac{dT_s(t_n)}{dt_n}\right) = - \dot{q}_{\text{cs}}(t_n) ... (21)$$

where $\bar{Q}_{\text{solar}}$ and $\bar{Q}_{\text{Lost}}$ are respectively the daily average values of the solar input and the overall steady-state rate of house heat loss, i.e. fabric plus ventilation and ground heat losses, $n_d$ is the day-time duration of sunshine in seconds, and $\bar{F}$ is the daily average value of the dimensionless direct solar-gain parameter, $f(t_d)$. In equation forms $Q_{\text{solar}}$, $\dot{Q}_{\text{Lost}}$ and $\bar{F}$ are respectively given by:

$$\bar{Q}_{\text{solar}} = A_c(\pi \alpha) H_T \bar{g} ... (22)$$
\[ \bar{Q}_{\text{Lost}} = (UA)_h \left( \bar{T}_t - \bar{T}_a \right) \] ... (23)

\[ F = \left( 1 - (\Delta t)\bar{R} \frac{\bar{Q}_{\text{Lost}}}{\bar{Q}_{\text{solar}}} \right) \] ... (24)

where \( H_T \) is the daily average amount of solar radiation falling per unit area on the south-facing glazing, and \( g \) is the daily average value of \( g(t_d) \) defined by:

\[ \bar{g} = \left( 1 + \frac{3}{\sum_{i=1}^{3} \frac{A_{\text{win},i}}{A_c} \frac{\bar{H}_{T,i}}{H_T}} \right) \] ... (25)

\( \bar{H}_{T,i} \) is the average per day of the amount of solar radiation falling per unit area on the house walls located in the east, west, and north. We evaluate, see Eq. (23), the steady-state rate of heat loss, \( \bar{Q}_{\text{Lost}} \), with respect to a reference indoor temperature, \( \bar{T}_r \), rather than with respect to the fixed thermostat set temperature. This technique allows for the contribution of the internal gains in reducing the house load. The reference temperature, \( \bar{T}_r \), is related to \( T_c \) by:

\[ \bar{T}_r = \left( T_c - \frac{\bar{Q}_{\text{int}}}{(\Delta t)(UA)_h} \right) \] ... (26)

where \( \bar{Q}_{\text{int}} \) is given by equation (17).

The solutions of equations (20) and (21), taking into consideration equations (22) through to (26), yields for the day-time and night-time storage temperatures the following expressions respectively:

FOR DIRECT-GAIN SYSTEM

During the day-time

\[ (T_{sd}(t_d) - T_c) = \left( F \frac{\bar{Q}_{\text{solar}}}{n_d U_{sd}} \right) (1 - \exp(-t_d/\tau_{sd})) \]

\[ + \left( T_{sd}(0) - T_c \right) \exp(-t_d/\tau_{sd}) \] ... (27)
During the night-time

\[ (T_{sd}(t_d) - T_c) = (T_{sd}(n_d) - T_c) \exp \left( -\frac{t_n}{\tau_{sd}} \right) \quad \ldots (28) \]

where \( T_{sd}(0) \) and \( T_{sd}(n_d) \) are respectively the storage temperatures at the beginning, i.e. at \( t_d = 0 \), and the end of the day, i.e. \( t_d = n_d \), and \( \tau_{sd} \) is the thermal time constant for the direct-gain storage floor as given by:

\[ \tau_{sd} = \frac{(mC)_{sd}}{U_{sd}} \quad \ldots (29) \]

For the un-vented Trombe wall system, see Fig. 2b, the heat absorbed by the heat-storage wall is conducted to the living space or simultaneously lost to the ambient environment. Thus equations (20) and (21) will respectively be modified as:

\[ (mC)_{sw} \left( \frac{dT_{sw}(t_d)}{dt_d} \right) = \tilde{F} \left( \tilde{q}_{\text{solar}}(n_d) - \dot{q}_{cs}(t_d) - \dot{q}_{lw}(t_d) \right) \quad \ldots (30) \]

\[ (mC)_{sw} \left( \frac{dT_{sw}(t_n)}{dt_n} \right) = -\dot{q}_{cs}(t_n) - \dot{q}_{lw}(t_n) \quad \ldots (31) \]

where \( \dot{q}_{lw}(t_d) \) and \( \dot{q}_{lw}(t_n) \) are respectively defined by:

\[ \dot{q}_{lw}(t_d) = \bar{U}_L A_s \left( T_{sw}(t_d) - T_c \right) \quad \ldots (32) \]

\[ \dot{q}_{lw}(t_n) = \bar{U}_L A_s \left( T_{sw}(t_n) - T_c \right) \quad \ldots (33) \]

where \( \bar{U}_L \) is the average heat-transfer coefficient from the outer heat storage wall surface through the glazing to the ambient environment: typically \( \bar{U}_L = 3.8 \text{ W m}^{-2} \text{ C}^{-1} \) \{(22)\}. The solution of equations (30) and (31) will give the following expressions for the day and night time storage temperatures respectively of the un-vented Trombe wall passive heating system:
During the day time

\[
\left( T_{sw}(t_d) - T_c \right) = F \left( Q_{solar}/n_d(U_{sw} + \bar{U}_L) \right) \left( 1 - \exp(- t_d/\tau_{sw}) \right)
- \left( \bar{U}_L/(U_{sw} + \bar{U}_L) \right) \left( T_c - \bar{T}_a \right) \left( 1 - \exp(- t_d/\tau_{sw}) \right)
+ \left( T_{sw}(0) - T_c \right) \exp(- t_d/\tau_{sw}) \quad \cdots (34)
\]

During the night time

\[
\left( T_{sw}(t_n) - T_c \right) = - \left( \bar{U}_L/(U_{sw} + \bar{U}_L) \right) \left( T_c - \bar{T}_a \right) \left( 1 - \exp(- t_n/\tau_{sw}) \right)
+ \left( T_{sw}(n_d) - T_c \right) \exp(- t_n/\tau_{sw}) \quad \cdots (35)
\]

where \( \tau_{sw} \) is the time thermal constant for the south-facing un-vented Trombe wall, and defined as:

\[
\tau_{sw} = \left( (m C)_{sw}/(U_{sw} + \bar{U}_L) \right) \quad \cdots (36)
\]

On a daily basis, the total energy (including the incidental gains) transferred to the room air during the day-time and night-time are respectively:

FOR THE DIRECT-GAIN SYSTEM

During the day time

\[
\bar{Q}_{dd} = (1 - F) Q_{solar} + \int_{0}^{n_d} U_{sd} \left( T_{sd}(t_d) - T_c \right) dt_d \quad \cdots (37)
\]

During the night time

\[
\bar{Q}_{nd} = \int_{0}^{n} U_{sd} \left( T_{sd}(t_n) - T_c \right) dt_n \quad \cdots (38)
\]
FOR THE UN-VENTED TROMBE WALL SYSTEM

During the day time

\[ \tilde{Q}_{dw} = (1 - \bar{F}) \left( \frac{U_{SW}}{U_{SW} + U_L} \right) Q_{solar} + \int_{0}^{n_d} U_{SW} (T_{SW}(t_d) - T_c) \, dt_d \]

... (39)

During the night time

\[ \tilde{Q}_{nw} = \int_{0}^{n_n} U_{SW} (T_{SW}(t_n) - T_c) \, dt_n \]

... (40)

Substituting from equations (27), (28), (34) and (35) into equations (37), (38), (39) and (40) respectively and integrating the latter equations yield for the energy transferred to the room air during the day-time and night-time the following expressions respectively:

For the Direct-Gain System

During the day time

\[ \tilde{Q}_{dw} = Q_{solar} \left( 1 - \bar{F} \left( \frac{\tau_{sd}}{n_d} \right) \left( 1 - \exp\left( - \frac{n_d}{\tau_{sd}} \right) \right) \right) \]

\[ + \tau_{sd} U_{sd} \left( T_{sd}(0) - T_c \right) \left( 1 - \exp\left( - \frac{n_d}{\tau_{sd}} \right) \right) \]

... (41)

During the night time

\[ \tilde{Q}_{nd} = \left( 1 - \exp\left( - \frac{n_n}{\tau_{sd}} \right) \right) \left( Q_{solar} \bar{F} \left( \frac{\tau_{sd}}{n_d} \right) \left( 1 - \exp\left( - \frac{n_d}{\tau_{sd}} \right) \right) \right) \]

\[ + \left( 1 - \exp\left( - \frac{n_n}{\tau_{sd}} \right) \right) \tau_{sd} U_{sd} \left( T_{sd}(0) - T_c \right) \exp\left( - \frac{n_d}{\tau_{sd}} \right) \]

... (42)
FOR THE UN-VENTED TROMBE WALL SYSTEM

During the day time

\[
\tilde{Q}_{dw} = \left( \frac{U_{sw}}{U_{sw} + U_L} \right) \tilde{Q}_{solar} \left( 1 - \tilde{F}(\tau_{sw}/n_d) \left( 1 - \exp\left(-\frac{n_d}{\tau_{sw}}\right) \right) \right) \\
+ \tau_{sw} U_{sw} (T_{sw}(0) - T_c) \left( 1 - \exp\left(-\frac{n_d}{\tau_{sw}}\right) \right) \quad \ldots \quad (43)
\]

During the night time

\[
\tilde{Q}_{nw} = \left( 1 - \exp\left(-\frac{n_n}{\tau_{sw}}\right) \right) \left( \frac{U_{sw}}{U_{sw} + U_L} \right) \tilde{Q}_{solar} \left( \tilde{F}(\tau_{sw}/n_d) \left( 1 - \exp\left(-\frac{n_d}{\tau_{sw}}\right) \right) \right) \\
+ \left( 1 - \exp\left(-\frac{n_n}{\tau_{sw}}\right) \right) \tau_{sw} U_{sw} (T_{sw}(0) - T_c) \exp\left(-\frac{n_d}{\tau_{sw}}\right) \exp\left(-\frac{n_n}{\tau_{sw}}\right) \\
\ldots \quad (44)
\]

Equations (41) through to (44) have terms which represent the fraction of \( \tilde{Q}_{solar} \) which is used profitably on the same day, and the fraction of \( \tilde{Q}_{solar} \) which remains in storage. Because day-to-day carry over is not considered in this analysis, then the residual energy, i.e. that fraction of \( \tilde{Q}_{solar} \) which remains in the store and not put into use on that same day can be determined by evaluating the energy transferred into the room air during day-time and night-time i.e. equations (41) through to (44), at \( T_s(0) = T_c \) and subtracting the sum from the total solar input. The result of this process gives for the residual energy, \( \tilde{Q}_R \), the following expressions:

FOR THE DIRECT-GAIN SYSTEM

\[
\tilde{Q}_R = \tilde{Q}_{solar} - (\tilde{Q}_{dd} + \tilde{Q}_{nd}) \quad T_{sd}(0) = T_c = \tilde{Q}_{solar} \tilde{F}(\tau_{sd}/n_d) (\exp\left(-\frac{n_n}{\tau_{sd}}\right) \exp\left(-\frac{n_n}{\tau_{sd}}\right)) \left( 1 - \exp\left(-\frac{n_d}{\tau_{sd}}\right) \right) \quad \ldots \quad (45)
\]
FOR THE UN-VENTED TROMBE WALL SYSTEM

\[ \bar{Q}_R = \left( \frac{U_{sw}}{U_{sw} + U_L} \right) \bar{Q}_{solar} - (\bar{Q}_{dw} + \bar{Q}_{nw}) T_{sw}(0) = T_c \]

\[ = \left( \frac{U_{sw}}{U_{sw} + U_L} \right) \bar{Q}_{solar} \tilde{F}(\tau_{sd}/n_d) \exp(-n_d/\tau_{sd}) \left( 1 - \exp(-n_d/\tau_{sd}) \right) \]

... (46)

Consequently, the average useful day-time and night-time energy-gains are respectively for direct-gain and Trombe heat-storage wall systems:

FOR THE DIRECT-GAIN SYSTEM

During the day time

\[ \bar{Q}_{udd} = \bar{Q}_{solar} \left[ 1 - \tilde{F}(\tau_{sd}/n_d) \left( 1 - \exp(-n_d/\tau_{sd}) \right) \left( 1 - \exp(-n_n/\tau_{sd}) \right) \right] \left( 1 - \exp\left(-\left(n_d + n_n\right)/\tau_{sd}\right) \right) \]

... (47)

During the night time

\[ \bar{Q}_{und} = \bar{Q}_{solar} - \bar{Q}_{udd} \]

... (48)

FOR THE UN-VENTED TROMBE WALL SYSTEM

During the day time

\[ \bar{Q}_{udw} = \bar{Q}_{solar} \left( \frac{U_{sw}}{U_{sw} + U_L} \right) \left[ 1 - \tilde{F}(\tau_{sd}/n_d) \left( 1 - \exp(-n_d/\tau_{sd}) \right) \left( 1 - \exp(-n_n/\tau_{sd}) \right) \right] \]

\[ \left( 1 - \exp\left(-\left(n_d + n_n\right)/\tau_{sd}\right) \right) \]

... (49)

During the night time

\[ \bar{Q}_{unw} = \left( \frac{U_{sw}}{U_{sw} + U_L} \right) \bar{Q}_{solar} - \bar{Q}_{udw} \]

... (50)
Defining respectively the dimensionless parameters of equations (47) and (49) as the direct-gain ambient-energy recuperation factor, $n_{rec,d}$, and the Trombe-wall ambient-energy recuperation factor, $n_{rec,w}$, then equations (47) and (49) respectively can be rewritten as:

$$Q_{udd} = n_{rec,d} \tilde{Q}_{solar} \quad \ldots (51)$$

and

$$Q_{udw} = \left( \frac{U_{sw}}{U_{sw} + U_L} \right) n_{rec,w} \tilde{Q}_{solar} \quad \ldots (52)$$

where $n_{rec,d}$ and $n_{rec,w}$ are respectively the direct-gain ambient-energy and the Trombe wall ambient-energy recuperation factors defined by:

$$n_{rec,d} = \left( 1 - \bar{F} g_{sd} \right) \quad \ldots (53)$$

and

$$n_{rec,w} = \left( 1 - \bar{F} g_{sw} \right) \quad \ldots (54)$$

where $\bar{F}$ is the daily average of the dimensionless direct solar-gain factor, $f(t_d)$, defined by equation (25), and $g_{sd}$; $g_{sw}$ are dimensionless storage parameters defined respectively for the direct-gain and the un-vented Trombe wall systems by:

$$g_{sd} = \frac{\left( \tau_{sd}/n_d \right) \left( 1 - \exp(-n_d/\tau_{sd}) \right) \left( 1 - \exp(-n_n/\tau_{sd}) \right)}{\left( 1 - \exp(-(n_d + n_n)/\tau_{sd}) \right)} \quad \ldots (55)$$

and

$$g_{sw} = \frac{\left( \tau_{sw}/n_d \right) \left( 1 - \exp(-n_d/\tau_{sw}) \right) \left( 1 - \exp(-n_n/\tau_{sw}) \right)}{\left( 1 - \exp(-(n_d + n_n)/\tau_{sw}) \right)} \quad \ldots (56)$$

According to equations (51) and (52), the physical significance of the ambient energy factors, $n_{rec,d}$ and $n_{rec,w}$ is to determine the useful amounts of solar and internal gains that are used in reducing the energy load for the house.
AUXILIARY ENERGY REQUIREMENTS

The auxiliary energy required by a finite thermal storage capacity house is defined \cite{23} in general by:

\[ Q_{\text{aux}} = Q_{\text{Load}} - Q_u \quad \ldots (57) \]

where \( Q_{\text{Load}} \) and \( Q_u \) are respectively the average daily house energy load and the actual amount of the daily average useful solar and internal energy gains. Thus the auxiliary energy required by a finite thermal store direct-gain or un-vented Trombe wall house can be determined by replacing \( Q_u \) in equation (57) by \( Q_{\text{u,dg}} \) for the direct gain system and by \( Q_{\text{u,dw}} \) for the un-vented Trombe wall system. Once this amount is known the temperature variations of the indoor temperature with respect to time on a daily basis, are defined \cite{23} as the sum of the daily average ambient air temperature, \( T_a \), and the daily average temperature increase resulting from solar and internal gains, and the temperature increase or decrease caused by the auxiliary energy used for heating or cooling the house, i.e.

\[ \bar{T}_i = \left[ \bar{T}_a + \left( \frac{Q_{\text{int}} + Q_{\text{solar}}}{\Delta t (UA)_h} \right) + \left( \frac{Q_{\text{aux}}}{Q_{\text{Load}}} \right) (T_c - \bar{T}_a) \right] \quad \ldots (58) \]
SECTION 3: PHYSICAL MEANINGS OF THE DIMENSIONLESS PARAMETERS USED IN THIS
STUDY AND THEIR RELATIONS TO COMMENSURATE ONES OF THE
UTILIZABILITY METHOD

The dimensionless parameters used in this analysis have physical significance. For instance, the direct solar-gain factor, \( \bar{F} \), measures the critical radiation level at which the solar input equals the house load. On the other hand, the ambient-energy recuperation factor, \( \eta_{rec,d} \), is an indication of the net amount of solar-energy input that is used in reducing the house's energy load. The equations for \( \bar{F}, \eta_{rec,d} \), and \( \eta_{rec,w} \), can respectively be rewritten in slightly modified forms for the purposes of establishing the analogy between \( \bar{F} \) and \( \bar{X}_c \) and consequently between \( \bar{\phi} \) and \( \eta_{rec,d} \), or \( \eta_{rec,w} \), viz

\[
\bar{F} = (1 - B p (\Delta T / \bar{H}_r)) 
\]

\[
\eta_{rec,d} = \left( 1 - g_{sd} \right) + g_{sd} B p (\Delta T / \bar{H}_r) 
\]

\[
\eta_{rec,w} = \left( 1 - g_{sw} \right) + g_{sw} B p (\Delta T / \bar{H}_r) 
\]

where \( \Delta T \) is the temperature difference between the thermostat set temperature, \( T_c \), and the ambient outside air temperature, and \( \bar{H}_r \) is the sum of the daily average solar radiation transmitted to the living space through the house windows and the south-facing glazing. It is defined in terms of the daily average solar radiation, \( \bar{H}_T \), falling on the south-facing collector as

\[
\bar{H}_r = \bar{g} (\bar{T}_a) \bar{H}_T 
\]

The parameter \( B \), used in eqs. (59) through to (61) indicates the thermal design efficiency of the considered house, i.e.,

\[
B = \left( \frac{(UA)_h / A_c}{} \right) 
\]

The dimensionless parameter \( p \) used in equations (59) to (61) is defined by

\[
p = \left( 1 + (\bar{T}_r - T_c) / (T_c - \bar{T}_a) \right) \bar{R} 
\]
where \( \bar{R} \) is the 24-hour average of the heat-loss reduction factor \( \{24\} \). According to equations (59), (60) and (61) the plots of \( \bar{F} \), \( n_{\text{rec},d} \), and \( n_{\text{rec},w} \) as functions of \( \Delta T/H_{\text{T}} \) will yield straight lines, see section 4, whose intersections with the \( \bar{F} \), \( n_{\text{rec},d} \) and \( n_{\text{rec},w} \) axes are respectively unity, \( (1-g_{\text{sd}}) \), and \( (1-g_{\text{sw}}) \). The slopes of these plots give the values of the parameter \( B \), see equations (59) to (61). Thus designers can, by using the presented correlations, determine the thermal design efficiencies of those buildings incorporating direct-gain or un-vented Trombe wall passive-heating systems as well as the values of the storage parameter, which in turn determines the thickness and the heat capacity of the required storage unit.

Unlike the utilizability method, see reference \( \{6\} \), the present design method is applicable for positive as well as negative temperature differences between the thermostat set temperature and the outside ambient air temperature. For the temperature domain, \( T_{\text{c}} > \bar{T}_{\text{a}} \), the \( \bar{F} \) factor is related to the monthly average critical radiation ratio, \( X_{\text{c}} \) – see equation (5), via the relation

\[
\bar{F} = (1 - Y \bar{X}_{\text{c}})
\]

where \( Y \) is a dimensionless constant defined by

\[
Y = (R_{\text{n}}/R_{\text{t}}) r_{\text{tn}} (\bar{R}/\bar{g})
\]

A similar analogy between \( \phi \) and \( n_{\text{rec}} \) can be obtained. For the temperature domain \( T_{\text{c}} > \bar{T}_{\text{a}} \), throughout which the utilizability method is valid, \( n_{\text{rec},d} \) and \( n_{\text{rec},w} \) (see equations (53) and (54)) can be approximated respectively by:

\[
n_{\text{rec},d} = \exp(-g_{\text{sd}}) \exp(g_{\text{sd}} Y \bar{X}_{\text{c}})
\]

and

\[
n_{\text{rec},w} = \exp(-g_{\text{sw}}) \exp(g_{\text{sw}} Y \bar{X}_{\text{c}})
\]
where \( g_{sd}, g_{sw} \) and \( Y \) are given respectively by equations (55), (56) and (66). When equations (67) and (68) are compared respectively with equation (5) it can be seen that:

\[
\eta_{rec,d} = \left( \exp(-g_{sd}) \exp((g_{sd} Y - Y_1) \bar{X}_C) \right) \bar{\phi} \quad \ldots \quad (69)
\]

and

\[
\eta_{rec,w} = \left( \exp(-g_{sw}) \exp((g_{sw} Y - Y_1) \bar{X}_C) \right) \bar{\phi} \quad \ldots \quad (70)
\]

where \( Y_1 \) is a constant defined by:

\[
Y_1 = \left( a + b \left( \frac{R_n}{R_t} \right) \right) \left( 1 + c \bar{X}_C \right) \quad \ldots \quad (71)
\]

For \( T_c < \bar{T}_a \), the ambient-energy recuperation factor determines the amount of heat that is in excess of the house load. For such a situation, the house load (see equation (23)) is negative and therefore the daily average value of the direct solar-gain factor, \( F \), is greater than unity - see equation (24). On the other hand, the ambient-energy recuperation factor, for the temperature domain \( T_c < \bar{T}_a \), is negative only if the product of the direct solar-gain factor, \( F \), and the storage parameter, \( g_{sd} \) or \( g_{sw} \), exceeds unity. It is clear from equation (53) for a direct gain system, and from equation (54), for the un-vented Trombe wall system, that the auxiliary heating curves, i.e. the plots of \( \eta_{rec,d} \) or \( \eta_{rec,w} \) versus \((T_c - \bar{T}_a)/\bar{H} \tau\) for \( T_c > \bar{T}_a \), converge to the points

\[
\bar{F} = \frac{1}{g_{sd}} \quad \text{(for the direct gain system)}
\]

and

\[
\bar{F} = \frac{1}{g_{sw}} \quad \text{(for the un-vented Trombe wall system)}.
\]

However, the auxiliary cooling curves, i.e. the plots of \( \eta_{rec} \) versus \((T_c - \bar{T}_a)/\bar{H} \tau\) for \( T_c < \bar{T}_a \), converge to the points

\[
\bar{F} = \frac{2}{g_{sd}} \quad \text{(for the direct-gain system)}
\]

and

\[
\bar{F} = \frac{2}{g_{sw}} \quad \text{(for the un-vented Trombe wall system)}.
\]
As far as the applications, see section 4 of this analysis, are concerned, we used two approximations: the first sets the value of the ambient-energy recuperation factor equal to unity whenever the value of the direct solar-gain factor is negative. In such a situation, \( F \) was put equal to zero. In the second approximation, we set the value of \( \eta_{\text{REC}} \) equal to minus unity whenever the product of \( F \) and the storage parameter becomes greater than unity. In such a case, the value of \( F \) is between unity and four. The first approximation resembles that of the utilizability method, where the values of \( \phi \) were set to unity whenever the values of \( X_c \) become zero or negative. The limitation of the \( F \) values in the second approximation, to between unity and four, resembles the technique used in the solar-load ratio method, where the ratio of the solar input to the house load was set equal to four whenever it exceeds this value \( \{3\} \). The justification for both approximations is to be able to compare the predictions of the presented method with those of existing computer simulation studies. It should be emphasised that the above approximations do not restrict the applicability of the present design method.
 SECTION FOUR: APPLICATIONS AND RESULTS

To illustrate the use of the presented design method, we first present a case study for a direct-gain house whose external walls are built either of stone or concrete. These two materials are those most commonly used for external walls in Yemeni dwellings. The monthly-average daily values of the weather data for the considered location, i.e. Sana'a (15°N) are plotted in fig. 1. Using the system parameters listed in Table 1 and the weather data of fig. 1 the values of the direct solar-gain factor and the direct-gain ambient energy recuperation factors are calculated via equations (24) and (53) respectively. The results are correlated with \( \Delta T/H_{\bar{T}} \) as shown in figures (3) and (4). Fig. 3 shows the graphical dependence of both the direct solar-gain factor, plotted in the upper part of fig. 3, and the direct-gain ambient-energy recuperation factor, plotted in the lower part of fig. 3, for a single-storey stone house employing a south-facing direct-gain passive heating system. This direct-gain house, assuming a typical house floor area of 220 m², is characterised by a B-factor, see equation (63), ranging from 28.6 to 180.4 W per °C per m² of the area of the south-facing passive collector. In other words, the house's overall average thermal conductance, as calculated by equation (3), ranges assuming a south-facing collector area of 5 to 50 m², from 0.9 to 1.34 kW °C⁻¹. This rate of heat loss per degree represents the sum of the fabric, ventilation and ground heat losses and therefore it is higher than that calculated by the method of reference (24) where the ground and ventilation heat losses were assumed to be balanced by the internal energy gains. It is clear from fig. 3 that as the collector-to-storage floor areas ratios increased the values of the direct solar-gain factor, \( \bar{F} \), decreased in the temperature range \( T_c < \bar{T}_a \) while they increased in the temperature range \( T_c > \bar{T}_a \). The effect of increasing the collector-to-storage floor areas ratio on the values of the direct-gain ambient energy recuperation factor is exactly the opposite - see the lower part of fig. 3. In practice, this behaviour means that the cooling auxiliary energy requirements are directly proportional, provided a fixed thermostat set temperature, to the collector-to-storage floor areas ratio. For example, the annual cooling auxiliary requirements at a thermostat set temperature of 18°C and a collector-to-storage floor areas ratio of 0.02 is only 0.6 of the auxiliary cooling requirements evaluated at the same thermostat set temperature, but at a
FIG. 3. CORRELATIONS OF THE DIRECT-GAIN AMBIENT ENERGY RECUPERATION FACTOR, $T_{rc}$, AND
OF THE DIRECT-SOLAR GAIN FACTOR, $F$, FOR A SINGLE STOREY STONE HOUSE WITH THE
THERMOSTAT-OUTDOOR TEMPERATURE DIFFERENCE DIVIDED BY THE TOTAL AMOUNT OF SOLAR
RADIATION TRANSMITTED TO THE CONSIDERED HOUSE.
FIG. 4 CORRELATIONS OF THE DIRECT-GAIN AMBIENT-ENERGY RECUPERATION FACTOR, $\eta_{\text{rec,g}}$, AND OF THE DIRECT-SOLAR GAIN FACTOR, $F$, FOR A SINGLE-STOREY CONCRETE HOUSE WITH THE THERMOSTAT-OUTDOOR TEMPERATURE DIFFERENCE DIVIDED BY THE TOTAL AMOUNT OF SOLAR RADIATION TRANSMITTED TO THE CONSIDERED HOUSE.
collector-to-storage floor areas ratio of 0.2. On the other hand, the increase of the thermal time constant, either by increasing the heat capacity of the storage element or decreasing the heat-transfer coefficient from storage to room air - see equation (16), leads to a decrease, except at the point \( n_{\text{rec},d} = 1 \), in the values of the direct-gain ambient-energy recuperation factor for both \( T_c > T_a \) and \( T_c < T_a \) - see the lower part of fig. 3. This behaviour is a direct consequence of the fact that the increase of the thermal time constant corresponds to delaying the release of heat from the storage element to the living space and increasing the values of the storage parameter see equation (55), thereby decreasing the value of the direct-gain ambient-energy recuperation factor. These values with \( n_{\text{rec},d} = 1 \) were not influenced by the increase of the thermal time constant. This is so because we set the value of \( n_{\text{rec},d} \) equal to unity whenever the product of the direct solar-gain factor, \( F \), and the storage parameter \( g_{sd} \), exceeds unity. This approximation is similar to that of the "Un-utilizability" design method {4} where the values of the monthly average daily utilizability function, \( \bar{\phi} \), were set equal to unity whenever the values of \( \bar{X}_c \) become smaller or equal to zero. Thus it is possible by changing the thermal time constant to construct a family of \( n_{\text{rec},d} \) curves which share the point \( n_{\text{rec},d} = 1 \) and intersect with the \( n_{\text{rec},d} \) axis, depending on the values of the thermal time constant, at different points. These intersection points, see equation (60) give the values of the storage parameter. Once this parameter is known, designers can, for a given geographical location, choose the appropriate thermal properties of the storage unit. The storage parameter can also be obtained by dividing, for a given collector-to-storage floor areas ratio, the slopes of the \( n_{\text{rec},d} \) factor by the corresponding one for the \( F \)-factor. In fig. 3 the effect of increasing the collector-to-storage floor areas ratio on the behaviour of the direct-gain ambient-energy recuperation factor can be obtained, for a given thermal time constant, by joining points (a) through to (j) with points (i), (ii), (iii) or (iv). On the other hand, the effect of increasing the thermal time constant on the behaviour of the direct-gain ambient-energy recuperation factor can be obtained, at a given collector-to-storage floor areas ratio, by joining point (a) ......., or (j) with points (i) through to (vi). The same results
apply to the curves of figure 4 where the non-south-facing walls of the direct-gain house are built of concrete rather than of stone. This change in the building material of the external walls of the direct-gain house increases, assuming the same collector-to-storage floor areas ratio occurs for the stone house, the values of the B-factor from 28.6 to 33.6 and from 180.4 to 185.4 W per °C per m² of the south-facing collector area. As a result, the values of the F-factor were below those of fig. 3 in the temperature domain $T_C > \bar{T}_a$ and above them at $T_C < \bar{T}_a$. The effect of such a change on the direct-gain ambient-energy recuperation factor is illustrated in fig. 5. It is evident, from fig. 5 that the use of relatively dense building materials, e.g. stone for the external walls of the direct-gain house reduces the values of $\eta_{rec,d}$ in the temperature range $T_C > \bar{T}_a$ while it increases them in the temperature domain $T_C < \bar{T}_a$. Practically this means that the auxiliary heating energy of a direct-gain house whose external walls are constructed of stone is smaller than that of a similar direct-gain house but with external walls built of concrete. The opposite case is true for the auxiliary cooling requirements. For example, at a thermostat set temperature of 21°C and a collector-to-storage floor areas ratio of 0.16, it was found that the annual auxiliary heating requirements of a direct-gain stone house are 0.6 those of a similar direct-gain concrete house. On the contrary, the annual auxiliary cooling requirements, evaluated for the same system parameters, of a single-storey direct-gain stone house were 1.044 times greater than those for a similar single-storey direct-gain concrete house. Thus the use of a relatively dense building material for the external walls of the direct-gain house will improve the houses's thermal efficiency and thereby reduce the amount of auxiliary heating requirements. The disadvantage however lies in the fact that the use of dense building materials, e.g. stone, for external walls of the direct-gain house increases the auxiliary cooling requirements as well as the monthly-average daily variations of the actual indoor temperature. The latter effect, as illustrated in figure 6, is evaluated at a thermostat set temperature of 21°C, a collector-to-storage floor ratio of 0.16 and a thermal time constant of 5 hours. It is clear that the use of stone for the external walls of the direct-gain house increases the monthly average daily variations of the actual indoor temperature relative to the fixed thermostat set...
Fig. 5

Effect of House Mass on the Direct-Gain Ambient Energy Recuperation Factor, T, a

(Direct-Gain Ambient Energy Recuperation Factor, T, a)
MONTHLY AVERAGE ACTUAL INDOOR TEMPERATURE, $T^\circ C$
temperature by 0.5 degrees during the winter-time while the increase was 2.5 degrees in the summer-time. For a direct-gain concrete house, the increases in the monthly-average daily variations of the actual indoor temperature were approximately similar to those of a direct-gain stone house during the winter-time and lower by one degree than that of stone during the summer times - see fig. 6.

This behaviour suggests the sizing of the direct-gain system, i.e. finding the values of $T_c$ and $A_c$ at which the auxiliary cooling requirements are minimal and the internal environment is comfortable during the winter and summer. That was accomplished by plotting the fraction of the year during which cooling is required, i.e. the total number of days during which the auxiliary energy requirements were negative divided by the total number of days in a year, as a function of the thermostat set temperature and the collector-to-storage floor area ratio. The results are presented graphically in fig. 7. At thermostat set temperatures smaller than 20°C, this fraction was greater than 0.6 for all collector-to-storage floor areas ratios considered in this analysis. This means that the cooling period exceeds 212 days per year and the incorporation of the direct-gain system will prove to be disadvantageous. Increasing the thermostat set temperatures from 20°C to 23°C reduces the duration of the cooling period to a minimum of 73 days per year for all collector-to-storage floor areas ratios. However at a thermostat set temperature of 24°C and a collector-to-storage floor areas ratio of 0.18, the cooling period was almost one month. By increasing the collector-to-storage floor areas ratio to 0.2, the cooling period at a thermostat set temperature of 24°C, increases again to a minimum total of 58 days per year. At thermostat set temperatures greater than 24°C, the cooling period, for the range of the collector-to-storage floor areas ratios considered here, was zero and consequently the direct-gain house needs to be heated for the whole year. It was found, from this analysis, that the annual auxiliary heating requirements at a thermostat set temperature of 25°C and with a south-facing collector area of 50 m² are 1.4 times greater than those at a thermostat set temperature of 24°C with a collector area of 40 m². For this reason, we choose the critical design parameters of the direct-gain house, i.e. the values of $T_c$ and $A_c$ at which the auxiliary cooling are minimal, to be 24°C, and 5 to 40 m².
FIG 7

CORRELATION OF THE ANNUAL COOLING PERIOD WITH THE THERMOSTAT SET TEMPERATURE AND THE COLLECTOR-TO-STORAGE FLOOR AREAS RATIOS.

FRACTION OF THE YEAR DURING WHICH COOLING IS REQUIRED

THERMOSTAT SET TEMPERATURE, T, (°C)

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

20 21 22 23 24

0.002 0.01 0.02 0.08
respectively. At $T_c = 24^\circ C$ and $A_c = 40 \text{ m}^2$, 98% of the annual auxiliary requirements are for heating while only 2% are needed for cooling during the month of June.

Once the critical design parameters are established, we evaluate the thermal performance of the direct-gain house by calculating the solar fraction, i.e. the ratio of the useful solar input to the house load. The results evaluated at the critical design parameters i.e. $T_c = 24^\circ C$, $A_c = 40 \text{ m}^2$ and $\tau_{sd} = 25 \text{ hours}$, are presented in fig. 8. Due to the lack of experimental data against which the predictions of this model can be validated, we choose to compare the predictions, as calculated by the present design method with those of the 'un-utilizability' method which in turn were compared with those of a high-level transient simulation model (4). The results of the comparisons, in the temperature range $T_c > T_a$ are shown in fig. 8. It is clear that the present design method overpredicts the values of the solar heating fraction and consequently underpredicts the amount of auxiliary heating requirements. This is so because of the fact that the definition of the solar-load ratio, as used in this analysis, is different from that of the un-utilizability method. In this analysis, the solar load ratio, SLR, was defined as:

$$\text{SLR} = \left(\tau_{a}\right) A_c \bar{g} H_T/\bar{Q}_{\text{Load}}$$

where $\bar{g}$ is a dimensionless parameter which measures the amount of solar radiation transmitted through the windows of the direct-gain house relative to that transmitted through the south-facing glazing. The above equation reduces to that of Monsen et. al. (4) by setting $\bar{g}$ equal to unity. The second source of error arose from the definition of the heat capacity of the store. In the "un-utilizability" method the heat capacity of the store was defined as the product of the "effective" heat capacity of the house, which was taken as 123 kJ per degree per square metre of house floor area, and the temperature difference between the low and high thermostat set temperatures. However in this analysis the heat capacity of the store was taken as 506 kJ per degree per square metre of the storage floor area. This corresponds to a thermal time constant of 25 hours and a heat-transfer coefficient from the store to the room air of 5.6 W m$^{-2}$$^\circ C^{-1}$. 

MONTHLY AVERAGE HEATING AUXILIARY REQUIREMENT AS CALCULATED BY
MONSEN ET AL METHOD (G) MONTH - 149 -

MONTHLY AVERAGE HEATING AUXILIARY REQUIREMENT AS CALCULATED
BY LA MONSEN ET AL METHOD - 149 -

SOLAR HEATING FRACTION AS CALCULATED
BY MONSEN ET AL METHOD - 149 -

SOLAR HEATING FRACTION AS CALCULATED
BY MONSEN ET AL METHOD - 149 -
APPLICATIONS TO THE TROMBE WALL SYSTEM

A set of graphs similar to those of figures 3 to 8 can be constructed for houses incorporating un-vented Trombe walls, rather than direct-gain passive heating systems. Because we assumed that the design details of the considered house, except for the thermal properties of the storage elements, are alike in both cases, then the use of the un-vented Trombe wall system in place of the direct-gain one will not affect the values of the $F$-factor. However, the values of the ambient energy factor will decrease due to the increase in the thermal time constant. As a result the amount of useful solar gains will be reduced - see equation (52).

Thereby it will be necessary to increase the auxiliary heating requirements, but the use of the un-vented Trombe wall will eliminate the disadvantages of the direct-gain system, such as the large temperature swings, strong directional day lighting, glare, and ultra-violet degradation of the materials within the house. Most importantly, it will preserve the privacy which is of prime concern in Yemeni culture. Upon comparing the thermal performances of both systems, it was found on annual basis that 0.4 of the house load will be provided by solar energy when a single-storey stone house incorporates a south-facing un-vented Trombe wall passive-heating system. This increases, see fig. B, irrespective of the values of the solar fraction which are greater than or equal to unity, to 0.63 when the same house uses the direct-gain approach for passive heating. For a single-storey concrete house, the annual average of the solar heating fraction is 0.3, when the house incorporates an unvented Trombe wall approach for passive heating compared with 0.53 when the same house uses a direct-gain approach for passive heating.

CONCLUSIONS

An ambient-energy recuperation factor has been developed as a function of the overall thermal conductance of the house, the total solar and internal gains, and the thermophysical properties of the employed building materials. The correlations of this factor with the thermostat-outdoor temperature differences divided by the monthly average of the daily amounts of solar radiation transmitted to the house are prescribed respectively
for heavy and medium thermal-mass houses incorporating south-facing direct-gain passive heating systems. The predictions of the presented design method for the auxiliary heating required per annum by a finite storage capacity direct-gain house agreed to within a 6% error with those deduced using the "un-utilizability" method - see fig. (8). The presented method enables designers to estimate (in addition to the auxiliary heating requirement) the auxiliary requirement for cooling as well as the variation of the actual indoor temperature with time. It also permits the plotting of a number of design graphs which would help designers in tropical climates to choose the most suitable system parameters, such as: the area of the south-facing glazing, which does not result in overheating of the house; the critical thermostat set temperature at which the auxiliary cooling requirement is a minimum; and the thermal properties of the storage unit.
REFERENCES


APPENDIX 1

Arabic-to-English Translation of the 1982 Energy Survey
INTRODUCTION

The aim of this survey is to estimate the contribution of solar energy in solving the local energy crisis. Surely it is the time to replace the non-renewable energy resources, used in our houses and factories, with the everlasting source of energy "SOLAR ENERGY". Justification of this change over is obvious, namely sunlight is everlasting and free to use. In addition, solar energy solves the problems of the depletion of resources, economic dependency on the oil producing countries, pollution, and the waste hazards associated with the other energy resources as for example with nuclear energy.

We all believe that "Sun is the source of life, so why not use it as a source of energy?".

My confidence in your help and ability to answer the attached group of questions arises from our promise to publish and generalise the results so that every individual can benefit from them. Let us share the introduction of these new concepts and be confident in their potential.

The Researcher
Sana'a University
Faculty of Science
Physics Department
April-1982
CONTENTS

This questionnaire contains a total of 22 questions distributed as follows:

1 to 7 : General information questions
8 to 18 : Fuel use information questions
17 to 21 : Water use information questions

In addition to these there is one question which deals with your opinion regarding the ranking of the low-temperature solar-energy applications according to the urban and rural uses.
SECTION ONE: General Information Questions

PLEASE COMPLETE THE FOLLOWING QUESTIONS

1) a) Geographical location of your house

   Province       City

   Children       Adults

   East West North South

b) Number of family members living in your house

2) 

<table>
<thead>
<tr>
<th></th>
<th>East</th>
<th>West</th>
<th>North</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) House location in the city of residence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b) Dimension of the walls (length x width) (SQ.M.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) Dimension of the flat roof (length x width) (SQ.M)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d) Number of house storeys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e) Monthly income (Rial/month)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3) **EFFECT OF OBSTRUCTION ON THE HOUSE WALLS AND ROOF**

If your house is surrounded by trees, neighbouring houses, or it has a yard, please complete the following tables.

**a) Trees**

Indicate in the following table, the height, location and the distance of the trees from your house walls in the respective directions.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Height (m)</th>
<th>Distance from house walls (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**b) House yard specifications**

Indicate in the following table, the distance between the yard walls and the house walls of your house in the respective directions.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td></td>
</tr>
<tr>
<td>West</td>
<td></td>
</tr>
<tr>
<td>North</td>
<td></td>
</tr>
<tr>
<td>South</td>
<td></td>
</tr>
</tbody>
</table>
c) Neighbouring house specifications

Indicate in the following table, the number of storeys and the distance between your house or yard walls and those of your neighbouring houses in the respective directions.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Number of storeys of neighbouring houses</th>
<th>Distance between your house walls and those of the neighbouring houses (m)</th>
<th>Distance between your yard walls and those of the neighbouring houses (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4) TYPE OF EXTERNAL WALL BUILDING MATERIALS

Please mark the appropriate type of masonry materials which are employed in constructing the external walls of each storey of your house.

<table>
<thead>
<tr>
<th>Storey Number</th>
<th>Type of masonry material per each storey</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stone</td>
</tr>
<tr>
<td>first storey</td>
<td></td>
</tr>
<tr>
<td>second storey</td>
<td></td>
</tr>
<tr>
<td>third storey</td>
<td></td>
</tr>
<tr>
<td>fourth storey</td>
<td></td>
</tr>
<tr>
<td>fifth storey</td>
<td></td>
</tr>
<tr>
<td>sixth storey</td>
<td></td>
</tr>
<tr>
<td>seventh storey</td>
<td></td>
</tr>
<tr>
<td>eighth storey</td>
<td></td>
</tr>
<tr>
<td>ninth storey</td>
<td></td>
</tr>
<tr>
<td>tenth storey</td>
<td></td>
</tr>
</tbody>
</table>
5) **ROOF EXPOSURE TO THE SUN**

Answer the following questions with YES or NO according to the situation of your house roof:

a) is the roof of your house fully exposed to the Sun?  
   b) is the roof of your house partly exposed to the Sun?  

6) **WINDOWS EXPOSURE TO THE SUN**

Choose the appropriate answers which give the most suitable description for the exposure of your house windows to the Sun. Also indicate the total number of windows and their corresponding total area per each storey.

<table>
<thead>
<tr>
<th>Storey</th>
<th>Number of windows exposed to the Sun per each storey</th>
<th>Total number of windows per each storey</th>
<th>Total area of windows per each storey (M²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East</td>
<td>West</td>
<td>North</td>
</tr>
<tr>
<td>first</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>third</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fourth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>fifth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sixth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>seventh</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7) **ROOM SPECIFICATIONS**

Please complete the following table taking into considerations the following directions:

Room type: receiving, sitting, sleeping, reading, dining, social gathering, toilets, kitchen and halls

If you have more than one room with the same type or of a type omitted from the above list, please identify them and give their dimensions.

<table>
<thead>
<tr>
<th>Room type</th>
<th>Storey at which the room is located</th>
<th>Room dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Length (m)</td>
<td>Width (m)</td>
</tr>
</tbody>
</table>
SECTION TWO: Fuel Use Information Questions

8) Delete those of the following energy resources which are used in your house.

- Electricity
- Wood
- Natural gas
- Charcoal
- Animal waste
- Agricultural residues
- Kerosene

9) ELECTRICITY USE

Delete the functions listed below for which electricity is used in your house.

- Lighting
- Cooking
- Water heating
- Clothes washing
- Refrigeration
- Water distillation
- House space cooling
- House space heating
- Operating household equipment
10) In front of each one of the following items of equipment, please indicate the number of times per day or week it is used and the approximate duration of each period of use.

<table>
<thead>
<tr>
<th>Number of times each item of equipment is used</th>
<th>Approximate duration of each use</th>
</tr>
</thead>
<tbody>
<tr>
<td>per day</td>
<td>per week</td>
</tr>
</tbody>
</table>

| Mud stove          |          |          |
| Gas oven           |          |          |
| Electric oven      |          |          |
| Electric heater (for domestic water heating) |          |          |
| Electric heater (for house space heating)   |          |          |
| Separate immersion heater (for water heating) |          |          |
| Water pump         |          |          |
| Air conditioner (for house space cooling)   |          |          |
| Ceiling fan        |          |          |
| Washing machine    |          |          |
| Food processors    |          |          |
| Refrigerator       |          |          |
| Television         |          |          |
| Radio              |          |          |
| Others (please specify) |      |          |
11) Please indicate in the following table the amount of money you spent per a typical month in winter and a typical month in summer on the following types of fuels.

<table>
<thead>
<tr>
<th>Amount of money spent on fuel (Rial/month)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood/charcoal/animal waste/agricultural residues</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kerosene</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12) Please review the electricity bills of your house and indicate in the following table the amount of electricity you consumed during a typical month in winter, a typical month in summer and if possible the amount of electricity consumed during the month of fasting.

<table>
<thead>
<tr>
<th>Month</th>
<th>Amount of electricity consumed (kW hr/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Month of fasting</td>
<td></td>
</tr>
</tbody>
</table>
13) Please indicate in the following table the rated power and the name of the manufacturer of all electrical appliances in your house.

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Rated power (W)</th>
<th>Name of manufacturing company</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
14) Wood Use

Delete the functions for which wood is used in your house.

- Cooking of meat and/or vegetables
- Bread baking
- House space heating
- Domestic water heating
- Coffee making
- Others (please specify)

15) Charcoal Use

- Cooking of meat and/or vegetables
- Coffee making
- House space heating
- Re-heating pre-prepared food
- Domestic water heating
- Others (please specify)

16) Delete the functions for which Kerosene is used in your house

- Cooking of meat and/or vegetables
- Emergency lighting
- Normal lighting
- Domestic water heating
- Coffee making
- Others (please specify)
SECTION THREE: Water Use Information Questions

17) Please answer YES or NO to the following set of questions.
   a) Do you have a roof-mounted water-storage tank?
   b) Do you have another water-storage tank located either in
      the first storey of your house or outside the house?
   c) Do you use the pressurized main water supply system?
   d) Do you pump the water to your roof-mounted water-storage tank?
   e) Do you have a potable water well inside your house?

18) Please review the water bills of your house. Indicate in the
    following table the amount of water consumed during a typical
    month in winter and a typical month in summer, and the respective
    costs in those months in Rial.

<table>
<thead>
<tr>
<th>Month</th>
<th>Amount of water consumed (please use the unit of capacity you are familiar with)</th>
<th>Cost (Rial/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>litres</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cubic metres</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tankah</td>
<td></td>
</tr>
<tr>
<td></td>
<td>litres</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cubic metres</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tankah</td>
<td></td>
</tr>
</tbody>
</table>
19) If you have several roof-mounted water-storage tanks, please indicate in the following table the capacity of each tank as well as the number of times it is filled with water during the day or week.

<table>
<thead>
<tr>
<th>Capacity Please use the unit of capacity you are familiar with</th>
<th>Number of times per day or week the roof-mounted storage-tank is filled with water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank number 1</td>
<td>Day</td>
</tr>
<tr>
<td>litres</td>
<td></td>
</tr>
<tr>
<td>cubic metres</td>
<td></td>
</tr>
<tr>
<td>Tankah</td>
<td></td>
</tr>
<tr>
<td>Tank number 2</td>
<td>Day</td>
</tr>
<tr>
<td>litres</td>
<td></td>
</tr>
<tr>
<td>cubic metres</td>
<td></td>
</tr>
<tr>
<td>Tankah</td>
<td></td>
</tr>
</tbody>
</table>

20) Hot Water Use

Delete the functions for which you use the hot water in your house. Please indicate in front of the deleted function the amount of hot water consumed for that function as measured in either litres, cubic metres, or Tankah per day.

<table>
<thead>
<tr>
<th>Amount of hot water consumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathing</td>
</tr>
<tr>
<td>Clothes washing</td>
</tr>
<tr>
<td>Dish washing</td>
</tr>
<tr>
<td>Cleansing before prayers</td>
</tr>
<tr>
<td>Others (please specify)</td>
</tr>
</tbody>
</table>
21) Please indicate in the following table the capacity and the location of all water-storage tanks present in your house as well as the period for which the stored water in each tank suffices your use in case of emergency stoppages. Please use either litres, cubic metres, or Tankah for the unit of capacity.

<table>
<thead>
<tr>
<th>Location</th>
<th>Capacity</th>
<th>period during which the stored water in each tank suffices the needs of the house</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank number 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tank number 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tank number 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tank number 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
22) Please rank the following low-temperature solar-energy applications according to your perception of their importance for urban and rural usages.

<table>
<thead>
<tr>
<th></th>
<th>Rank on a scale of 1 to 10 (10 being the least important)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>urban use</td>
</tr>
<tr>
<td>Water heating</td>
<td></td>
</tr>
<tr>
<td>Water pumping</td>
<td></td>
</tr>
<tr>
<td>House electrification</td>
<td></td>
</tr>
<tr>
<td>Water distillation</td>
<td></td>
</tr>
<tr>
<td>Crop-drying</td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
</tr>
<tr>
<td>House space heating</td>
<td></td>
</tr>
<tr>
<td>House space cooling</td>
<td></td>
</tr>
<tr>
<td>Refrigeration</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 2

Listings of the Computer Programs Used in the Analysis
SURVEY ANALYSIS COMPUTER PROGRAM
OPEN "I", #L, NS
IF #L = "END" THEN 36
INPUT #L, X
0 IF X = 6 THEN 16
31 INPUT #L, AX(X, Y)
2 SLY Y
33 PRINT
4 CLOSE #L
35 GO TO 26
6 EN Y = 6 TO 18
37 AX(1, Y) = Y
40 AX(Y - 12, Y) = (3, 14/12)
41 DEC(2, 2) = (3, 14/180)
42 J = 151 * (3, 14/160)
45 AX(2, Y) = H
50 IF WDR = 0 THEN DUR = DUR + AX(2, Y)
61 TUR = TUR + AX(2, Y)
12 GDR = (AX(2, Y)) + (AI(DEC) * SIN(H))
121 PRINT SIN(H)
50 IF END = 10 THEN EDUR = 0
140 AX(5, Y) = EDR
150 WDR = (AX(5, Y)) + (AI(DEC) * SIN(LR) * COS(H) - SIN(DEC) * COS(LR))
170 IF WDR = 0 THEN NDR = 0
190 IF END = 10 THEN SDUR = 0
20 GDR = (AX(5, Y)) + (AI(DEC) * SIN(LR) * COS(H) - SIN(DEC) * COS(LR))
220 IF NDR = 0 THEN NDR = 0
230 AX(E, Y) = NDR
240 HER = AX(5, Y) + (AX(4, Y) / 2)
250 AX(4, Y) = HER
260 HWR = AX(4, Y) + (AX(4, Y) / 2)
270 AX(10, Y) = HWR
280 HSR = AX(7, Y) + (AX(4, Y) / 2)
290 AX(11, Y) = HSR
300 HNR = AX(9, Y) + (AX(4, Y) / 2)
12 AX(12, Y) = HNR
320 DER = DER + AX(9, Y)
330 DW = DW + AX(10, Y)
340 DW + DUR = DUR(11, Y)
350 LER = LER + AX(12, Y)
351 NEXT Y
66 FOR Y = 1 TO 18
361 AX(13, Y) = Y
362 HLY = Y - 12 * (3, 14/12)
363 AX(14, Y) = H
371 DEC(20, 9) = (3, 14/160)
372 LAW = (151 * (3, 14/180)
460 TUR = TUR + AX(15, Y)
490 TUR = TUR + AX(16, Y)
411 PR IN (SIN(H))
420 CWR = (AX(15, Y)) + (AI(DEC) * SIN(H))
430 IF EDR = 0 THEN EDUR = 0
440 AX(17, Y) = EDR
450 WDR = (AX(15, Y)) + (AI(DEC) * SIN(H))
460 IF WDR = 0 THEN NDR = 0
470 AX(18, Y) = WDR
480 SWR = AX(15, Y) + (AI(DEC) * SIN(LR) * COS(H) - SIN(LR) * COS(LR))
490 IF SDRAW=0 THEN SDRAW=0
500 AX(1, Y)=SDRW
510 NDRAW=(AX(15, Y))+(COS(LK/9)*SIN(DECW)=COS(DECW)*SIN(LK/9)*COS(H))
520 IF NDRAW=0 THEN NDRAW=0
530 AX(20, Y)=NDRAW
540 HERWAX(17, Y)=(AX(16, Y)/2)
550 AX(21, Y)=HERW
560 HERWAX(19, Y)=(AX(16, Y)/2)
570 AX(22, Y)=HERW
580 HERWAX(21, Y)=(AX(16, Y)/2)
590 AX(24, Y)=HERW
600 HERWAX(24, Y)=(AX(16, Y)/2)
610 NEXT Y
620 LPRINT TAE(30): "$SUMMER DESIGN INTENSITIES IN THE Y. A. R."$ 
630 LPRINT "-----------------------------------------------"
640 LPRINT TAE(40): "$DRAW(SJ/K/M-2)""$ TAE(70): "$DRAW(SJ/K/M-2)"
650 LPRINT TAE(80): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
660 LPRINT TAE(90): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
670 LPRINT TAE(100): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
680 LPRINT TAE(110): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
690 LPRINT TAE(120): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
700 LPRINT TAE(130): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
710 LPRINT TAE(140): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
720 LPRINT TAE(150): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
730 LPRINT TAE(160): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
740 LPRINT TAE(170): "$DRAW(SJ/K/M-2)"$ TAE(70): "$DRAW(SJ/K/M-2)"
750 FOR Y=1 TO 18
760 FOR X=1 TO 12
770 LPRINT TAE((X-1)*7+6); AX(X, Y));
780 NEXT X
790 LPRINT TAE((X-1)*7+6); AX(X, Y));
800 LPRINT TAE((X-1)*7+6); AX(X, Y));
810 LPRINT TAE((X-1)*7+6); AX(X, Y));
820 LPRINT TAE((X-1)*7+6); AX(X, Y));
830 LPRINT TAE((X-1)*7+6); AX(X, Y));
840 LPRINT TAE((X-1)*7+6); AX(X, Y));
850 LPRINT TAE((X-1)*7+6); AX(X, Y));
860 LPRINT TAE((X-1)*7+6); AX(X, Y));
870 LPRINT TAE((X-1)*7+6); AX(X, Y));
880 LPRINT TAE((X-1)*7+6); AX(X, Y));
890 LPRINT TAE((X-1)*7+6); AX(X, Y));
900 LPRINT TAE((X-1)*7+6); AX(X, Y));
910 LPRINT TAE((X-1)*7+6); AX(X, Y));
920 LPRINT TAE((X-1)*7+6); AX(X, Y));
930 LPRINT TAE((X-1)*7+6); AX(X, Y));
940 LPRINT TAE((X-1)*7+6); AX(X, Y));
950 LPRINT TAE((X-1)*7+6); AX(X, Y));
960 LPRINT TAE((X-1)*7+6); AX(X, Y));
970 LPRINT TAE((X-1)*7+6); AX(X, Y));
980 LPRINT TAE((X-1)*7+6); AX(X, Y));
990 LPRINT TAE((X-1)*7+6); AX(X, Y));
1000 LPRINT TAE((X-1)*7+6); AX(X, Y));
1010 PRINT "INPUT Q1=66"
1020 INPUT BY(J, I)
1030 NEXT I
1050 IF H<1 THEN Z=0, GOTO 1060
1060 Z=RH+H: GOTO 1090
1070 LPRINT "$WRONG COMBINATION$"
1100 LPRINT"------------------------------"*
1110 LPRINT TAB(50),"FAMILY INDEX=";J
1120 LPRINT
1130 LPRINT"ROOF INDEX-------------------------------HOUSE INDEX-------------------------------ROOF-HOUSE"
1140 LPRINT
1150 LPRINT RETABLE(24);H1;TABLE(50);I
1160 LPRINT LPRINT
1170 LPRINT"SIDES WHICH ARE BLOCKED FROM THE SUN DURING THE DAY"*
1180 LPRINT"------------------------------------------N----------------------------------------S"
1190 LPRINT
1200 LPRINT DX(J,6);TAB(14);DX(J,7);TAB(29);DX(J,8);TAB(47);DX(J,9)
1210 LPRINT LPRINT
1220 FOR I=1 TO 12
1230 LPRINT TAB((1-1)*7+2);A(I)
1240 NEXT I
1250 LPRINT LPRINT
1260 FOR I=1 TO 12
1270 LPRINT TAB((1-1)*7+2);BX(J,1)
1280 NEXT I
1290 LPRINT LPRINT
1300 FOR I=1 TO 20
1310 LPRINT TAB((1-1)*7+2);BX(J,1)
1320 NEXT I
1330 LPRINT LPRINT
1340 FOR I=21 TO 30
1350 LPRINT TAB((1-21)*7+2);A(I)
1360 NEXT I
1370 LPRINT LPRINT
1380 FOR I=21 TO 30
1390 LPRINT TAB((1-21)*7+2);BX(J,1)
1400 NEXT I
1410 LPRINT LPRINT
1420 IF EX(J,6)=1 THEN ESE=0:GOTO 1270
1430 IF EX(J,6)=1 THEN ESE=0:GOTO 1290
1440 IF EX(J,7)=2 THEN WSE=0:GOTO 1210
1450 IF EX(J,7)=2 THEN WSE=0:GOTO 1230
1460 IF EX(J,8)=2 THEN NSE=0:GOTO 1250
1470 IF EX(J,8)=2 THEN NSE=0:GOTO 1270
1480 IF EX(J,9)=3 THEN NSE=0:GOTO 1290
1490 IF EX(J,9)=3 THEN NSE=0:GOTO 1310
1500 IF EX(J,9)=4 THEN NSE=0:GOTO 1330
1510 IF EX(J,9)=4 THEN NSE=0:GOTO 1350
1520 IF EX(J,9)=4 THEN NSE=0:GOTO 1370
1530 IF EX(J,9)=4 THEN NSE=0:GOTO 1390
1540 IF EX(J,9)=4 THEN NSE=0:GOTO 1410
1550 IF EX(J,9)=4 THEN NSE=0:GOTO 1430
1560 IF EX(J,9)=4 THEN NSE=0:GOTO 1450
1570 IF EX(J,9)=4 THEN NSE=0:GOTO 1470
1580 IF EX(J,9)=4 THEN NSE=0:GOTO 1490
1590 IF EX(J,9)=4 THEN NSE=0:GOTO 1510
1600 IF EX(J,9)=4 THEN NSE=0:GOTO 1530
1610 IF EX(J,9)=4 THEN NSE=0:GOTO 1550
1620 IF EX(J,9)=4 THEN NSE=0:GOTO 1570
1630 IF EX(J,9)=4 THEN NSE=0:GOTO 1590
1640 IF EX(J,9)=4 THEN NSE=0:GOTO 1610
1650 IF EX(J,9)=4 THEN NSE=0:GOTO 1630
1660 IF EX(J,9)=4 THEN NSE=0:GOTO 1650
1670 IF EX(J,9)=4 THEN NSE=0:GOTO 1670
1680 IF EX(J,9)=4 THEN NSE=0:GOTO 1690
1690 IF EX(J,9)=4 THEN NSE=0:GOTO 1710
1700 PRINT"SOLAR ENERGY FALLING ON THE EXTERIOR WALLS AND ITS DIST"*
1710 LPRINT LPRINT"*"*"*"*
1720 LPRINT LPRINT"------------------------------"*
1730 LPRINT LPRINT"------------------------------"*
1740 LPRINT LPRINT"------------------------------"*
1750 LPRINT LPRINT"------------------------------"*
1760 LPRINT LPRINT"------------------------------"*
1770 LPRINT LPRINT"------------------------------"*
1780 LPRINT LPRINT"------------------------------"*
1790 LPRINT LPRINT"------------------------------"*
1800 LPRINT LPRINT"------------------------------"*
1810 LPRINT LPRINT"------------------------------"*
1820 LPRINT LPRINT"------------------------------"*
1830 LPRINT LPRINT"------------------------------"*
1840 LPRINT LPRINT"------------------------------"*
1850 LPRINT LPRINT"------------------------------"*
1860 LPRINT LPRINT"------------------------------"*
1870 LPRINT LPRINT"------------------------------"*
1880 LPRINT LPRINT"------------------------------"*
1890 LPRINT LPRINT"------------------------------"*
1900 LPRINT LPRINT"------------------------------"*
1910 LPRINT LPRINT"------------------------------"*
1920 LPRINT LPRINT"------------------------------"*
1930 LPRINT LPRINT"------------------------------"*
1940 LPRINT LPRINT"------------------------------"*
1950 LPRINT LPRINT"------------------------------"*
1960 LPRINT LPRINT"------------------------------"*
1970 LPRINT LPRINT"------------------------------"*
1980 LPRINT LPRINT"------------------------------"*
1990 LPRINT LPRINT"------------------------------"*
2000 LPRINT LPRINT"------------------------------"*
2010 LPRINT LPRINT"------------------------------"*
2020 LPRINT LPRINT"------------------------------"*
2030 LPRINT LPRINT"------------------------------"*
2040 LPRINT LPRINT"------------------------------"*
2050 LPRINT LPRINT"------------------------------"*
2060 LPRINT LPRINT"------------------------------"*
2070 LPRINT LPRINT"------------------------------"*
2080 LPRINT LPRINT"------------------------------"*
2090 LPRINT LPRINT"------------------------------"*
2100 LPRINT LPRINT"------------------------------"*
2110 LPRINT LPRINT"------------------------------"*
2120 LPRINT LPRINT"------------------------------"*
2130 LPRINT LPRINT"------------------------------"*
2140 LPRINT LPRINT"------------------------------"*
2150 LPRINT LPRINT"------------------------------"*
2160 LPRINT LPRINT"------------------------------"*
2170 LPRINT LPRINT"------------------------------"*
2180 LPRINT LPRINT"------------------------------"*
2190 LPRINT LPRINT"------------------------------"*
2200 LPRINT LPRINT"------------------------------"*
2210 LPRINT LPRINT"------------------------------"*
2220 LPRINT LPRINT"------------------------------"*
2230 LPRINT LPRINT"------------------------------"*
2240 LPRINT LPRINT"------------------------------"*
2250 LPRINT LPRINT"------------------------------"*
2260 LPRINT LPRINT"------------------------------"*
2270 LPRINT LPRINT"------------------------------"*
2280 LPRINT LPRINT"------------------------------"*
2290 LPRINT LPRINT"------------------------------"*
2300 LPRINT LPRINT"------------------------------"*
2310 LPRINT LPRINT"------------------------------"*
2320 LPRINT LPRINT"------------------------------"*
2330 LPRINT LPRINT"------------------------------"*
2340 LPRINT LPRINT"------------------------------"*
2350 LPRINT LPRINT"------------------------------"*
2360 LPRINT LPRINT"------------------------------"*
2370 LPRINT LPRINT"------------------------------"*
2380 LPRINT LPRINT"------------------------------"*
2390 LPRINT LPRINT"------------------------------"*
2400 LPRINT LPRINT"------------------------------"*
2410 LPRINT LPRINT"------------------------------"*
2420 LPRINT LPRINT"------------------------------"*
2430 LPRINT LPRINT"------------------------------"*
2440 LPRINT LPRINT"------------------------------"*
2450 LPRINT LPRINT"------------------------------"*
2460 LPRINT LPRINT"------------------------------"*
2470 LPRINT LPRINT"------------------------------"*
2480 LPRINT LPRINT"------------------------------"*
2490 LPRINT LPRINT"------------------------------"*
2500 LPRINT LPRINT"------------------------------"*
2510 LPRINT LPRINT"------------------------------"*
2520 LPRINT LPRINT"------------------------------"*
2530 LPRINT LPRINT"------------------------------"*
2540 LPRINT LPRINT"------------------------------"*
2550 LPRINT LPRINT"------------------------------"*
2560 LPRINT LPRINT"------------------------------"*
2570 LPRINT LPRINT"------------------------------"*
2580 LPRINT LPRINT"------------------------------"*
2590 LPRINT LPRINT"------------------------------"*
2600 LPRINT LPRINT"------------------------------"*
2610 LPRINT LPRINT"------------------------------"*
2620 LPRINT LPRINT"------------------------------"*
2630 LPRINT LPRINT"------------------------------"*
2640 LPRINT LPRINT"------------------------------"*
2650 LPRINT LPRINT"------------------------------"*
2660 LPRINT LPRINT"------------------------------"*
2670 LPRINT LPRINT"------------------------------"*
2680 LPRINT LPRINT"------------------------------"*
2690 LPRINT LPRINT"------------------------------"*
2700 LPRINT LPRINT"------------------------------"*
2710 LPRINT LPRINT"------------------------------"*
2720 LPRINT LPRINT"------------------------------"*
2730 LPRINT LPRINT"------------------------------"*
2740 LPRINT LPRINT"------------------------------"*
2750 LPRINT LPRINT"------------------------------"*
2760 LPRINT LPRINT"------------------------------"*
2770 LPRINT LPRINT"------------------------------"*
2780 LPRINT LPRINT"------------------------------"*
2790 LPRINT LPRINT"------------------------------"*
2800 LPRINT LPRINT"------------------------------"*
2810 LPRINT LPRINT"------------------------------"*
2820 LPRINT LPRINT"------------------------------"*
2830 LPRINT LPRINT"------------------------------"*
2840 LPRINT LPRINT"------------------------------"*
2850 LPRINT LPRINT"------------------------------"*
2860 LPRINT LPRINT"------------------------------"*
2870 LPRINT LPRINT"------------------------------"*
2880 LPRINT LPRINT"------------------------------"*
2890 LPRINT LPRINT"------------------------------"*
2900 LPRINT LPRINT"------------------------------"*
2910 LPRINT LPRINT"------------------------------"*
2920 LPRINT LPRINT"------------------------------"*
2930 LPRINT LPRINT"------------------------------"*
2940 LPRINT LPRINT"------------------------------"*
1440 PRINT" WINTER TO:
1441 LPRINT "ESE WSW NSE SSE ESEW":
1443 LPRINT
1444 PRINT ESE: TAB(12); WSE: TAB(24); NSE: TAB(30); SSE: TAB(46); ESW: TAB(60);
1445 LPRINT ESEW: TAB(72); WSW: TAB(94); NSEW: TAB(96); SSEW: TAB(108); EPHW
1446 PRINT"
1447 LPRINT T=0Z(J, 10)
1450 PRINT "INPUT THE STORY REPEATITION"
1455 INPUT X
1460 FOR L=1 TO X
1470 FOR M=1 TO 17
1475 PRINT "INPUT ST MATRIX; ROOM-AREA AND WINDOW AREA MUST INPUTED DIR" "
1479 INPUT CLR(M)
1480 NEXT M
1482 RA(L)=CLR(L, 2)*CLR(L, 3)
1484 NW(L)=CLR(L, 17)
1485 BM(L)=CLR(L, 9)
1486 EXPW(L)=CLR(L, 12)-CLR(L, 9))
1487 EWA(L)=CLR(L, 14)+CLR(L, 10)-CLR(L, 11)
1489 WSA=0 THEN 1650
1491 WCL(L)=(ESEW)*(EWA(L)/EWA)/WSW(L)=(ESEW)*(EWA(L)/ESA)
1493 WSW(L)=CLR(L, 5)+CLR(L, 12)-CLR(L, 13)
1495 IF WSA=0 THEN 1650
1497 WEL(L)=(WSW(L)*(WSW(L)+WSW(L))=CLR(L, 6)+CLR(L, 14)-CLR(L, 15)
1499 WSA=0 THEN 1650
1501 WEL(L)=CLR(L, 7)+CLR(L, 16)-CLR(L, 17)
1503 ELS=0 THEN 1650
1505 WEL(L)=(LSW(L)*LSW(L)/LSW(L)=CLR(L, 8)+CLR(L, 19)
1507 ETCL(L)=(L, WEL(L)+WEIL(L)+WEIL(L)+WEIL(L)
1509 ELL(L)=CLR(L, 9)+CLR(L, 10)+CLR(L, 11)+CLR(L, 12)
1511 ETH=LHET(L)
1513 LPRINT ETHETH(L)
1515 NW(L)=EWA(L)+SW(L)+SW(L)+NW(L)
1517 NW(L)=EWA(L)+SW(L)+SW(L)+NW(L)
1519 LPRINT ETHETH(L)
1521 LPRINT E trọng IN THE HOUSE IN (KJ/DAY)"
1523 LPRINT
1524 LPRINT "TYPE OF THE ROOM-TRANSMITTED ENERGY"
1525 LPRINT "WINDOW AREAS(M)"
1527 LPRINT TAB(119): "M2"; TAB(122): "M2"
1529 LPRINT "SUMMER WINTER"
1531 LPRINT "ENERGY TRANSMITTED TO EACH ROOM IN THE HOUSE IN (KJ/DAY)"
1533 LPRINT "ENERGY TRANSMITTED TO THE HOUSE IN (KJ/DAY)"
1535 LPRINT "SUMMER WINTER"
1537 LPRINT"ETH; TAB(40); ETLA"
1969 IF T=1 THEN 1966
1965 FOR K=1 TO T
1966 PRINT "INPUT TOEXWM M=1, RD=2, S=3, REWCM=4, SWCN=5, CN=6, LSWN=7, RILN=8"
1967 INPUT A(K)
1968 IF A(K)<3 THEN PRINT "INPUT CIP P=1"; INPUT P
1969 IF A(K)=1 THEN UW1=2.58 00 TO 1973
1970 IF A(K)=2 THEN UW1=4.66 00 TO 1973
1971 IF A(K)=3 THEN UW1=5.29 00 TO 1973
1972 IF A(K)<3 THEN 1975
1973 GREAL(E)=(24*16, 5)*((TPA-TWA)/T)*(UW1); TWEW=TWEW+GREAL(E)
1974 IF A(K)=3 THEN 1983
1975 IF A(K)=4 THEN UW2=10 352 00 TO 1980
1976 IF A(K)=5 THEN UW2=10 533 00 TO 1980
1977 IF A(K)=6 THEN UW2=12 140 00 TO 1980
1978 IF A(K)=7 THEN UW2=13 670 00 TO 1990
1979 IF A(K)=8 THEN UW2=19 240 00 TO 1990
1980 GREL(E)=(24*16, 5)*((TPA-TWA)/T)*UW2
1981 TWEW=TWEW+GREL(E)
1982 PRINT "INPUT CIP P=2"; INPUT P
1983 LW1=0; UW2=0; NEXT K
1984 IF T>1 THEN 1999
1985 PRINT "INPUT WALL INSIDE PLASTER P=1 FOR GYPSUM, P=2 FOR CEMENT"
1986 INPUT W
1987 IF W<1 THEN UW1=0; GO TO 1997
1988 IF W=2 THEN UW1=4 66 00 TO 1997
1989 IF W=3 THEN UW1=5 29 00 TO 1997
1990 IF W=4 THEN UW1=10 352 00 TO 1997
1991 IF W=5 THEN UW1=10 533 00 TO 1997
1992 IF W=6 THEN UW1=12 140 00 TO 1997
1993 IF W=7 THEN UW1=13 670 00 TO 1997
1994 IF W=8 THEN UW1=19 240 00 TO 1997
1995 IF W=9 THEN UW2=14 970 00 TO 1999
1996 IF W=10 THEN UW2=20 1 00 TO 2010
1997 IF P=1 THEN UR1=144; UR2=1 00 TO 2010
1998 IF P=2 THEN UR2=8; UR3=37 2; UR=7 975 00 TO 2010
2000 FOR L=1 TO X
2001 IF P=2 THEN 2030
2002 GREAL(L)=(24*16, 5)*((UR(L))+(RA(L))
2003 TWEW=L*TWEW+GREAL(L)
2004 TWEW=TWEW+TWEW(L)
2005 FOR K=1 TO 2140
2006 GREL(L)=(24*16, 5)*((UR(L))+(RA(L))
2007 IF K=1 THEN TREL1=GREL(L)
2100 TREL2=TREL2+GREL(L)
2101 TREL=TREL1+TREL2
2102 EWEL(L)=(24*16, 5)*((EW(L))+(NW(L))
2103 IF L=1 THEN EWEL1=EWEL(L)
2104 EWEL=L*37 6; NWEL(L)
2105 EWEL=(24*16, 5)*((EW(L))+(NW(L))
2106 TWEW=TWEW+TWEW(L)
2107 HWEW=TWEW+TWEW(L)
2200 IF Y=1 TO 5
OVER ALL HOUSE HEAT LOSS

HOUSE QUALITY FACTORS

ELCR(K) = E

ELCR(K/J)=U
3540 NEXT Y: X=U, T=U, W=U, P=U
3550 NEXT J
3560 END
10 DIM B$(40), FX(10, 30), D(13, 3), WH(13), DH(13), M%(4, 3), W(6)
.90 U(7), U(5), AWLE(20), AWLE(20)
25 PRINT CHR$(27)"*";
26 INPUT "ENTER FUEL NUMBER"
27 OPEN "F%.61", N$;
20 FOR J=1 TO 25
40 INPUT #, L, B%(I)
50 NEXT I
73 FOR J=1 TO 10
100 PRINT "INPUT TYPE OF FUEL AND THE USE OF ENERGY RESOURCES"
100 INPUT FX(J, I)
110 NEXT I
120 IF FX(J, I)>0 THEN GOSUB 500
130 IF FX(J, I) THEN GOSUB 1000
140 IF FX(J, I) THEN GOSUB 1500
150 IF FX(J, I) THEN GOSUB 2000
160 LPRINT
115 LPRINT TAB(50); F$="*"
166 LPRINT
167 LPRINT TAB(50); "TYPE OF ENERGY RESOURCES USED IN YEMEN BUILDINGS"
168 LPRINT
169 FOR J=1 TO 7
170 LPRINT B$(I), FX(J, I)
171 NEXT I
172 LPRINT
173 LPRINT TAB(50); "USE OF ENERGY RESOURCES"
174 LPRINT
175 LPRINT TAB(50); "ELECTRICITY USE"
176 LPRINT
177 FOR J=1 TO 17
178 LPRINT B$(I), FX(J, I)
179 NEXT I
180 LPRINT
181 LPRINT TAB(50); "WOOD USE"
182 LPRINT
183 FOR J=18 TO 22
184 LPRINT B$(I), FX(J, I)
185 NEXT I
186 LPRINT
187 LPRINT TAB(50); "CHARCOAL USE"
188 LPRINT
189 FOR J=24 TO 30
190 LPRINT B$(I), FX(J, I)
191 NEXT I
192 LPRINT
193 LPRINT TAB(50); "KEROSESNE USE"
194 LPRINT
195 FOR J=31 TO 35
196 LPRINT B$(I), FX(J, I)
197 NEXT I
198 LPRINT
199 FOR K=1 TO 15
200 FOR L=1 TO 3
201 U(G, L)=0
202 NEXT L
203 D(K)=0
204 NEXT K
205 FOR K=1 TO 4
206 NEXT K
207 FOR N=1 TO 3
208 NEXT N
209 FOR M=1 TO 3
210 NEXT M
211 HCEW=0
212 NL=0
213 HCE=0
287 A(acc)=0
288 A(CEL)=0
289 A(cel)=0
290 A(cel)=0
291 A(cel)=0
292 A(cel)=0
293 A(cel)=0
294 A(cel)=0
295 A(cel)=0
296 FOR Y=1 TO 6
297 W(Y)=0
298 NEXT Y
299 FOR X=1 TO 7
300 C(X)=0
301 NEXT X
302 W(D)=0
303 D(s)=0
304 FOR R=1 TO 5
305 L(s)=0
306 NEXT R
307 FOR L=1 TO 3
308 PRINT "INPUT EQUIP USE AND TIME IN MINUTEs"
309 INPUT (K,L)
310 NEXT L
311 PRINT K
312 NEXT K
313 FOR K=1 TO 13
314 D(K)=((D(K,1)+D(K,2)+1)*D(K,1)+1)*D(K,2)))
315 NEXT K
316 L=SIGN TUC(20);"EQUIPMENTS USED IN THE HOUSE AND THEIR USE IN (HR/DA)
317 L=SIGN TUC(20);"EQUIPMENTS USED IN THE HOUSE AND THEIR USE IN (HR/DA)
318 L=SIGN TUC(20);"EQUIPMENTS USED IN THE HOUSE AND THEIR USE IN (HR/DA)
319 L=SIGN TUC(20);"EQUIPMENTS USED IN THE HOUSE AND THEIR USE IN (HR/DA)
320 FOR M=1 TO 4
321 PRINT "INPUT AMOUNT OF MONEY SPENT ON FUEL IN FORM OF 3X4 MATRIX"
322 INPUT MX(N,M)
323 NEXT N
324 NEXT M
325 LPRINT
326 LPRINT "AMOUNT OF MONEY SPENT ON FUEL IN (RAIL/MONTH)"
327 LPRINT
328 LPRINT "WINTER----SUMMER----RAMADAN"
329 LPRINT
330 LPRINT
331 LPRINT
700 IF X=1 THEN DCEW=(MX(2,1))/(30)*0.75
710 DCCW=(MX(2,1))/(30)*0.75
720 DCES=(MX(2,1))/(30)*0.75
730 DCEP=(MX(2,3))/(30)
735 ADC=(DCEW+DCES+DCEP)/(3)
740 IF FX(U,9)=0 THEN ACER=0:GO TO 745
745 IF FX(U,9)=0 THEN ACER=0:GO TO 770
750 IF FX(U,13)=0 THEN ACER=0:GO TO 780
760 IF FX(U,16)=0 THEN ACER=0:GO TO 790
770 ACER=ACER/(6/24)
780 IF MY(U,15) THEN ACER=0:GO TO 790
790 IF MY(U,16) THEN ACER=0:GO TO 790
800 IF MY(U,15) THEN ACER=0:GO TO 790
810 LPRINT "DAILY CONSUMPTION OF ELECTRICITY IN KWH/DAY"
820 5:8 9 0 LPRINT "---WINTER SUMMER KAMALAN AVG"
830 LPRINT 831 LPRINT TAE(8),DCEW,TAE(21),DCEP,TAB(21),DCEP,TAE(45),ACER
840 LPRINT 850 FOR K=4 TO 12
860 ACER(K)=ACER(K)+ACER(24)
870 LPRINT 880 NEXT K
890 LPRINT "DISTRIBUTION OF ELECTRICITY IN KWH/DAY"
910 LPRINT "TAE"--"WINTER"--"SUMMER"
920 LPRINT "TAE"--"WINTER"--"SUMMER"
930 LPRINT 940 LPRINT "TAE"--"WINTER"--"SUMMER"
950 LPRINT "TAE"--"WINTER"--"SUMMER"
960 LPRINT "TAE"--"WINTER"--"SUMMER"
970 LPRINT 980 FOR K=4 TO 12
990 LPRINT 1000 NEXT K
1010 LPRINT 1020 LPRINT 1030 LET Z=DH(1)
1040 IF Z=0 THEN 1050
1050 HCW=(MX(1,11)*0.5)/(12*Z)
1050 HCS=(MX(1,12)*0.5)/(20*Z)
1051 YCDW=(1.5165*12*10^-4)*(MX(1,11))
1052 YCHS=(1.5165*12*10^-4)*(MX(1,12))
1053  WES=(3.856)*(YCNW)
1054  WES=(4.697)*(YCNW)
1055  APCR=(1740)*(NEW)
1056  ARES=(4044)*(NEW)
1060  LPRINT
1110  LPRINT "WOOD INFORMATION"
1140  LPRINT
1141  WINTER SUMMER
1150  LPRINT "CONSUMPTION (KG/HR)"; TAB(32); HCHW; TAB(46); HCHW
1190  LPRINT
1191  LPRINT "COST (RAIL/MON)"; TAB(32); M$(1,1)/50; TAB(46); M$(1,2)/50
1191  LPRINT
1194  LPRINT "YEARLY NO. OF CORDS"; TAB(32); YCNW; TAB(46); YCNW
1197  LPRINT
1195  LPRINT "ENERGY EQIV. (KWHR/DD)"; TAB(32); WES; TAB(46); WES
1199  LPRINT
1200  LPRINT
1201  LPRINT
1202  LPRINT "COST (RAIL/YEAR)"; TAB(32); AMES; TAB(46); AMES
1205  LPRINT
1206  LPRINT "WOOD CONS (M$/YEAR)"; TAB(32); (3.625*YCNW)
1207  LPRINT LPRINT
1208  IF F$(J,5)=0 THEN 1060
1360  RETURN
1360  LPRINT YAC(50); "GAS INFORMATION"
1370  LPRINT
1371  LPRINT YAC(50); "WINTER ------------SUMMER"
1375  LPRINT
1376  LPRINT "COST (RAIL/MON)"; TAB(32); M$(0,1); TAB(46); M$(0,2)
1390  DUG=DUG(21)+DUG(3)
1390  KUG=WHR(21)+WHR(3)
1390  IF DUG=0 THEN 1980
1379  DUG=(M$(5,1)+M$(3,2))/(60*D0.65)
1379  KUG=DUG/DUG
1390  LPRINT
1390  LPRINT "DAILY USE OF GAS (HK)"; TAB(40); DUG
1397  LPRINT
1400  LPRINT "GAS CONS. (L/HR)"; TAB(40); HCHG
1400  RETURN
2000  LPRINT LPRINT
2045  LPRINT "KERISONE INFORMATION"
2050  LPRINT
2070  LPRINT "COST (RAIL/MON)"; TAB(32); M$(4,1); TAB(46); M$(4,2)
2250  RETURN
2140 TDIR=DRAC1+DRAC2+DRAC3
2145 WRC=WRAC1+WRAC2+WRAC3
2146 GRC=TRAC+TWRAC7
2150 FOR Y=1 TO 3
2170 IF Y=1 THEN RC1=(O.1)*(GRC) GO TO 2200
2180 IF Y=2 THEN RC2=(U.03)*(GRC) GO TO 2200
2190 RC3=(O.6)*(GRC)
2200 NEXT Y
2210 TRC=(RC1*1)+(RC2*1)+(RC3*1)
2220 RFR=(TRC/19)
2230 IF WI=1 THEN 2204
2230 IF WX(J,29)=O THEN 2230
2240 LOC=(WX(J,29)/WX(J,29))
2250 IF WX(J,39)=O THEN 2250
2260 LOC=(WX(J,29)/WX(J,50)*F))
2270 FOR Y=1 TO 3
2280 IF Y=1 THEN GCL=(O.1)*(GDC) GO TO 2210
2290 IF Y=2 THEN GCD=(U.03)*(GDC) GO TO 2210
2300 GCE=(O.6)*(GDC)
2310 NEXT Y
2320 TUC=(LC1*1)+(LC2*E)+(LC3*E)
2330 GFR=(TUC/19)
2340 IF WI=1 THEN 2250
2350 IF WX(J,29)=O THEN 2230
2370 TAF=(10**3)*WX(J,13)+W(J,13)+WX(J,13))
2570 SW=(7.5*10**3)*(GFR)
2590 QS=(12.14*10**3)*(AFR)
2600 LW=(O.0062)*(AFR/TA)
2670 EPS=(0.12737/AFR/TA)
2680 LK=(0.9/AFR)*SW/AFR
2690 ENMW=(0.00247)*(THMD)
2700 LSH=(S.CO*777)*(THMD)
2710 LEM=(l.0)*(THMD/TA)
2720 LEE=(20)*ALS/LF/TA)
2730 HUXM=(0.00269)*(LEW)
2740 HUX=(S.CC*678)*(LEU)
2750 TLW=HUXUENHM
2760 TL=HUXUENHM
2770 PSLM=(269.330)*TLW
2780 ML.SM=(269.330)*TLW
2790 IF WI=3 THEN 2560
2790 ATRC=(TLD+TWC+TCD+T GC)/(3)
2790 ADDC=(TLCW+TRC+TGC)/(3)
2800 ADCC=(TLD+TRC+TGC)/(3)
2810 AFRA=(FRM+AFR+GFR)/(3)
2830 NAACW=(AFRA)*19)
2840 NAAC=(AFRA)*19)
2850 PEW=(AAAC+ADCC)/(DOW)
2860 PES=(NAAC+ADCC)/(DOW)
2870 IF WI=12 THEN 2760
2880 ATRC=(TLW+TWC)/(2)
2890 ADRC=(TLD+TWC)/(2)
2890 ADDS=(TLDW+TWC)/(2)
2890 AFRG=(FRG+AFR)/(2)
2900 AFRG=(FRG+AFR)/(2)
2910 NACW=(AFRA)*19)
2920 NAAC=(AFRA)*19)
2930 PEW=(NAAC+ADCC)/(DOW)
2940 PES=(NAAC+ADCC)/(DOW)
2950 IF WI=3 THEN 2760
2960 ATRC=(TLW+TWC)/(2)
2970 ADRC=(TLD+TWC)/(2)
2980 ADRS=(TLDW+TWC)/(2)
2990 AFRG=(FRG+AFR)/(2)
3000 NACW=(AFRA)*19)
3010 NAAC=(AFRA)*19)
3020 PEW=(NAAC+ADCC)/(DOW)
3030 PES=(NAAC+ADCC)/(DOW)
3040 IF WI=9 THEN 2760
3050 ATRC=(TLW+TWC)/(2)
3060 ADRS=(TLDW+TWC)/(2)
3070 ADRS=(TLDW+TGC)/(2)
3070 AFRG=(FRG+AFR)/(2)
3080 NACW=(AFRA)*19)
3090 NAAC=(AFRA)*19)
3100 PEW=(NAAC+ADCC)/(DOW)
3110 PES=(NAAC+ADCC)/(DOW)
FAMILY INDEX = J

REM IF W=4 THEN 2840

LPRINT "DISTRIBUTION OF COLD WATER CONSUMED FROM STORAGE TANKS"

LPRINT "AVERAGE DAILY CONSUMPTION OF COLD WATER IN WINTER" SUM

LPRINT "CORRECTED AVERAGE DAILY CONSUMPTION OF WATER(L/DAY)"

LPRINT "AVERAGE FLOW RATE(L/HR)"

LPRINT "PERCENTAGE OF ERROR"

LPRINT "AMOUNT OF ENERGY GAINED BY TANKS(MJ/HR) IN WINTER" SUM

LPRINT "AVERAGE TANK INSTENEOUS EFFICIENCY IN WINTER" SUM

LPRINT "TANK U-FACTOR (W/M°2K)

LPRINT "ENERGY NEEDED TO HEAT WATER (GU) IN WINTER"

LPRINT "HOT WATER LOAD (W) IN WINTER" SUM

LPRINT "AUX ENERGY(GU) IN WINTER"

LPRINT "MONTHLY TOTAL LOAD (GU) IN WINTER" SUM

LPRINT "MONTHLY MONEY SPENT TO MELT THE LOAD" SUM

LPRINT "CITY PUMP SYSTEM" 

IF W=13 THEN LPRINT "PUMP SYSTEM WITH G AND R TANK" GOTO 5070

IF W=0 THEN LPRINT "ROOF PUMP SYSTEM WITH ROOF TANK ONLY" GOTO 50X
5030 IF W1=6 THEN LPRINT "HOUSE PUMP SYSTEM WITH HOUSE TANK" GO TO 5230
5040 IF W1=1 THEN LPRINT "PUMP SYSTEM WITH NO STORAGE" GO TO 5260
5050 IF W1=2 THEN LPRINT "HOME PUMP SYSTEM WITH NO STORAGE" GO TO 5260
5060 IF W1=1 THEN LPRINT "ROOF PUMP SYSTEM WITH NO STORAGE" GO TO 5260
5070 PRINT "INPUT THE NO. OF ROOF TANKS"
5080 INPUT N
5090 IF W2(J,12)=0 THEN PC1=WX(J,9)*WX(J,11) GO TO 5105
5100 PC1=WX(J,9)*WX(J,12)/7
5110 IF Z=1 THEN 5150
5120 IF W2(J,16)=0 THEN PC2=WX(J,16)*WX(J,12)/7
5130 IF Z=2 THEN 5150
5140 PC2=WX(J,17)*WX(J,16)/7
5150 INPUT PC1
5160 FOR Y=1 TO 3
5170 IF Y=1 THEN PDD1=0.1*(TFC) GO TO 5200
5180 IF Y=2 THEN PDD2=0.033*(TFC) GO TO 5200
5190 PDD3=0*(0.06)**(TFC)
5200 NEXT Y
5210 TFC=(PDD1*PDD2*PDD3*8)
5220 RFPR=T(V1D/19)
5230 IF W1=9 THEN 5250
5240 IF W2(J,20)=0 THEN PGC=(WX(J,28)*WX(J,29))/71
5250 IF Y=1 TO 3
5260 IF Y=1 THEN PDD1=0.1*(TFC) GO TO 5200
5270 IF Y=2 THEN PDD2=0.033*(TFC) GO TO 5200
5280 PDD3=0*(0.06)**(TFC)
5290 NEXT Y
5300 INPUT PDD1.PDD2.PDD3
5310 PCF=1*(TFC/19)
5320 NPT1=0.0125*WX(J,11)*WX(J,15)*WX(J,19)
5330 NPT2=0.0125*WX(J,28)*WX(J,30)*WX(J,20)
5340 NPT3=0.0125*WX(J,12)*WX(J,16)*WX(J,20)
5350 NPT4=0.0125*WX(J,13)*WX(J,17)*WX(J,20)
5360 NPT5=0.0125*WX(J,14)*WX(J,18)*WX(J,20)
5370 NPT6=0.0125*WX(J,15)*WX(J,19)*WX(J,20)
5380 LF=(1212)*((EWF-IF))
5390 CL=27.286*RFPR*(TANAES(LF))
5400 ENW=(0.02471*THWD)
5410 ENW=(0.02471*THWD)
5420 ELM=(101*TAABES(LF))
5430 ELM=(101*TAABES(LF))
5440 HAUCW=(0.00260)*(LEW)
5450 HAUCW=(0.00260)*(LEW)
5460 PDP=(0.351*.7457)*(PCF*NPT)
5470 M=(0.75+21)**(PCF)
5480 TLD=HAUXW+ENW
5490 TLE=HAUXW+ENW
5500 IF W1=9 THEN 5560
5510 RFPR=(TLD+IFP)+(TFC/19)
5520 ADCS=(TODS+TPD+TODP)/(2)
5530 AFRA=(RFPR+FRW*ADCS)/(2)
5540 AFRA=(RFPR+FRW*ADCS)/(2)
5550 NADCS=(AFRA)*(19)
5560 NADCS=(AFRA)*(19)
5570 PED=(NADCS-ADCS)/(DCWS)
5580 IF W1=10 THEN 5760
5590 ADCS=(TODS+TPOD)/(2)
5600 AULS=(TULS+TPOD)/(2)
5610 AFRA=(FRW+AFRA)/(2)
5600 NADCW = (ARFB) * (19)
5610 NADW = (ARFS) * (19)
5620 PEN = (NADW-NADGW) / (DCW)
5625 FES = (NADCS-NADCS) / (DCW)
5640 IF WI = 9 THEN 5760
5650 ACW = (TACW+TPD) / (2)
5660 NADCS = (TACW+TPD) / (2)
5670 ARFW = (FRX+PFER) / (2)
5690 ARFW = (FRX+PFER) / (2)
5700 NADCS = (APRS) * (19)
5710 FLOW = (NADGW-NADCS) / (DCW)
5720 PES = (NADCS-NADCS) / (DCW)

2735 LPRINT "FAMILY INDEX = " J
5730 LPRINT T1 P1
5740 LPRINT 274 LPRINT WI, TACW(25), T1, TAB(50), P1
5760 LPRINT "WATER CONSUMPTION AND DISTRIBUTION"
5770 LPRINT 5780 LPRINT "TOTAL CONSUMPTION (L/DAY)"
5990 LPRINT 5990 LPRINT TACW(25), TPE, TACW(25), TPF, TACW(45), PCE, TAB(55), TUD
5990 LPRINT 6990 LPRINT "DISTRIBUTION (L/HR)" 6-8-18-18-17-24
5990 LPRINT 5990 LPRINT TACW(25), TPE, TACW(25), TPF, TACW(45), PCE, TAB(55), TUD
5990 LPRINT 5990 LPRINT TAB(25), PCE, TAB(35), PCD, TAB(45), PCD
5990 LPRINT 5990 LPRINT TACW(25), TPE, TACW(25), TPF, TACW(45), PCE, TAB(55), TUD
5990 LPRINT 5990 LPRINT TAB(25), PCE, TAB(35), PCD, TAB(45), PCD
5990 LPRINT 5990 LPRINT TAB(25), TACW(25), FR, TACW(25), GYR, TACW(45), AF, TAB(55), ARFS
5990 LPRINT 5990 LPRINT "CORRECTED AVERAGE OF DAILY CONSUMPTION (L/DAY)"
5990 LPRINT 5990 LPRINT TAB(25), TACW(25), PCE, TACW(55), PCD
5990 LPRINT 5990 LPRINT "PERCENTAGE OF ERROR"
5990 LPRINT 5990 LPRINT "TANL EFFICIENCY IN WINTER"
5990 LPRINT 5990 LPRINT TAB(25), LFW, TAB(25), PCD
5990 LPRINT 5990 LPRINT "TANL LOSS FACTOR" (W/M² DEG.)
5990 LPRINT 5990 LPRINT TAB(25), LFW, TAB(25), PCD
5990 LPRINT 5990 LPRINT "TEMPERATURE RATIO (TON/TUFF)"
5990 LPRINT 5990 LPRINT TAB(25), PF
5990 LPRINT 5990 LPRINT "ENW(W)---ENWH(W)---LES(W)---LES(W)"
5990 LPRINT 5990 LPRINT "ENWH(W)---ENW(W)---LES(W)---LES(W)"
5990 LPRINT 5990 LPRINT "HAUX(W)---HAUXH(W)---TLW(W)---TLW(W)"
5990 LPRINT 5990 LPRINT "HAUX(W)---HAUXH(W)---TLW(W)---TLW(W)"
5990 LPRINT 5990 LPRINT "POWER-CONSUMED IN PUMPING PER DAY (KWH)"
5990 LPRINT 5990 LPRINT "POWER-CONSUMED IN PUMPING PER DAY (KWH)"
6005 LPRINT
6006 LPRINT "MONTHLY MONEY SPENT TO MEET THE LOAD (RAIL)" ---
6007 LPRINT
5063 LPRINT TAB(60), M
6010 RETURN
5020 LPRINT "DEVELOPE THE OTHER SYSTEM"
7000 RETURN
SOLAR RADIATION MODEL PROGRAM
DIM A(34,19)
10 INPUT "NAME OF DATA FILE";#1
20 OPEN #1 FOR OUTPUT AS FILE #1
30 IF #1$="MNM" GO TO 180
40 INPUT "INPUT DATE";X
50 IF X$="MON" THEN GO TO 30
60 PRINT X$,
70 INPUT "ENTER THE DATA OF THE 4TH HOUR";Z
80 IF Z$="00" THEN GO TO 90
90 PRINT "MAKE SURE"
100 INPUT "ENTER DATA OF THE 6TH HOUR AGAIN";Z$2
110 IF Z$2$>0 THEN 100
120 PRINT X$;Z$1;
130 IF X$="TUE" THEN 105
140 PRINT X$;Z$1;
150 GO TO 105
160 PRINT X$;Z$1;
170 FOR Y=1 TO 19
180 LET Z$=Z$1
190 PRINT "ENTER DATA FOR HOUR";Y
200 INPUT Z$2
210 IF Z$2$=0 THEN A(X,Y)=1
220 IF Z$2$>0 THEN Z$2=ABS(Z$2)
230 IF Z$2$>150 THEN Z$2=150
240 IF Z$2$=0 THEN 120
250 IF Z$2$=Z$ THEN A(X,Y)=Z$-Z$2
260 PRINT A(X,Y),
270 NEXT Y
280 PRINT X$
290 FOR Y=1 TO 19
300 PRINT A(X,Y)
310 NEXT Y
320 END
900 DIM ALT(34,19)
901 PRINT "STATION- " TYPE OF RADIATION- "
902 PRINT "LAT---LON- " M00---TR---"
910 PRINT "--------------
920 PRINT "DAY---- A----- 7----- 6----- 9----- 10----- 12----- 13----- 14----- 15-----"
930 PRINT "--------------
945 DT=0
955 INPUT "ENTER FILE DATA NAME"; N$
956 IF N$="NON" GO TO 1131
960 DT=DT+1
1000 OPEN N$ FOR INPUT AS FILE 11
1010 INPUT N1, X
1011 PRINT X;
1090 FOR Y=A TO 19
1092 INPUT 111, AI(X, Y)
1100 REM PRINT AI(X, Y);
1110 NEXT Y
1115 PRINT
1120 CLOSE 11
1130 GOTO 955
1132 FOR X=1 TO DT
1133 FOR Y=6 TO 19
1134 PRINT TAB(6)+AI(X, Y); AI(Y-6,101)
1135 NEXT Y
1136 NEXT X
1210 PRINT "-------------------------------------------------
1212 PRINT "TOTAL",;;
1215 C=0
1216 FOR X=1 TO DT
1217 FOR Y=6 TO 19
1218 PRINT TAB(Y-6); AI(X, Y); AI(Y-6)+AI(34, Y)
1219 NEXT Y
1220 NEXT X
1290 LET AI(34, Y)=C/D
1291 REM =TOTAL/A
1292 IF L<3 GO TO 2150
1293 IF L>2 GO TO 2100
1295 PRINT TAB(6)+AI(Y-6,101); TOTAL;
1296 GO TO 2200
1300 PRINT TAB(6)+AI(Y-6,101); C;
1301 GO TO 2200
1350 PRINT TAB(6)+AI(Y-6,101); AI(34, Y);
1360 NEXT Y
1201 IF L=2 GO TO 2400
1202 IF L=3 THEN 2450
1203 L=2
1210 PRINT
1215 PRINT "COUNT";
1220 GO TO 2915
1230 L=3
1240 PRINT
1245 PRINT "MEAN";
1250 GO TO 2915
1255 PRINT "TMEAN"; TMEAN
1260 END
10 G1=H(4),B(7),D(365)
20 FOR S=1 TO 4
30 R=H(S)
40 Dw1n 0.386470,-0.792624,0.377853,0.030124
50 NEXT S
60 FOR H=1 TO 7
70 R=H(B(H))
80 Dw1n 1.1049,-1.4354,-1.0720,6.6849,-13.8990,13.0796,-4.4631
90 NEXT H
100 FOR Y=1 TO 365
110 T=(3.142/180)*(360/365)*Y
120 T1=-1*3.142/180
130 W=.845+.0115*SINT(T)
140 S=1
150 D=r+tS. +M( +1J*(COS(T)-29.345*SINT(T)+2*3*COS(2*T)+.346*T*SINT(2*T))
160 D(Y)=C(Y)+G1
170 PRINT I, D(Y)
180 DEC=3.142/180*(DT)
190 C0.S=D=COS(DEC) ; SIND=SIN(DEC)
200 FOR K=1 TO 14
210 K+=112.5-tk+5! ý*15*3.142/180,
220 SIIIH=SINH+I: COSH-COSH(I)
230 X=COSL*COSH*COSL+SINL*=I1I1L
240 S. L=.13.0796*10)-4.4631*(Z^12)
250 PRINT "S. +L="; Sº+L*k180/3.142)
260 Z=(1-2*3.142)*S+L
270 IF S., L=0 THEN GR=O: GOTO 260
280 IF S., L=0 THEN DSR=0: GOTO 260
290 G[G1=W*1.14354*(Z^2)-1.072*(Z^4)+6.6849*(Z^6)-13.899*(Z^8))
300 GR=GR1+Gk2: GR=Gk*1000
310 DSR=DTSR+GSR*1000
320 GSR=DTSR+GSR*1000
330 PRINT "DTGR(WHk/M*11 DA: )i"IGTGR; "DTGR(MJ, M*M DAi)_"; GTGR*i3.6.1000)
340 PRINT "DTDSR(Whr/SQ. M DAY) "IDTDSR; "DTDSR(MJ/SQ. M. Dr4 )="; DTDSR
350 PRINT"DTDFR(WHR/SQ. M DA0="; DT0FR; "DTDFR(MJ/SQ. M. Dr4 )="; GTDFR
360 V=(15-12.5)/7.5
370 C1=26.789453-.760391*V-.265076*(V^2)-.007734*(V^3)
380 C2=.092481-.0500124*V+.004731*(V^2)-.00619*(V^3)
390 C3=.018456-.025926*V-.013157*(V^2)+.015157*(V^3)
400 C4=.112969+.075469*V+.007031*(V^2)-.037969*(V^3)
410 C5=.06616+.017846*V+.005554*(V^2)-.037515*(V^3)
420 C6=.012969+.075469*V+.007031*(V^2)-.037969*(V^3)
430 C7=0.06616+.017846*V+.005554*(V^2)-.037515*(V^3)
440 H=C1*COS(T)+C3*COS(2*T)+C4*COS(3*T)+C5*SINT(T)+C6*SINT(2*T)+C7*SINT(T)
450 PRINT Y, H
460 NEXT Y
HEAT LOSS MODEL PROGRAM
```plaintext
10 DIM UW(8), FW(8), DH(8), ABH(8), LH01(8), LH02(8), CLB1(8), CLB2(8), ETA(8)
15 DIM UR(9), FR(9), DR(9), ABR(9), UK(9)
20 DIM H(12), SE(12), SN1(12), SS(12), SNE(12), SSE(12), TA(12), TH(12), SF(12), TV(12)
25 DIM G(8, 9)
30 DIM DO(12), QC(12), OL(12), TT(12), QA(12), QAH(12)
40 DIM FS(12), GM(12), EEM(12), THN(12), TI(12), QU(12), QAQ(12), EFF(12)
50 DIM QST(12), TS(12), QTH(12), QAQ(12)
200 PRINT "ENTER CITY CODE: TYPE 0 FOR YEMEN; 1 FOR UK; 3 FOR GREECE"
210 INPUT CC
220 PRINT "ENTER RUN INDEX ACCORDING TO THE FOLLOWING TABLE"
230 PRINT "RUN INDEX OPTIONS"
235 PRINT " 1 MASSIVE WALLS+HORZ. ROOF" " "
240 PRINT " 2 BUFFER+GARAGE+CASE I"
245 PRINT " 3 BUFFER+SUNSPACE+CASE I" " "
250 PRINT " 4 TWO BUFFERS(GARAGE+SUNSPACE)+CASE I"
260 PRINT " 5 SUNSPACE COUPLED WITH AIRCOND.+CASE I"
265 PRINT " 6 OPEN LOOP SOLAR WALL+CASE I"
270 PRINT " 7 TROMBE WALL+CASE I"
275 PRINT " 8 OPEN LOOP SOLAR COLL.INST.ON ROOF+CASE I"
280 PRINT "ENTER RUN INDEX": INPUT RI
530 FOR H=1 To 8
540 READ UW(H), FW(H), DH(H), ABH(H), LH01(H), LH02(H), CLB1(H), CLB2(H)
550 DATA 1.47, 0.05, 0.52, 0.4, 12.5, 18.7, 0.94, 0.89
560 DATA 1.29, 0.07, 0.41, 0.6, 11.0, 17.3, 0.94, 0.90
570 DATA 3.36, 0.06, 0.45, 0.65, 26.3, 32.5, 0.87, 0.81
580 DATA 0.72, 0.04, 0.62, 0.64, 6.30, 12.5, 0.97, 0.92
590 DATA 5.34, 0.45, 0.17, 0.65, 38.7, 44.5, 0.71, 0.74
600 DATA 2.89, 0.26, 0.22, 0.64, 23.1, 29.3, 0.88, 0.83
610 DATA 2.93, 0.14, 0.32, 0.4, 23.2, 29.6, 0.86, 0.83
620 DATA 5.19, 0.17, 0.29, 0.4, 37.9, 43.7, 0.81, 0.75
630 NEXT H
650 FOR M=1 To 9
655 READ ETA(H)
660 DATA 0.085, 0.07, 0.105, 0.045, 0.105, 0.105, 0.105
670 NEXT M
680 NEXT H
690 FOR M=1 To 9
700 READ ET(M)
710 DATA 0.1, 0.06
720 NEXT M
730 NEXT H
740 FOR J=1 To 12
750 READ H(J), SE(J), SN(J), SS(J), SNE(J), SSE(J), TA(J), N(J)
760 DATA 5.52, 2.10, 0.18, 4.26, 0.36, 3.24, 15.90, 31
770 DATA 6.24, 2.40, 0.24, 3.36, 0.72, 2.88, 18.20, 28
780 DATA 7.10, 2.64, 0.24, 1.92, 1.20, 2.40, 18.20, 31
790 DATA 7.20, 2.76, 0.60, 0.36, 1.92, 1.80, 20.30, 30
800 DATA 7.80, 2.60, 0.60, 0.36, 1.52, 1.80, 20.30, 30
810 DATA 8.00, 2.88, 1.80, 0.24, 2.40, 1.32, 22.00, 31
820 DATA 7.80, 2.76, 2.40, 0.24, 2.64, 1.08, 22.80, 30
830 DATA 7.80, 2.88, 1.80, 0.24, 2.40, 1.32, 22.30, 31
840 DATA 7.80, 2.76, 2.40, 0.24, 2.64, 1.08, 22.80, 30
850 DATA 7.80, 2.88, 1.80, 0.24, 2.40, 1.32, 22.30, 31
860 DATA 7.80, 2.76, 2.40, 0.24, 2.64, 1.08, 22.80, 30
870 DATA 6.24, 2.40, 0.24, 3.36, 0.72, 2.88, 17.80, 31
880 DATA 5.52, 2.10, 0.18, 4.26, 0.36, 3.24, 16.10, 30
890 DATA 5.16, 1.98, 0.18, 4.50, 0.24, 3.24, 14.30, 31
920 NEXT J
```
925 FOR J=1 TO 12
926 READ SF(J),TF(J)
927 DATA 0.555,1.26,0.396,1.097,0.416,0.974,0.437,0.839,0.452,0.766,0.458
928 DATA 0.452,0.763,0.437,0.837,0.416,0.982,0.395,1.11,0.555,1.27,0.549,1
929 NEXT J
1370 IF RI=1 THEN GOSUB 5000
1380 IF RI=2 THEN GOSUB 5500
1390 IF RI=3 THEN GOSUB 6000
1400 IF RI=4 THEN GOSUB 6500
1405 IF RI=5 THEN GOSUB 7000
1410 IF RI=6 THEN GOSUB 7500
1415 IF RI=7 THEN GOSUB 8000
1420 IF RI=8 THEN GOSUB 9000
1422 IF WC=2 THEN GOSUB 1444
1443 PRINT"ENTER WALL, ROOF CONSTRUCTION NUMBER": INPUT H,M
1444 FOR J=1 TO 12
1445 IF J=3 THEN TT=18: GOTO 1448
1446 IF J=10 THEN TT=18: GOTO 1448
1447 TT=22
1448 DD(J)=TT*(1-J)*N(J); DC(J)=DC(J)-TT)*N(J)
1449 IF DC(J)<0 THEN DD(J)=0
1450 IF DD(J)<0 THEN DC(J)=0
1451 QH(J)=0.24*(H(M)+N(J))*Q(J)
1452 QC(J)=0.24*(H(M)+N(J))*Q(J)
1453 QL(J)=QC(J)+Q(J)
1454 TT(J)=TT: NEXT J
1455 PRINT"MONTH INSIDE TEMP": ENERGY IN (KWH)
1456 PRINT"WITHOUT WITH LOAD AXIAL"
1457 PRINT
1460 IQ=.13*F
1470 FOR J=1 TO 12
1480 QQG+QGE+QH)*SE(J)+AGN+QH(J)+AGS*SS(J); QTH(J)=QG+SF(J)
1481 IF H<2 THEN U=U+1: GOTO 1498
1487 U=U+(H)
1488 IF WC=2 THEN AB=.6: GOTO 1490
1489 ABR=A(H)
1490 IF WC=2 THEN FH=.45: GOTO 1495
1491 FH=F(H)
1495 QH+QH*QF*F+22*((QHE+AHE)*SE(J)+AGSN(J)+AGSNSS(J))
1500 QH=QH
1501 IF HC=2 THEN AB=.6: GOTO 1525
1502 IF TR=2 THEN AB=.3: GOTO 1525
1502 ABR=ABR(H)
1525 IF WC=2 THEN UR=UR+1: GOTO 1550
1530 IF TR=3 THEN UR=UR+1: GOTO 1550
1540 ER=UR(M)
1550 IF WC=2 THEN FR=.5: GOTO 1555
1551 FR=FR(H)
1555 QH=UR+FR*ABR+22*AF*H(J); QABR(J)=QABR
1570 QQH+QH(J)+1+QH(J)+QABR(J)
1580 IF RI=1 THEN EEN=QHH: GOTO 1600
1590 IF RI=2 THEN EEN=QHH: GOTO 1600
1600 IF RI=3 THEN EEN=QHH+QST(J); GOTO 1600
1620 IF RI=4 THEN EEN=QHH+QST(J); GOTO 1600
1640 IF RI=5 THEN EEN=QHH+QST(J); GOTO 1600
1660 IF RI=6 THEN EEN=QHH+QST(J); GOTO 1600
1670 IF RI=7 THEN EEN=QHH+QST(J)
1675 IF RI=8 THEN EEN=QH(J)+1+QH(J)+(QABR(J)-AC*(H(J))*TF(J)+QAC(J)
1680 EEN(J)=QHH
1690 TNE(J)=TNE(J)+EEN(J)/(.024*V*G(H,M))
1691 X=TT+TNE(J)
1692 IF H>4 THEN GOSUB 10000
1693 IF H>4 THEN GOSUB 10500
1695 QU(J) = (EFF/100) * EEN(J) * N(J)
1696 IF QL(J) = 0 THEN QAX(J) = 0: GOTO 1700
1698 QAX(J) = QL(J) - QU(J)
1700 IF QL(J) = 0 THEN T(J) = T(NH(J)): GOTO 1710
1705 T(J) = T(J) + EEN(J) / (.024 * G(H, M) * T(J)) + (QAX(J) / QL(J)) * (T(T(J)) - T(J))
1710 EFF(J) = EFF
1715 PRINT J; TAB(5); INT(T(J)); TAB(15); INT(Q(L)); TAB(30); INT(EEN(J)); TAB(60); INT(QL(J)); TAB(70)
1720 NEXT J
1725 PRINT "WOULD LIKE A PRINT OUT: TYPE 1 FOR YES, 0 FOR NO": INPUT PI
1726 IF PI = 0 THEN 2610
1730 IF PI = 1 THEN 2610
1735 PRINT "TYPE OF ROOF"
1740 PRINT RI; THB; TR
1745 PRINT "DESIGN CHARACTERISTICS OF THE CONSIDERED CASE"
1750 PRINT "SOLID WALL AREA GLAZED AREA ROOF AREA"
1755 PRINT "EAST WEST NORTH SOUTH EAST WEST NORTH SOUTH"
1760 PRINT "HEATING/COOLING LOADS OF THE HOUSE"
1770 PRINT "WALL ROOF MONTH DEGREE-DAYS AMBIENT LOAD IN (KWH)"
1775 PRINT "TYPE TYPE HEATING COOL AIR TEMP. HEATING COOLING TOTAL"
1780 PRINT "-------------------------------------------------------------"
1790 FOR J = 1 TO 12
1800 PRINT T(J); DD(J); T(J); DD(J); DD(J); T(J)
1810 QH(J); T(J); QCT(J); Q(J); Q(J); Q(J); Q(J); Q(J); Q(J); Q(J)
1820 QLT; QLT; T(J)
1830 NEXT J
1840 PRINT "EFFECT OF WALL-ROOF COUPLING ON HEAT GAINS"
1850 PRINT "WALL ROOF MONTH ENERGY GAINS IN (KWH/DAY)"
1860 PRINT "TYPE TYPE TRANSMITTED ABSORBED"
1870 PRINT "VIA HINGENS WALL ROOF"
1880 PRINT "-------------------------------------------------------------"
1890 FOR J = 1 TO 12
1900 PRINT T(J); EEH(J); T(J); EEH(J); EEH(J); T(J)
1910 NEXT J
1920 PRINT "EFFECT OF WALL-ROOF COUPLING ON THE USEFUL ENERGY GAINS"
1930 PRINT "WALL ROOF MONTH ENERGY USEFUL GAIN"
1940 PRINT "TYPE TYPE ENTERED GAIN"
1950 PRINT "TO THE HOUSE"
1960 PRINT "-------------------------------------------------------------"
1970 FOR J = 1 TO 12
1980 PRINT T(J); EEH(J); T(J); EEH(J); EEH(J); T(J)
1990 NEXT J
2000 PRINT "EFFECT OF WALL-ROOF COUPLING ON THE USEFUL ENERGY GAINS"
2010 PRINT "WALL ROOF MONTH ENERGY USEFUL GAIN"
2020 PRINT "TYPE TYPE ENTERED GAIN"
2030 PRINT "TO THE HOUSE"
2040 PRINT "-------------------------------------------------------------"
2050 FOR J = 1 TO 12
2060 PRINT T(J); EEH(J); T(J); EEH(J); EEH(J); T(J)
2070 NEXT J
2080 PRINT "EFFECT OF WALL-ROOF COUPLING ON THE USEFUL ENERGY GAINS"
2090 PRINT "WALL ROOF MONTH ENERGY USEFUL GAIN"
2100 PRINT "TYPE TYPE ENTERED GAIN"
2110 PRINT "TO THE HOUSE"
2120 PRINT "-------------------------------------------------------------"
2130 FOR J = 1 TO 12
2140 PRINT T(J); EEH(J); T(J); EEH(J); EEH(J); T(J)
2150 NEXT J
2160 QAX(J) = ABS(QAX(J))
2230 LPRINT
2240 NEXT J
2250 LPRINT"-------------"
2255 LPRINT TAB(30);TQU;TAB(45);TAX
2290 LPRINT"-------------"
2300 LPRINT"TABLE 4: EFFECT OF WALL-ROOF COUPLING ON THE EFFICIENT INSIDE TEMP. (C)
2310 LPRINT"WALL ROOF MONTH EFFICIENCY INSIDE HOUSE TEMP. (C)
2320 LPRINT"--------------" WITH AX WITHOUT AX
2325 LPRINT"--------------"
2330 LPRINT	
2340 LPRINT H;
2360 LPRINT TAB(5);M;
2370 FOR J=1 TO 12
2380 LPRINT TAB(15);EFF(J);TAB(25);TA(J);TAB(35);TNH(J);TAB(45);
2390 IF OL(J)=0 THEN DELT=EH(J)+0.24*G(H,M)*V:GOTO 2420
2410 DELT=EH(J)+0.24*G(H,M)*V+(QAX(J)/G(L,V))*(TT(J)-TA(J))
2420 LPRINT T(J);TAB(55);TT(J);T(J);TAB(65);TA(J);TAB(35);TI(J);T(J)
2430 LPRINT H;
2450 FOR J=1 TO 12
2455 LPRINT TAB(20);EFF(J);TAB(40);TNH(J);TAB(50);T(J);TAB(60);DELTT
2475 G(J)=0:GGH(J)=0:QT=0:QCH(J)=0:QCT=0:QLT=0:TEEH(J)=0:Q(J)=0:QU(J)=0:TNHT(J)=0:TNHT(J)=0
2480 Q(J)=0:REAM(J)=0:EFF(J)=0:TI(J)=0
2490 NEXT J
2500 IF H=1 THEN 2655
2510 IF M=1 THEN 2655
2520 FOR H=1 TO 8
2530 IF P1=0 THEN 2650
2540 FOR M=1 TO 9
2550 Q(H,M)=0
2560 NEXT M
2570 NEXT H
2580 GOTO 2690
2585 LPRINT H;
2590 FOR M=1 TO 9
2595 IF P1=0 THEN 2650
2600 LPRINT TAB(10);1/UR(H);TAB(30);1/UR(M);TAB(45);G(H,M);
2610 LPRINT M;
2620 H;
2630 NEXT M
2640 NEXT H
2650 LPRINT H;
2655 PRINT"WOULD YOU LIKE TO CHANGE WALL/ROOF CONST. MATT?"
2660 PRINT"ENTER 1 IF YES, 0 IF NO":INPUT RR
2670 IF RR=1 THEN 1442
2680 PRINT"WOULD YOU LIKE NAH OTHER OPTION: TYPE 1 FOR YES, 0 FOR NO"
2690 INPUT RR1
2700 IF RR1=1 THEN 2691
2710 END
2711 FOR H=1 TO 8
2720 FOR M=1 TO 9
2730 G(H,M)=0
2740 NEXT M
2750 NEXT H
2760 PRINT"---OPTIONS---"
2770 PRINT" 1 HOUSE"
2780 PRINT" 2 HOUSE+GARAGE"
2790 PRINT" 3 HOUSE+SUNSPACE"
2800 PRINT" 4 HOUSE+GARAGE+SUNSPACE"
2810 PRINT" 5 HOUSE+SUNSPACE COUPLED WITH AIR EXCHANGER"
2820 PRINT" 6 OPEN LOOP SOLAR WALL INST. ON THE SOUTH+HOUSE"
2830 PRINT" 7 TROMBE WALL"
2840 PRINT" 8 OPEN LOOP SOLAR COLLECTOR INST ON ROOF+HOUSE"
2850 PRINT"----------------------"
2860 INPUT RR1:GOTO 1370
2920 AGE=1.2:AHG=1.92:AGN=0:AGS=3.12
2925 PRINT"ENTER TYPE OF ROOF: 1 ORDINARY, 2 WITH WHITE TILE, 3 WITH AIR SPA,
5030 PRINT "ENTER WALL/ROOF CODE: 1 FOR YEMENI WALLS/ROOFS, 2 INTERNATIONAL".
5035 IF WC=1 THEN 5045
5036 PRINT "ENTER WALL, UROOF, AND UWINDOW": INPUT UW1, UR1, UWIN
5037 G1=GW1*UW1+AF*UR1+AG*UWIN+3.33*AG+2.1*LF+.34*V
5038 IF R=8 THEN G1=G1-.34*EFFC*Q
5039 G1=G1/V
5040 0010 5140
5045 FOR H=1 TO 8
5050 FOR M=1 TO 9
5055 IF TR=3 THEN UR=UR(H): GOTO 5585
5060 UR=UR(M)
5065 X1=30*H
5070 G=G+AF*UR+AG*3.33*AD+2.1*LF+.34*(V-X1)+AD*30+LHD1(H)
5075 G=G/V: G(H, M)=G
5078 NEXT M
5079 NEXT H: GOTO 5595
5080 G1=UW1*GW+UR1*AF+UWIN*AG+2.1*LF+.34*(V-CLB1(H)+LHD1(H)
5081 RETURN
5090 INPUT "ENTER TYPE OF ROOF: 1 ORDINARY, 2 WITH WHITE PAINT, 3 AIR SPACE": TR
5095 PRINT "ENTER 1 FOR EAST/WEST DIRECTIONS, 2 FOR NORTH, 3 FOR SOUTH"
5100 IF HC=2 THEN PRINT "ENTER WALL, UROOF, UWIN": INPUT UW1, UR1, UWIN: GOTO 5560
5105 FOR M=1 TO 9
5110 IF TR=3 THEN UR=UR(M): GOTO 5585
5115 UR=UR(M)
5120 X1=30*H
5125 G=G+AF*UR+AG*3.33*AD+2.1*LF+.34*(V-X1)+AD*30+LHD1(H)
5129 G=G/V: G(H, M)=G
5130 NEXT M
5131 NEXT H: GOTO 5595
5132 PRINT "ENTER NUMBER OF COLLECTING SURFACES": INPUT NCS
5135 PRINT "ENTER AREA OF THE COLLECTING SURFACES IN THE FOLLOWING ORDER"
6057 PRINT "ENTER AREA OF THE COLLECTING SURFACE BETWEEN SUNSPACE AND HEATED SPACE";
6058 INPUT AGS1, AGSW, AGS, AGS14, AGS15
6059 INPUT AGS2
6060 IF WC=1 THEN 6100
6065 PRINT "ENTER UWALL, UROOF, UWIND": 11NPUT UW1, URI, UWIN
6070 IF WC-1 THEN X1=.34*V*(1-.4*(90/V)-.4*(1-CLB2(H))*(90/V)): GOTO 6080
6075 Al=.34*V*(1-(90/V)*11-CLB1(H))
6080 G1=UW1*44+URI*AF+UWIN*AG+3.33*AD+2.1*LF+X1
6090 G1=G1/V: GOTO 6200
6100 FOR H=1 TO 8
6120 FOR M=1 TO 9
6130 IF TR=3 THEN UR=URA(M): GOTO 6150
6140 UR=UR(M)
6150 X1=.34*V*(1-(90/V)*11-CLB1(H))*(90/V)): GOTO 6170
6160 X1=.34*V*(1-(90/V)*11-CLB1(H))
6170 G=UW1*44+URI*AF+UWIN*AG+3.33*AD+2.1*LF+X1
6180 G=G1/(V*M)=G
6195 NEXT M
6136 NEXT H
6285 IF WC=1 THEN 7010
6290 RETURN
6500 4=7.0: AG=4.8: AD=2.1: LF=7.6: V=167.503: AF=48
6510 4=21.4: AG=20.7: V=15.3
6520 AGE=1.21: AG=1.92: AGS=1.68
6525 4=7.6: AGS=4.8: AGSS
6550 PRINT "ENTER NO. OF COLLECTING SURFACES": INPUT NCS
6551 PRINT "ENTER AREA OF THE COLLECTING SUR. IN EAST, WEST, NORTH, AND SOUTH"
6552 INPUT AGS1, AGS2, AGS3, AGS4
6553 PRINT "ENTER DIRECTION OF THE WINDOW BETWEEN SUNSPACE AND HEATED SPACE"
6554 PRINT "ENTER TYPE OF WINDOW: 1 ORDINARY, 2 WITH WP, 3 WITH HS": INPUT TR
6555 PRINT "ENTER TYPE OF COLLECTING SURFACE: 1 NONTRANS, 2 TRANS": INPUT TB
6556 PRINT "ENTER DIRECTION OF WINDOW BETWEEN S.S. AND H.S.:": INPUT DR
6557 PRINT "ENTER ROOF CODE: 1 'YEMENI, 2 INTERNATIONAL": INPUT WC
6580 IF WC=1 THEN 6640
6590 X1=.34*V*(1-(30/V)*(1-CLB1(H))-(90/V)*1-CLB2(H))
6600 PRINT "ENTER UWALL, UROOF, UWIND": INPUT UW1, URI, UWIN
6610 G1=UW1*44+URI*AF+UWIN*AG+3.33*AD+2.1*LF+LHD1(H)+LHD2(H)+X1
6620 G=G1/V
6630 GOTO 6600
6640 FOR H=1 TO 8
6660 FOR M=1 TO 9
6670 IF TR=3 THEN UR=URA(M): GOTO 6685
6680 UR=UR(M)
6685 X1=.34*V*(1-(30/V)*(1-CLB1(H))-(90/V)*1-CLB2(H))
6690 G=UW1*44+URI*AF+UWIN*AG+3.33*AD+2.1*LF+LHD1(H)+LHD2(H)
6700 G=G1/(V*M)=G
6730 NEXT M
6740 NEXT H
6820 RETURN
7000 IF RI=5 THEN 6000
7010 RETURN
7510 4=20.7: AG=20.22: AF=24.35
7520 AGE=1.21: AG=1.92: AGS=1.92
7525 IF RI=7 THEN 7540
7530 PRINT "ENTER AREA OF O.L.S.W.:": INPUT AGS1, AGS10: AGS10=AGS
7535 AGS1=7.6: AGS1=AGS
7540 PRINT "ENTER TYPE OF ROOF, 1 ORDINARY, 2 WHITE P., 3 A.S": INPUT TR
7545 PRINT "ENTER WALL/ROOF CODE, 1 FOR YEMENI, 1 FOR INTERNATIONAL": INPUT WC
7550 IF WC=1 THEN 7600
7555 PRINT "ENTER UA, UR, UWIND": INPUT UW1, URI, UWIN
7560 G=UW1*44+URI*AF+UWIN*AG+3.33*AD+2.1*LF+3.4*V*(1-QSH/V)+ETA(S)
7565 G=G1/V
755/5 LPRINT V;TAB(30);AF;TAB(40);G1
7560 LPRINT~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
7590 GOTO 7665
7600 FOR H=1 TO 8
7615 FOR M=1 TO 9
7620 IF TR=3 THEN UR=UR(A):GOTO 7630
7625 UR=UR(M)
7630 G=UW(H)*., J+UR*AF+4.3*AG+3.3*AD+2.1*LF+. 34*V*(1-(QSW/V)*ETA(H))
7640 G(H,M)=G/V
7655 NEXT M
7660 NEXT H
7665 IF RI-7 THEN 8225
7666 PRINT"SPECIFY THE CONST.MATERIAL OF THE OPEN LOOP SOLAR WALL(1 TO 8)"
7667 INPUT H
7670 AB=ABW(H)
7680 FOR J=1 TO 12
7690 F=AS44*A6W*.8*SS(J)
7695 IF WC=1 THEN 7710
7700 ETw=ETr,: 8)sX1=(1+. 11*UW1)/: UW1*ASW;: GOTO 7750
7710 ETA=ET,; (H): X1=(1+. 11*U4IH))/(UWkH)*ASW)
7750 Co+SW=. 34*Gý-1J*ETN*F*. 9*Ai
7760 IF WC=2 THEN UW=UWI: GOTO 7780
7770 LIW=I Hi
7780 CB4 SW=F*UW*. 22*. 9
7790 GT(Ji=G: +ýýý+0N5N: PRINT"GT="; GT(J)
7795 NEXT J
7800 RETURN
8000 PRINT"ENTER AREA OF TRMEE WALL":INPUT ATW
8010 PRINT"SPECIFY THE EMISSIVITY OF THE ABSORBER(0.1 OR 0.9)":INPUT EM
8020 PRINT"SPECIFY THE NATURE OF GLAZING:1 SINGLE, 2 DOUBLE":INPUT NG
8030 PRINT"IS THERE AN INSULATING SHUTTER AT NIGHT(1 YES, 0 NO)":INPUT NI
8040 IF NG=1 THEN 8100
8050 IF EM=. 5 THEN 8070
8060 IF NI=1 THEN C=. 8499999:GOTO 8220
8065 C=. 66: GGTO 8220
8070 IF NI=1 THEN C=. 761GOTO 8220
8080 C=. 661GOTO 8220
8090 IF EM=9 THEN 8070
8100 IF NI=1 THEN C=. 8499999:GOTO 8220
8110 IF NI=1 THEN C=. 761GOTO 8220
8120 C=. 66: GGTO 8220
8125 FOR J=1 TO 12
8130 F1=r+TW*. b*EP1*SF(J)*SS(J)
8140 FTW(J)=F1*C
8150 PRINT"QTW"; QTWiJ)
8160 NEXT J
8165 RETURN
9000 PRINT"ENTER AREA OF OPEN LOOP SOLAR COLL.":INPUT AC
9010 PRINT"ENTER TYPE OF ROOF: TYPE 1 FOR ORD, 2 WHITE P., 3 AIR SPACE"
9020 PRINT"ENTER WALL/ROOF CODE:TYPE 1 FOR YEMEN,2 FOR INTERNATIONAL"
9040 PRINT"ENTER FLOW RATE":INPUT Q
9045 Z=q/AC
9050 IF INT(Z)=20 THEN EFFC=. 32:GOTO 9200
9060 IF INT(Z)=30 THEN EFFC=. 36:GOTO 9200
9070 IF INT(Z)=40 THEN EFFC=. 41:GOTO 9200
9080 IF INT(Z)=50 THEN EFFC=. 44:GOTO 9200
9090 IF INT(Z)=60 THEN EFFC=. 47:GOTO 9200
9100 IF INT(Z)=70 THEN EFFC=. 49:GOTO 9200
9110 IF INT(Z)=80 THEN EFFC=. 51:GOTO 9200
9200 PRINT"Z, EFFC":Z,EFFC
9205 GOTO 5000
9210 FOR J=1 TO 12
PRINT "IS THERE MASS WALL WITHIN THE SUNSPACE; TYPE 1 FOR YES, 0 IF NO""
PRINT "IS THERE AN OPAQUE ROOF; TYPE 1 FOR YES, 0 FOR NO"" INPUT R1
PRINT "IS THE SUNSPACE USED TO PREHEAT THE AIR; TYPE 1 FOR YES, 0 NO"
PRINT "IS THE SUNSPACE COUPLED WITH HEAT EXCHANGER; TYPE 1 FOR YES, 0 NO"
PRINT "FOR J = 1 TO 12: IF NCS = 4 THEN A1 = .7""
PRINT "IF NCS = 4 THEN A2 = .89""
PRINT "IF NCS = 3 THEN A1 = .67""
PRINT "IF NCS = 3 THEN A2 = .8499999""
PRINT "IF NCS = 2 THEN A1 = .87""
PRINT "IF NCS = 2 THEN A2 = .87""
PRINT "IF NCS = 1 THEN A1 = .4199999""
PRINT "IF NCS = 1 THEN A2 = .9199999""
PRINT "PRINT "IS THE SUNSPACE USED TO PREHEAT THE AIR; TYPE 1 FOR YES, 0 NO""
PRINT "IS THE SUNSPACE COUPLED WITH HEAT EXCHANGER; TYPE 1 FOR YES, 0 NO"
PRINT "FOR J = 1 TO 12: IF NCS = 4 THEN A1 = .7""
PRINT "IF NCS = 4 THEN A2 = .89""
PRINT "IF NCS = 3 THEN A1 = .67""
PRINT "IF NCS = 3 THEN A2 = .8499999""
PRINT "IF NCS = 2 THEN A1 = .87""
PRINT "IF NCS = 2 THEN A2 = .87""
PRINT "IF NCS = 1 THEN A1 = .4199999""
PRINT "IF NCS = 1 THEN A2 = .9199999""
10530 IF INT(X) = -4 THEN EFF = 4
10540 IF INT(X) = -3 THEN EFF = 48
10550 IF INT(X) = -2 THEN EFF = 55
10560 IF INT(X) = -1 THEN EFF = 62
10570 IF INT(X) = 0 THEN EFF = 67
10580 IF INT(X) = 1 THEN EFF = 75
10590 IF INT(X) = 2 THEN EFF = 78
10600 IF INT(X) = 3 THEN EFF = 84
10610 IF INT(X) = 4 THEN EFF = 88
10620 IF INT(X) = 5 THEN EFF = 92
10630 IF INT(X) = 6 THEN EFF = 94
10640 IF INT(X) = 7 THEN EFF = 96
10650 IF INT(X) = 8 THEN EFF = 99
10660 RETURN
I0 DIM UW(8), FW(8), ABH(8), LD1(8), LD2(8), CLB1(8), CLB2(8), ETA(8)
15 DIM UR(9), FR(9), DR(9), ABR(9), URH(9)
20 DIM HI(12), SE(12), SN(12), SS(12), SHE(12), SSE(12), TA(12), N(12), SF(12)
25 DIM G(9,9)
30 DIM HI(12), H1(12), H2(12), SS(12), SE(12), T(12), N(12)
35 DIM DD(12), DD1(12), QH(12), QC(12), QL(12), TT(12), QTH(12), Gr+BW(12)
40 DIM FS(12), Qº, R(12), EEH(12), TNH(12), TI(12), OU(12), 0: (12), EFF(12)
45 DIM CST(12), TS(12), QT(12), QTW(12), QAC(12)

200 PRINT "ENTER CITY CODE: TYPE 0 FOR YEMEN; 1 FOR U.K.; 3 FOR GREECE";
210 INPUT CC
220 PRINT "ENTER RUN INDEX ACCORDING TO THE FOLLOWING TABLE"
230 PRINT "INDEX OPTIONS"
235 PRINT " 1 MASSIVE WALLS+ROOF";
240 PRINT " 2 BUFFER+RIDGE+CASE 1";
245 PRINT " 3 BUFFER+SUNSPACE+CASE 1";
250 PRINT " 4 TWO BUFFERS(GARAGE+SUNSPACE)+CASE 1"
260 PRINT " 5 SUNSPACE COUPLED WITH AIRCOND.+CASE 1"
265 PRINT " 6 OPEN LOOP SOLAR WALL+CASE 1"
270 PRINT " 7 TROMBE WALL+CASE 1"
275 PRINT " 8 OPEN LOOP SOLAR COLL.INST. ON ROOF+CASE 1"
280 PRINT "ENTER RUN INDEX": INPUT RI
530 FOR H=1 TO 8
540 READ UW(H), FW(H), ABH(H), LD1(H), LD2(H), CLB1(H), CLB2(H)
550 DATA 1.47,0.05,0.52,0.4,12.5,16.7,0.94,0.89
560 C+TM 1.29,0.07,0.42,0.6,11.0,17.3,0.94,0.89
570 DATA 3.36,0.06,0.45,0.5,26.3,32.5,0.87,0.81
580 DATA 0.72,0.04,0.62,0.4,6.3,12.5,0.97,0.92
590 DATA 5.34,0.45,0.17,0.5,36.7,44.5,0.80,0.74
600 DATA 2.89,0.28,0.22,0.64,25.1,29.3,0.88,0.83
610 DATA 2.93,0.14,0.32,0.4,23.2,29.6,0.88,0.83
620 DATA 5.19,0.17,0.29,0.4,37.9,43.7,0.81,0.75
630 NEXT H
651 FOR H=1 TO 9
652 READ ETF(H)
653 DATA 0.06,0.07,0.105,0.045,0.105,0.105,0.105,0.105,0.105
654 NEXT H
656 R=1.06
640 FOR M=1 TO 9
650 READ UR(M), FR(M), DR(M), ABR(M)
660 DATA 2.66,0.45,0.15,0.6
670 DATA 2.10,0.45,0.15,0.6
680 DATA 1.83,0.50,0.13,0.6
690 DATA 2.11,0.42,0.14,0.65
700 DATA 2.72,0.45,0.15,0.65
710 DATA 10.22,0.45,0.15,0.65
720 DATA 7.72,0.27,0.22,0.65
730 DATA 2.86,0.19,0.26,0.65
740 DATA 2.30,0.10,0.36,0.65
745 URM(H)=UR(M)+(1+R*UR(M))
785 NEXT M
780 FOR J=1 TO 12
770 READ HI(J), SE(J), SN(J), SS(J), SHE(J), SSE(J), TA(J), N(J)
780 DATA 5.52,2.10,0.18,4.26,0.36,3.24,15.90,31
790 DATA 6.24,2.40,0.24,3.36,0.72,2.68,18.20,28
800 DATA 7.10,2.64,0.24,1.92,1.20,2.40,18.20,31
810 DATA 7.80,2.76,0.60,0.36,1.92,1.80,20.30,30
820 DATA 7.80,2.88,1.80,0.24,2.40,1.32,22.00,31
830 DATA 7.80,2.76,2.40,0.24,2.64,1.08,22.80,30
840 DATA 7.80,2.88,1.80,0.24,2.40,1.32,23.20,31
850 DATA 7.80,2.76,0.60,0.36,1.92,1.80,22.50,31
860 DATA 7.10,2.64,0.24,1.92,1.20,2.40,19.80,30
870 DATA 6.24,2.40,0.24,3.36,0.72,2.68,17.80,31
880 DATA 5.52,2.10,0.18,4.26,0.36,3.24,16.10,30
890 DATA 5.16,1.98,0.18,4.50,0.24,3.24,14.30,31
920 NEXT J
925 FOR J=1 TO 12
926 READ SF(J), TF(J)
927 DATA 0.555,1.26,0.396,1.097,0.437,0.839,0.452,0.974,0.437,0.839
928 DATA 0.452,0.763,0.437,0.837,0.416,0.982,0.395,1.11,0.555,1.27,0.549
929 NEXT J
1370 IF k1=1 THEN GOSUB 5000
1380 IF R1=2 THEN GOSUB 5500
1390 IF RI=3 THEN GOSUB 6000
1395 IF RI=4 THEN GOSUB 6500
1400 IF RI=5 THEN GOSUB 7000
1410 IF RI=6 THEN GOSUB 7500
1415 IF RI=7 THEN 9500
1420 IF RI=8 THEN GOSUB 8000
1440 IF RI=9 THEN GOSUB 9000
1442 IF WC=2 THEN 1444
1443 PRINT"ENTER WALL, ROOF CONSTRUCTION NUMBER: INPUT H,M"
1444 FOR J=1 TO 12
1445 IF J=3 THEN TT=18: GOTO 1448
1446 IF J=10 THEN TT=18: GOTO 1448
1447 TT=22
1448 DD(J)=(TT-TA(J))*N(J):DDC(J)=(TA(J)-TT)*N(J)
1449 IF DD(J)<>0 THEN DD(J)=0
1450 IF DDC(J)<>0 THEN DDC(J)=0
1451 QH(J)=0.024*(H*M)*N(DC(J))
1452 QC(J)=0.024*(H*M)*N(DC(J))
1453 QL(J)=QC(J)+QH(J)
1454 TT(J)=TT: NEXT J: LPRINT"ENERGY IN (KWH)"
1455 PRINT"MONTH EFF TEMPERATURE IN (C)"
1456 PRINT"TA TT TNH TI ENTERING USEFUL LOAD"
1457 PRINT"TO THE"
1458 PRINT"HOUSE"
1459 LPRINT"MONTH EFF TEMPERATURE IN (C)"
1460 LPRINT"TA TT TNH TI ENTERING USEFUL LOAD"
1461 LPRINT"TO THE"
1462 LPRINT"HOUSE"
1463 I=1...J=F
1470 FOR J=1 TO 12
1480 QQG=(QGE+QGH)*SE(J)+AGN*SN(J)+AGS*SS(J):QTH(J)=QQG*SF(J)
1486 IF WC=2 THEN UB=0: GOTO 1488
1487 UB=UB(J)
1488 IF WC=2 THEN ABH=.6: GOTO 1490
1489 ABH=.6BH(J)
1490 IF WC=2 THEN FH=.45: GOTO 1495
1491 FH=F(H)
1495 QQAB=QBH+QEB+SFH..22*(H&H+E&H)*SE(J)+AGH*SN(J)+AHS+SS(J)
1500 QQAB=QQAB(J)
1505 IF WC=2 THEN ABR=.6: GOTO 1525
1510 IF TA=2 THEN ABR=.3: GOTO 1525
1520 =BR=BR(J)
1525 IF WC=2 THEN UBR=1: GOTO 1550
1530 IF TA=3 THEN UBR=UBR(J): GOTO 1550
1540 UBR=UBR(J)
1550 IF WC=2 THEN FR=.5: GOTO 1555
1551 FR=FR(J)
1555 QQBR=UB*FR+ABBXX.22%AFK(J)+QAB(J)
1570 QHH=QTH(J)+IQ+QHH(J)+QAB(J)
1580 IF RI=1 THEN EHH=QHH: GOTO 1680
1590 IF RI=2 THEN EHH=QHH1: GOTO 1680
1600 IF RI=3 THEN EHH=QHH2: GOTO 1680
1620 IF RI=4 THEN EHH=QHH3: GOTO 1680
1640 IF RI=5 THEN EHH=QHH4: GOTO 1680
1660 IF RI=6 THEN EHH=QHH5: GOTO 1680
1670 IF RI=7 THEN EHH=QHH6: GOTO 1680
1675 IF RI=8 THEN EHH=QHH7: GOTO 1680
1680 EHH(J)=QHH
1680 TNNH(J)=TA(J)+EHH(J)/(0.024*V*G(H,M))
1691 X=TT(J)-TNH(J)
1692 IF H=1 THEN EFF=FXP(1.9+.966*LOG(X+14))-14: GOTO 1695
1693 IF H=4 THEN EFF=EXP(1.9+.966*LOG(X+14))-14:GOTO 1695
1694 EFF=EXP(1.55+.05*LOG(X+14))-14
1695 IF EFF=.1 THEN EFF=100
1696 IF EFF=.0 THEN EFF=0
1697 QX(J)=EFF/100:EEH(J)*NN(J)
1698 IF QX(J)=0 THEN QX(J)=0:GOTO 1700
1699 QX(J)=QX(J)-Q(J)
1700 IF QX(J)=0 THEN Q(J)=Q(J)
1701 Q(J)=Q(J)+QX(J)
1702 IF Q(J)=0 THEN T(J)=T(J)
1703 T(J)=T(J)+EEH(J)/(-.024*K(H,H)*V)+(Q(J)/Q(J))*(T(J)-T(J))
1704 EFF(J)=EFF
1705 PRINT J; TAB(5); INT(EFF(J)); TAB(10); INT(T(J)); TAB(15); INT(T(J));
1706 PRINT INT(U(J)); TAB(5); INT(Q(J)); TAB(65); INT(QX(J));
1707 PRINT INT(T(J)); TAB(65); INT(T(J));
1708 PRINT INT(EF(J)); TAB(5); INT(T(J)); TAB(65); INT(Q(J));
1709 PRINT INT(T(J)); TAB(65); INT(QX(J));
1710 PRINT INT(U(J)); TAB(5); INT(Q(J)); TAB(65); INT(QX(J));
1711 PRINT INT(EF(J)); TAB(5); INT(Q(J)); TAB(65); INT(QX(J));
1712 PRINT
1713 FOR J=1 TO 12
1714 T(J)=T(J)+DD(J); DDC(J); TAB(35); T(J)
1715 DDC(D(J))=DCT+DDC(J)+O(J)+QH(J)
1716 QH(J)=QH(J)+Q(J)+Q(J)
1717 QL(J)=QL(T+Q(J))
1718 PRINT "---------------------------------------------------"
1719 PRINT "WALL ROOF MONTH ENERGY GAINS IN (KWH, W/HR)
1720 PRINT "TYPE TRANSMITTED ABSORBED"
1721 PRINT "VIA WINDOWS WALL ROOF"
1722 PRINT "---------------------------------------------------"
1723 PRINT "---------------------------------------------------"
1724 PRINT "---------------------------------------------------"
1725 PRINT "---------------------------------------------------"
LPRINT "TABLE 5: EFFECT OF WALL-ROOF COUPLING ON THE USEFUL ENERGY GAINS"
LPRINT "WALL ROOF MONTH ENERGY USEFUL AUX"
LPRINT "TYPE TYPE ENTERED GAIN"
LPRINT "TO THE HOUSE"
LPRINT "( KWHR ) (KWHR) (KWHR)
---------------------------------------------------------------
FOR J=1 TO 12
LPRINT TAB(10);J;TAB(15);EFF(J);TAB(35);TNH(J);TAB(45)
IF QJ(J)=0 THEN GELT=EEH(J)+1.024*G(M,J)*V:GOTO 2420
GELT=EEH(J)+1.024*G(M,J) *(QJ(J)-T(J)-T(J))
T(J)=T(J)+T(J)
NEXT J
LPRINT "--------------------------------------------------------------
WITHOUT AX WITH AX"
LPRINT "TABLE 4: EFFECT OF WALL-ROOF COUPLING ON THE INSIDE TEMP.
WALL ROOF MONTH EFFICIENCY INSIDE HOUSE TEMP. TEMP. INCREASE"
LPRINT "(C) (C"
LPRINT "WITHOUT A) WITH A"
FOR J=1 TO 12
LPRINT TAB(30);EFF(J);TAB(45)
GELT=EFF(J)*0.024*G(M,J)*V:GOTO 2420
GELT=EFF(J)*0.024*G(M,J) *(QJ(J)-T(J)-T(J))
DELTA(J)=T(J)+T(J)
NEXT J
FOR H=1 TO 8
FOR P=1 TO 9
PRINT "WOULD YOU LIKE TO CHANGE WALL/ROOF CONST. MAT. FOR THE SAME OPT.
ENTER 1 IF YES 0 IF NO"; INPUT RR
IF RR=1 THEN 2442
IF RR=1 THEN 2442
END
PRINT "WALL/ROOF CONST. MAT. FOR THE SAME OPT."
PRINT "ENTER 1 IF YES 0 IF NO": INPUT RR
IF RR=1 THEN 1442
PRINT "YOUR SELECTION IS NOT VALID:"; INPUT RR
IF RR=1 THEN 1442
END
2700 PRINT "RUN INDEX OPTIONS"
2710 PRINT " 1 HOUSE"
2720 PRINT " 2 HOUSE + GARAGE"
2730 PRINT " 3 HOUSE + SUNSPACE"
2740 PRINT " 4 HOUSE + GARAGE + SUNSPACE"
2750 PRINT " 5 HOUSE + SUNSPACE COUPLED WITH AIR EXCHANGER"
2760 PRINT " 6 OPEN LOOP SOLAR WALL INST. ON THE SOUTH + HOUSE"
2770 PRINT " 7 TROMBE WALL"
2780 PRINT " 8 OPEN LOOP SOLAR COLLECTOR INST. ON ROOF + HOUSE"
2790 INPUT RI: GOTO 1370
5000 A=90.24: AF=48.133: AD=2.1: LF=7.6: V=167.503
5010 AHE=21.4: AHW=20.7: AHN=24.4: AHS=23.3
5020 AGE=1.2: AAG=1.92: AKN=0.1: AGS=3.12
5025 PRINT "ENTER TYPE OF ROOF: 1 ORDINARY, 2 WITH WHITE TILE, 3 WITH AIR SPA"
5030 PRINT "ENTER WALL/ROOF CODE: 1 FOR YEMENI WALLS/ROOFS, 2 INTERNATIONAL"
5035 IF WC=1 THEN 5045
5036 PRINT "ENTER WALL, UROOF, AND UNWINDOW": INPUT UH1, UR1, UWIN
5037 IF RI=8 THEN G1=G1+.34*EFFC*Q
5038 IF RI=8 THEN G=G-X2
5039 G1=G1/V
5040 GOTO 5140
5045 FOR H=1 TO 8
5050 FOR M=1 TO 9
5060 IF TR=3 THEN UR=URA+M): GOTO 5075
5070 UR=URM
5075 G=UW(H)*AF+UR*AD+3.33*AD+2.1*LF+.34*V
5076 G=G-X2
5080 G=UW(H)*AF+UR*AD+3.33*AD+2.1*LF+.34*V
5085 IF RI=8 THEN G=G-X2
5090 G(H,M)=G/V
5100 NEXT M
5110 NEXT H
5130 IF RI=8 THEN 9210
5135 PRINT "ENTER TYPE OF ROOF: 1 ORDINARY, 2 WITH WHITE PAINT, 3 WITH AIR SPA"
5136 PRINT "ENTER WALL/ROOF CODE: 1 FOR YEMENI WALLS/ROOFS, 2 INTERNATIONAL"
5137 INPUT PI
5138 IF PI=0 THEN 5025
5140 LPRINT "TABLE 1: CHARACTERISTICS OF THE INPUTTED HOUSE"
5145 LPRINT "SOLID WALL AREA IN (SQ. M.): EAST WEST NORTH SOUTH"
5150 LPRINT TAB(20): AGE; TAB(30): AAG; TAB(40): AKN; TAB(50): AHS; TAB(60): AHS
5160 LPRINT "WINDOW AREA IN (SQ. M.):"
5170 LPRINT TAB(20): AGE; TAB(30): AAG; TAB(40): AKN; TAB(50): AHS; TAB(60): AHS
5180 LPRINT "ROOF AREA VOLUME G_FACTOR"
5185 LPRINT *(SQ. M.)" (CUBIC M)" *(W/CMC)"
5190 LPRINT AF;TAB(35); V; TAB(55); G1
5195 LPRINT LPRINT;LPRINT;LPRINT
5200 LPRINT "-----------------------------------------------"
5210 RETURN
5500 AHE=0.75: AAG=6.24: AF=48.133: AD=2.1: LF=7.6: V=167.503
5510 AGE=21.4: AAG=20.7: AHN=12.2: AHS=23.3
5520 AAG=1.2: AAG=1.92: AKN=0.1: AGS=3.12
5525 PRINT "ENTER TYPE OF ROOF: 1 ORDINARY, 2 WITH WHITE PAINT, 3 WITH AIR SPA"
5530 PRINT "ENTER WALL/ROOF CODE: 1 FOR YEMENI WALLS/ROOFS, 2 INTERNATIONAL"
5540 IF WC=2 THEN PRINT "ENTER WALL, UROOF, UWIN": INPUT UH1, UR1, UWIN
5550 FOR H=1 TO 8
5560 FOR M=1 TO 9
5570 IF TR=3 THEN UR=URA+M): GOTO 5585
5580 UR=URM
5585 X1=1-CLBL(H)
5590 G=UH(H)*AF+UH(H)*AF+4.3*AG+3.33*AD+2.1*LF+.34*(V-X1*30)+LHD1(H)
5595 G=G/V16(H,M)
214

NEXT H

NEXT H: GOTO 5695

G1=W1*U1+U1*AF+U1*IN*AG+2.1*LF+3.33*AD+3.4*(V-CLB1(8)*30)+LMD1(8)

G1=G1/V

RETURN

PRINT "ENTER TYPE OF BUFFER: 1 FOR NON-TRANS, 2 FOR TRANS. PARENT"

PRINT "ENTER TYPE OF ROOF: 1 FOR HEATED, 2 FOR TRANS. PARENT"

PRINT "ENTER DIRECTION OF THE WINDOW BETWEEN HEATED AND SUNSPACE"

PRINT "ENTER WALL/ROOF CODE: 1 FOR "YEMENI, 2 INTERNATIONAL"

PRINT "ENTER NUMBER OF COLLECTING SURFACES: INPUT NCS"

PRINT "ENTER AREA OF THE COLLECTING SURFACES IN THE FOLLOWING ORDER:"

PRINT "EAST, WEST, NORTH, AND SOUTH": INPUT AGSE, AGSH, AGSN, AGSS

PRINT "ENTER AREA OF THE WINDOW BETWEEN SUNSPACE AND HEATED SPACE": INPUT AGSH

IF WC=1 THEN 6100

PRINT "ENTER UWALL, UROOF, UWIN": INPUT U1, U1, U1IN

IF R1=5 THEN 6100

RETURN

FOR H=1 TO 8

FOR M=1 TO 9

IF TR=3 THEN UR=URA(M): GOTO 6150

IF RI=5 THEN 6100

G=LW4K1(H, 2)+LW5K1(H, 1)+X1

G=G/V: GIH, M)-G

NEXT M

NEXT H

IF RI=5 THEN 7010

RETURN

RETURN

RETURN

RETURN

RETURN

RETURN

RETURN

RETURN

RETURN

RETURN

RETURN

RETURN
7000 IF RI=5 THEN 6000
7010 RETURN
7510 AGE=20.7: AH=20.22: AI=24.35
7520 AGE=1.92: AGH=2.4: AGH=0. AGS=1.92
7525 IF RI=7 THEN 7540
7530 PRINT"ENTER AREA OF O.L.S.W." INPUT ASW: QSH=10*ASH
7535 ASH=7.6: AS=3.48: AGS=ASH
7540 PRINT"ENTER TYPE OF ROOF: 1 ORDINARY, 2 WHITE P., 3 AIR SPACE" INPUT TR
7545 PRINT"ENTER WALL/ROOF CODE, 1 FOR YEMENI, 2 INTERNATIONAL:" INPUT WC
7550 IF WC=1 THEN 7600
7555 PRINT"ENTER W=1, UR, W 11: INPUT WU1, U1, W11
7560 GW=U1: UH=U1*AF+U1: AGH=AG: AD=2.1*LF+. 34*V*(1-(QSW/V)*ETA(B))
7565 IF RI=7 THEN 6225
7570 LPRINT"VOLUME AREA OF ROOF G-FACTOR" LPRINT V; TAB(30); AF; TAB(40); Gl
7575 LPRINT"---------------------------------------------------------
7580 GOTO 7665
7580 FOR H=1 TO 8
7590 FOR M=1 TO 9
7600 IF TR=3 THEN UR=U(M): GOTO 7630
7610 UR=UR+M
7620 GW=H*(U1 AF)+U1: AG+3.3*AD+2.1*LF+. 34*V*(1-(QSW/V)*ETA(B))
7630 GOTO 7665
7640 IF RI=7 THEN 6225
7650 LPRINT"SPECIFY THE CONST. MATERIAL OF THE OPEN LOOP SOLAR WALL(1 TO 8)" LPRINT H; SW=HFA4k H)
7660 FOR J=1 TO 12
7670 F=HSW*. 55*: SS(J)
7680 IF WC=1 THEN 7750
7690 IF WC=2 THEN U=U1: GOTO 7780
7700 IF WC=1 THEN 7750
7710 ETA=ETA: (+1.11*UW1)/(UW1*ASH): GOTO 7750
7720 ETA=ETA: (+1.11*UH)/(UH*ASH)
7730 QASW=. 34*QSW*ETA*. 9*1
7740 QWSW=F*UW*. 22*. 9
7750 QT(J)=QASW+QWSW: PRINT"QT="; QT(J)
7760 NEXT J
7770 NEXT H
7780 RETURN
7800 PRINT"ENTER AREA OF TRIME WALL": INPUT ATH
7810 PRINT"SPECIFY THE EMISSIVITY OF THE ABSORBER(0.1 OR 0.9)" INPUT EM
7820 PRINT"SPECIFY THE NATURE OF GLAZING: 1 SINGLE, 2 DOUBLE": INPUT NG
7830 PRINT"IS THERE AN INSULATING SHUTTER AT NIGHT(1 YES, 0 NO)" INPUT NI
7840 IF NG=1 THEN 8100
7850 IF EM=. 9 THEN 8070
7860 IF NI=1 THEN C=. 4599999: GOTO 8220
7870 C=. 4599999: GOTO 8220
7880 C=. 66: GOTO 8220
7890 C=. 66: GOTO 8220
7900 IF EM=. 9 THEN 8070
7910 IF NI=1 THEN C=. 58: GOTO 8220
7920 C=. 46: GOTO 8200
7930 C=. 58: GOTO 8200
7940 C=. 46: GOTO 8200
7950 C=. 46: GOTO 8200
7960 C=. 58: GOTO 8200
7970 C=. 46: GOTO 8200
7980 C=. 58: GOTO 8200
7990 C=. 46: GOTO 8200
8000 IF EM=. 9 THEN 8070
8010 IF NI=1 THEN C=. 66: GOTO 8220
8020 C=. 66: GOTO 8220
8030 C=. 66: GOTO 8220
8040 C=. 66: GOTO 8220
8050 C=. 66: GOTO 8220
8060 C=. 66: GOTO 8220
8070 C=. 66: GOTO 8220
8080 C=. 66: GOTO 8220
8090 C=. 66: GOTO 8220
8100 IF EM=. 9 THEN 8070
8110 IF NI=1 THEN C=. 76: GOTO 8220
8120 C=. 65: GOTO 8220
8130 C=. 58: GOTO 8220
8140 C=. 46: GOTO 8220
8150 C=. 58: GOTO 8220
8160 C=. 46: GOTO 8220
8170 C=. 58: GOTO 8220
8180 C=. 46: GOTO 8220
8190 C=. 58: GOTO 8220
8200 PRINT"ENTER AREA OF OPEN LOOP SOLAR COLL.": INPUT AC
8210 PRINT"ENTER TYPE OF ROOF TYPE 1 FOR ORD. 2 WHITE P., 3 AIR SPACE"
PRINT "ENTER WALL ROOF CODE TYPE 1 FOR YEMEN 2 FOR INTERNATIONAL"
Z = Q / AC
IF INT(Z) = 20 THEN EFFC = 0.42: GOTO 9200
IF INT(Z) = 30 THEN EFFC = 0.47: GOTO 9200
IF INT(Z) = 40 THEN EFFC = 0.5: GOTO 9200
IF INT(Z) = 50 THEN EFFC = 0.51: GOTO 9200
IF INT(Z) = 60 THEN EFFC = 0.55: GOTO 9200
IF INT(Z) = 70 THEN EFFC = 0.56: GOTO 9200
IF INT(Z) = 80 THEN EFFC = 0.57: GOTO 9200
PRINT "Z EFFC" Z EFFC
GOTO 9200
FOR J = 1 TO 12
QAC(J) = (.8499999 * EFFC) * H(J) * AC * TF(J)
PRINT "J QAC(J)" J QAC(J)
NEXT J
RETURN
PRINT "IS THERE MASS WALL WITHIN THE SUNSPACE TYPE 1 IF YES 0 IF NO" INPUT MS
IF MS = 0 THEN 9505
PRINT "ENTER Insulation Const (10.9 TO 1)" INPUT AIC
PRINT "ENTER OVERALL TRANS. COEFF" INPUT TWA
PRINT "IS THERE OPAQUE ROOF TYPE 1 FOR YES 0 FOR NO" INPUT R1
IF R1 = 1 THEN 9510
PRINT "ENTER TYPE OF ROOF CONST (1 TO 9)" INPUT ATR
HL = R1 * ATR
IF HL = 0 THEN 9505
PRINT "TS THE SUN SPACE USED TO PREHEAT THE AIR TYPE 1 FOR YES 0 FOR NO" INPUT V1
PRINT "SPECIFY THE TYPE OF WALL CONST OF THE HOUSE 1 TO 9" INPUT V2
PRINT "IS THE SUNSPACE COUPLED WITH HEAT EXCHANGER TYPE 1 FOR YES" INPUT HE
FOR J = 1 TO 12
IF NCS = 1 THEN A1 = .7
IF NCS = 2 THEN A1 = .7
IF NCS = 3 THEN A1 = .8499999
IF NCS = 4 THEN A1 = .9199999
IF NCS = 5 THEN A1 = .9199999
QS = AGSE + AGSW + SE(J) + AGSN*SN(J) + AGSS*SS(J)
IF DR = 1 THEN QSE = AGSH*SE(J) * SF(J) * .8499999 * .8 * .8
IF DR = 2 THEN QSE = AGSH*SN(J) * SF(J) * .8499999 * .8 * .8
IF DR = 3 THEN QSE = AGSH*SS(J) * SF(J) * .8499999 * .8 * .8
IF MS = 0 THEN 9505
IF DR = 1 THEN QSLN = (.11 * U(H) * AIC * H(V1)) * TWP * SF(J) * SF(J)
IF DR = 2 THEN QSLN = (.11 * U(H) * AIC * H(V1)) * TWP * SF(J) * SF(J)
IF DR = 3 THEN QSLN = (.11 * U(H) * AIC * H(V1)) * TWP * SF(J) * SF(J)
QS = (AGSE + AGSW)*SE(J) + AGSN*SN(J) + AGSS*SS(J)
QST(J) = QST + QSLN + QSB + QS
PRINT "J QSE QSUW QSB QSA QST TS" J QSE QSUW QSB QSA QST TS
NEXT J
GOTO 1442
DIRECT-GAIN AND TROMBE WALL COMPUTER SIMULATION PROGRAM
10 DIM N(12), Th(12), DD(12), N(12), H(12), H0(12), K(12), DE(12), H(12), DL(12),
20 DIM R/1(12), LA(12), RD(12), RDN(12), REN(12), ATK(12), RDH(12),
30 DIM R(12), H(12), A(12), B(12), C(12),
35 DIM DDD(12), DDDB(12), DDB(12), L(12), LA1(12), LA(12), LH(12), TH(12), OIS(12),
40 DIM Q(12), DCD(12), DCS(12), XCD(12), XCS(12), PD(12), PS(12), QOD(12),
41 DIM Q(12), DXQ(12), DX(12), FSD(12), FIS(12), KS(12), FZD(12), FZS(12),
42 DIM S(12), FSD(12), FS(12), DXQ(12), Q(12), ETA(12), ETAS(12), TH(12),
43 DIM DELT(12), DELT(12),
50 FOR J = 1 TO 12
60 READ N(J), Th(J)
65 FOR J = 1 TO 12
70 READ A(J), B(J), C(J), D(J), E(J), F(J), G(J), H(J)
75 DATA 31, 15.9, 28, 18.2, 31, 18.2, 30, 21.3, 22, 36, 22.8, 31, 23.2, 10, 22.5
80 DATA 30, 19.8, 31.7, 8.3, 30, 16.1, 31, 14.3
85 NEXT J
90 FOR J = 1 TO 12
95 RE = D(J), H(J), H0(J)
100 DATA 21, 18.7, 28.9, 35.1, 110, 24.1, 37.6, 14.1, 104.4, 23.6
105 NEXT J
110 FOR H = 1 TO 8
115 RE = D(J), H(J)
120 DATA 1.4, 1.29, 3.36, 0.72, 5.34, 2.89, 2.9, 5.19
125 NEXT H
130 FOR 1 = 1 TO 9
135 READ UR(J)
140 DATA 2.26, 0.1, 1.83, 2.11, 2.72, 10.12, 7.72, 2.86, 2.3
145 NEXT M
150 L = (3.142 \times 180) \times 15 \times \cos(L) \times \sin(L) \times \tan(L) \times \tan(L)
155 FOR J = 1 TO 12
160 DEC(J) = (3.142 / 180) \times 360 \times (365 / 365) \times (N(J) - 284)
165 DATA 110, 24.1, 37.6, 14.1, 104.4, 23.6
170 DEC(J) = (3.142 / 180) \times \cos(D) \times \cos(DEC) \times \sin(D) \times \sin(DEC)
175 DATA 1.4, 1.29, 3.36, 0.72, 5.34, 2.89, 2.9, 5.19
180 DATA 2.26, 0.1, 1.83, 2.11, 2.72, 10.12, 7.72, 2.86, 2.3
185 NEXT H
190 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
195 FOR J = 1 TO 12
200 K(J) = (3.142 \times 180) \times 360 \times (365 / 365) \times (N(J) - 284)
205 DATA 110, 24.1, 37.6, 14.1, 104.4, 23.6
210 DATA 1.4, 1.29, 3.36, 0.72, 5.34, 2.89, 2.9, 5.19
215 DATA 2.26, 0.1, 1.83, 2.11, 2.72, 10.12, 7.72, 2.86, 2.3
220 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
225 FOR J = 1 TO 12
230 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
235 FOR J = 1 TO 12
240 DATA 1.4, 1.29, 3.36, 0.72, 5.34, 2.89, 2.9, 5.19
245 FOR J = 1 TO 12
250 DATA 2.26, 0.1, 1.83, 2.11, 2.72, 10.12, 7.72, 2.86, 2.3
255 FOR J = 1 TO 12
260 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
265 PRINT RT = RT + R(J)
270 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
275 FOR J = 1 TO 12
280 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
285 FOR J = 1 TO 12
290 FOR J = 1 TO 12
295 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
300 PRINT RT = RT + R(J)
305 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
310 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
315 PRINT RT = RT + R(J)
320 FOR J = 1 TO 12
325 FOR J = 1 TO 12
330 FOR J = 1 TO 12
335 FOR J = 1 TO 12
340 DATA 3.142 \times 180 \times 15 \times ((5 + Y) - 12) \times \cos(S) \times \sin(M) \times \sin(M)
345 FOR J = 1 TO 12
350 FOR J = 1 TO 12
355 FOR J = 1 TO 12
360 FOR J = 1 TO 12
365 FOR J = 1 TO 12
370 FOR J = 1 TO 12
375 PRINT RT = RT + R(J)
380 FOR J = 1 TO 12
385 FOR J = 1 TO 12
390 FOR J = 1 TO 12
395 FOR J = 1 TO 12
400 FOR J = 1 TO 12
405 FOR J = 1 TO 12
410 FOR J = 1 TO 12
415 FOR J = 1 TO 12
420 FOR J = 1 TO 12
425 FOR J = 1 TO 12
430 FOR J = 1 TO 12
435 FOR J = 1 TO 12
440 FOR J = 1 TO 12
450 \( R_1(J) = R(J) \times R(J) \)
460 \( H_1(J) = R(J) \times H(J) \)
461 \( A(J) = 2.943 - 9.271 \times K(J) + 4.031 \times K(J) \times K(J) \)
462 \( B(J) = -4.345 + 8.853 \times K(J) - 3.602 \times K(J) \times K(J) \)
463 \( C(J) = -1.7 - 30.8 \times K(J) + 2.936 \times K(J) \times K(J) \)
464 \( R = 0 \)
490 NEXT J
495 PRINT "ENTER PRINTING INDEX, 1 TO PRINTER 0 TO SCREEN"; INPUT PI
496 IF PI = 0 THEN 755
500 PRINT "TABLE1: SOLAR RADIATION FALLING ON THE TILTED AND HORIZONTAL"
501 PRINT "SURFACES OF A HOUSE IN THE YEMEN EVALUATED ON 21ST DAY"
510 PRINT "MONTH SOLAR RADIATION (IN MJ/M-DAY) CLEARNESS FACTOR"
520 PRINT "EXT. HORIZONTAL VERTICAL"
530 PRINT "---
540 LPRINT "---
550 LPRINT "---
560 FOR J = 1 TO 12
570 LPRINT J; TAB(10); H0(J); TAB(20); H(J); TAB(25); HT(J); TAB(45); K(J);
580 LPRINT NEXT J
590 LPRINT "---
600 LPRINT "---
610 PRINT "TABLE2: COMPONENT OF SOLAR RADIATION AS EVALUATED ON THE 21ST"
620 PRINT "MONTH DIFFUSE DIRECT GLOBAL"
630 PRINT "---
640 LPRINT "---
650 FOR J = 1 TO 12
660 LPRINT J; TAB(10); RGH(J); TAB(30); RBK(J); TAB(55); R(J)
670 LPRINT NEXT J
680 LPRINT "---
690 PRINT "---
700 LPRINT "TABLE3: COMPONENT OF SOLAR RADIATION AS EVALUATED ON THE 21ST"
710 PRINT "OF THE 21ST DAY OF THE MONTH"
720 FOR J = 1 TO 12
730 LPRINT J; TAB(10); RBN(J); TAB(20); R(N(J)); TAB(30); RDN(J); TAB(40); FTM(J)
740 LPRINT RGND(J); TAB(60); R(J)
750 NEXT J
755 PRINT "ENTER FLOOR AREA (220 SQ. M.)"; INPUT AF
760 PRINT "ENTER THERMOSTAT SET TEMPERATURE"; INPUT TE
770 PRINT "INPUT THICKNESS AND THERMAL CONDUCTIVITY OF THE STORAGE WALL"
780 PRINT "ENTER IN METER AND (W/M^2K) RESPECTIVELY"; INPUT D1, K1
790 PRINT "ENTER DENSITY (KG/CUBE METER), SPECIFIC HEAT IN (J/KG°C)"; INPUT AR
800 PRINT "ENTER AREA OF THE STORAGE WALL (IN SQ. M.)"; INPUT M
810 PRINT "SPECIFY TYPE OF EXTERNAL HOUSE WALL INT. FROM 1 TO 8"; INPUT H
820 PRINT "SPECIFY THE TYPE OF ROOF (INT FROM 1 TO 9)"; INPUT HG
825 PRINT "ENTER GLAZED AREA"; INPUT MG
830 UH = AF * K1/(H + 4.3 * AG)
840 UH = 1/(1/(5.7) + (1/8.3) + (D1/K1))
845 UH = AF * K1
850 NS = 0.24 * 3.6
860 UK = 8.3 * K1 / (K1 + D1 * 8.3)
870 DELT = 0.13 * AF * 3.6 / (UW - 0.24 * 3.6) / (UH * 0.24 * 3.6)
875 TB = TE - DELT * TD - DELT0
880 FOR J = 1 TO 12
890 UH = N(J) * (TE - TB(J))
905 IF DCR = 0 THEN DCR = 0
910 L4 = DCR * UV * 0.24 * 3.6 / UH = DCR * UV * 0.24 * 3.6
920 L4 = DCR * UV * K1 * 0.24 * 3.6
930 F1 = HT(J) * 84999994NS * (UK * TE + 3.7 * TH(J))
940 TH = (F1 / (UK + 3.7 * NS))
950 Q1 = UK * AF * (TH - TE) * NS * N(J)
960 Q1 = HT(J) * 84999994NS * N(J)
970 IF LA\(\leq 0\) THEN 975
971 QXSI=LA-QIS
975 IF LA\(\leq 0\) THEN 1000
990 QCD=LA-QID
1000 ICQ=(\((4.8999999*AG)\)*(TE-Th(J))
1010 F2=(\((4.8999999*AW)\)*(TE-TA(J))
1020 IC2=F2=(\((4.8999999*AW)\)
1030 IF IC2=0 THEN \(XCD=0\) GOTO 1050
1040 XCD=(\((0.036*ICD)/(RTN(J)*RN(J)*H(T))\))
1050 IF IC2=0 THEN \(XCS=0\) GOTO 1070
1060 XCS=(\((0.036*IC)/(RTN(J)*RN(J)*H(T))\))
1070 F3=(\((4.11*ICD/J)/(4.11*ICD)\)\)\((1+C(J)*XCD))
1080 \(PD=EXP(F3)\)
1090 PS=EXP(F4)
1100 QDS=PD-QID
1120 QDS=(\((UK*0.8499999*AW)/(3.7+UK)*H(T)*PS*N1(J)\))
1130 IF LA\(\leq 0\) THEN 1145
1140 QSZ=LA-QIS
1145 IF LA\(\leq 0\) THEN 1160
1150 QXZ=LA-QIS
1160 IF LA\(\leq 0\) THEN \(FID=1\) GOTO 1180
1170 FID=(\((1-QXDI/LA)\))
1180 \(FID=1\) GOTO 1200
1190 IF LA\(\leq 0\) THEN \(XD=0\) GOTO 1220
1200 XD=QID/LA
1215 IF XD=4 THEN \(XD=4\)
1220 IF (LA+QID)\(=0\) THEN \(XS=0\) GOTO 1240
1230 XS=HT(J)*0.8499999*AW\(N1(J)\)/(LA+LA)
1235 IF XS=4 THEN \(XS=4\)
1240 \(FZD=(1-PD)*FID\)
1245 \(FZS=FID=(1-PD)*FID\)
1250 \(FZS=FS=(UK/(3.7+UK))*PS*XS\)
1260 \(YD=(1.13*DF*TE-18.3)*N1(J)\)/(QDD)
1270 \(SB=(1.13*DF*TE-18.3)*N1(J)\)
1280 \(SW=(R(P*Q1*DT)+(2+1.64*86400))/QIS\)
1290 \(YS=(SB+SM*0.47)/QDS\)
1300 \(Pi=(1-EXP(-.294*YD)))^0.652\)
1310 \(P2=(1-EXP(-.144*YS))^0.53\)
1320 \(P3=Pi+YD*4.3*1.124*FDD*1-EXP(-.329*YD))\)
1325 \(F5=S^2*F5*1-EXP(-1.26*F5))\)
1340 IF FD=1 THEN FD=1.
1350 IF FS=1 THEN FS=1
1360 QX=DF\(=\)LA
1370 QX=SF\(=\)LALH
1390 \(ETAD=(LA1/QID)*FD\)
1400 \(L11=LAH+LH\)
1410 IF L11\(=0\) THEN L11=0
1420 \(ETAD=(L11/QIS)*FS\)
1430 IF ETAD=0 THEN ETAD=0
1440 IF ETAD=0 THEN ETAD=0
1445 IF ETAD=1 THEN ETAD=1
1446 IF ETAD=1 THEN ETAD=1
1450 \(TNHD=TA(J)+\(QID/(N(J)*\(U1(J)*U2(J)*3.6)\))\)
1460 \(TNHS=TA(J)+\(N(J)/(U1(J)+1.8+4.6)\))\)
1470 \(DELT1=TE-TNHD;DELT2=TE-TNHS\)
1480 \(PRINT J;TAB(5);INT(DELT1);TAB(15);INT(100*ETAD);TAB(25);INT(DELT2)\)
1490 \(PRINT INT(100*ETAD);TAB(45);INT(TNHD);TAB(55);INT(TNHS)\)
1500 \(LA(J)=LA(J)+LAH(J);LH(J)=LH;TH(J)=TH(J)+TW\)
1510 \(QIS(J)=QIS;QID(J)=QID;QXS(J)=QXS;PD(J)=PD;PS(J)=PS;QDD(J)=QDD;QCS(J)=QCS\)
1530 QDX(J)=QDXZ: FID(J)=FID: FIS(J)=FIS: XD(J)=XD: XS(J)=XS: FZD(J)=FZD
1540 Y(J)=Y(J): FS(J)=FS: FD(J)=FD: FS(J)=FS: QDX(J)=QDX: QXS(J)=QXS
1555 DOR(J)=DOR
1560 NEXT J
1561 PRINT END "ENTER PRINT INDEX(1 TO PRINTER, 0 NO PRINT)" INPUT PI
1562 IF PI=1 THEN GOSUB 3000
1570 PRINT "WOULD YOU LIKE ANOTHER RUN(1=YES, 0-NO)" INPUT RI
1580 IF RI=1 THEN 1590
1585 END
1590 FOR J=1 TO 12
1600 LA(J)=LA(J): LW(J)=LW(J): TH(J)=TH(J): QIS(J)=QIS(J): QID(J)=QID(J)
1610 QDX(J)=QDX(J): QC(J)=QC(J): XCD(J)=XCD(J): XCS(J)=XCS(J): PD(J)=PD(J)
1620 QDX(J)=QDX(J): QC(J)=QC(J): XCD(J)=XCD(J): XCS(J)=XCS(J): PD(J)=PD(J)
1640 ETAS(J)=ETAS(J): TNHD(J)=TNHD(J): TNHS(J)=TNHS(J): DELT1(J)=DELT2(J)
1645 DOR(J)=DOR
1650 NEXT J
1660 GOTO 755
3000 LPRINT "THERMAL PERFORMANCE OF DIRECT GAIN HOUSE"
3010 LPRINT "-------------------------------------"
3020 LPRINT "GLAZED AREA FLOOR AREA RATIO OF GLAZED/FLOOR TE"
3030 LPRINT "MONTH DEGREE-DAYS LOAD INPUT DUMP HU"
3040 FOR J=1 TO 12
3050 LPRINT AT TE
3060 LPRINT "(E-DAYS)"
3070 LPRINT (GJ) (GJ) (GJ)
3080 LPRINT "AT TE"
3090 FOR J=1 TO 12
3100 LPRINT J; TAB(15); INT(DGRI); THB(25); L+1T(J)-1000; L; TAB(35); QID(J); O000; TAB(45); QGG(J); O000; TAB(55); 0; DELT(J)
3110 LPRINT "MONTH UA IC F SL W/C, SQ. M"
3120 LPRINT FOR J=1 TO 12
3130 FOR J=1 TO 12
3140 LPRINT "MONTH TEMPERATURE EFF TEMPERATURE"
3150 LPRINT "TA TE TI"
3160 LPRINT "(C) (C)"
3170 LPRINT "PERFORMANCE OF THE STORAGE-HALL SYSTEM"
3180 IF IC(J)=0 THEN IC(J)=0
3190 LPRINT J; TAB(5); TAB(15); TAB(35); TAB(35); AC(J); PD(J); QCD(J); QCD(J)
3200 LPRINT F(J); TAB(55); XCD(J); TAB(25); TE-TH(J)
3210 LPRINT DOR(J); DELT(J)
3220 NEXT J
3230 LPRINT DOR(J); DELT(J)
3240 LPRINT "PERFORMANCE OF THE STORAGE-HALL SYSTEM"
3250 LPRINT "COLLECTOR FLOOR AREA RATIO(AC/AF) THERMAL PROPERTIES"
3260 LPRINT "AREA STORAGE HALL"
3270 LPRINT "CAPACITY"
3367 LPRINT* (SQ.M) (SQ.M.) (H-SQ.MC) (MJ-CM) * 

3368 LPRINT 
3370 LPRINT AH;TAB(10);AF;TAB(15);AH/AF;TAB(35);UH;TAB(45);(RO*CF) 
3375 LPRINT TAB(55);K1;TAB(25);D1 
3380 LPRINT: LPRINT: LPRINT* 
3390 LPRINT"MONTH DEGREE LOAD INPUT" * 
3400 LPRINT* DAYS * 
3401 LPRINT* AT TE LA LH * 
3402 LPRINT* (C-DAYS) (GJ) (GJ) * 
3430 LPRINT 
3440 FOR J=1 TO 12 
3450 LPRINT J;TAB(5);DDR(J);TAB(15);LA(J)/1000;TAB(25);LH(J)/1000 
3460 LPRINT Q5(J)/1000;TAB(55);QDS(J)/1000;TAB(65);QXS(J)/1000; 
3470 LPRINT 
3480 NEXT J 
3490 LPRINT: LPRINT: LPRINT 
3500 LPRINT"MONTH UA IC PHI XCF F SLR" 
3510 LPRINT* (W/C) (W-SQ.M) * 
3520 LPRINT 
3530 FOR J=1 TO 12 
3540 IF ICS(J)=0 THEN ICS(J)=0 
3550 LPRINT J;TAB(5);UA(TAB(15);ICS(J);TAB(25);FS(J);TAB(35);CS(J). 
3560 LPRINT FS(J);TAB(55);XS(J);TAB(65);TE-TA(J) 
3570 LPRINT 
3580 NEXT J 
3590 LPRINT: LPRINT: LPRINT 
3600 LPRINT* TEMPERATURE EFF 
3610 LPRINT* TA TH TE TI (%) TE-TI 
3620 LPRINT* (C) 
3630 LPRINT 
3640 FOR J=1 TO 12 
3650 LPRINT J;TAB(5);TA(J);TAB(15);TH(J);TAB(25);TE;TAB(35);TNHS(J); 
3660 LPRINT ETAS(J);TAB(65);DELT2(J); 
3670 LPRINT 
3680 NEXT J 
3690 RETURN
10 DIM N1(12), TA(12), ND(12), N(12), H0(12), KT(12), DEC(12), H(12), OL(12)
20 DIM RBJ(12), UR(9), UR(12), RDH(12), R(12), RBH(12), RDN(12), ATH(12), RDN(12)
30 DIM R1(12), HT(12), R(12), B(12), C(12)
35 DIM DELT(12), AG(9), UAH(9), IC(12,9), XC(12,9), PHI(12,9), QI(12,9), L(12)
36 DIM GA(12), F1(12), FZ(12), 1(12), X1(12), F(12), DA(12), QD(12)
390 DIM X(12), T(12), D(12), C0(12)
40 PRINT "ENTER THERMOSTAT SET TEMP." : INPUT TE
50 FOR J=1 TO 12
60 READ N(J), TA(J)
75 DATA 21,18.7,28.93,49,20.9,32.31,80,22.7,35.43,110,24.1,37.69,141.24.8
80 NEXT J
100 FOR J=1 TO 12
110 READ IN(J), H(J), HO(J)
120 DATA 21,18.7,28.93,49,20.9,32.31,80,22.7,35.43,110,24.1,37.69,141.24.8
130 DD(J)=N(J)*(TE-TN(J))
150 NEXT J
150 FOR H=1 TO 8
151 READ UR(H)
152 DD1=2.26,2.1,1.03,2.11,2.72,10.32,7.72,2.86,2.3
153 NEXT H
155 FOR H=1 TO 9
156 DD2=2.26,2.1,1.03,2.11,2.72,10.32,7.72,2.86,2.3
157 NEXT H
160 L=(3.142/180)*151*COS(L):SIN(L):TAN(L)=TAN(L)
170 FOR J=1 TO 12
180 KT(J)=H(J)/HO(J)
190 DEC=(31.142/180)*(360/365)*(N(J)+284):DEC(J)=DEC
200 DEC=(31.142/180)*(DEC*DEC+DEC*DEC):SIN=DEC:DEC=DEC
210 X=1-TAN(T*L):X=1-TAN(T*L)
220 D(J)=(180/3.142)*X2
230 FOR J=1 TO 12
240 H=M+(3.142/180)*15*((5+)/(1-X4*X4))
250 X=1-COS(L)*COS(L)*SIN(L)*SIN(L)
260 X=1-COS(L)*COS(L)*SIN(L)*SIN(L)
270 X=1-COS(L)*COS(L)*SIN(L)*SIN(L)
275 IF J=3 THEN 285
280 S=L*SQR(1-X4*X4)
290 IF S=0 THEN 310
300 R=SIN(L)*SIN(L)*SIN(L)
305 IF R=0 THEN 310
310 IF R=0 THEN 310
315 R=R+R
320 PRINT *(5+3.142)*S
321 S=L*(180/3.142),DEC(J),R
330 AT=R
340 NEXT Y
350 IF J=3 THEN 360
360 DD1=R=RT,DL(J)*PRINT "RB"*RBJ(J)
370 RDH(J)=1.39-4.03*K(T(J)+5.53*K(T(J)+R(J)+RDH(J)
375 PRINT "RT"=R(J)
380 RDH(J)=1.39-4.03*K(T(J)+5.53*K(T(J)+R(J)+RDH(J)
390 RDH(J)=R(J)+RT(J)*(1+0.25*SIN(X(2)-3.142/180)*)R(J)*COS(X(2))
400 RT(J)=R(J)+RT(J)*(1+0.25*SIN(X(2)-3.142/180)*)R(J)*COS(X(2))
410 X=5*COS(L)*SIN(L)*SIN(L)
420 S=L*SQR(1-X4*X4)
430 RBJ(H)=COS(SALN)*SIN(SALN)
440 R(J)=1-RD(J)/RT(J)/RDN(J)+RD(J)/RT(J)+RDH(J)
450 R1(J)=R(J);RN(J)
460 HT(J)=R(J)*H(J)
465 RT=0
470 NEXT J
490 PRINT 'ENTER PRINTING INDEX, 1 TO PRINTER 0 TO SCREEN': INPUT PI
500 IF PI=0 THEN 760
510 LPRINT 'TABLE 1: SOLAR RADIATION FALLING ON THE TILTED AND HORIZONTAL SURFACES OF A HOUSE IN THE YEMEN EVALUATED ON 21ST DAY
520 LPRINT 'MONTH SOLAR RADIATION IN (MJ/M2-DAY) CLEARNESS FACTOR'
530 LPRINT 'EXT. HORIZONTAL VERTICAL'
540 LPRINT
550 LPRINT
560 FOR J=1 TO 12
570 LPRINT J;TAB(10);H(0(J);TAB(20);H(J);TAB(25);HT(J);TAB(45);RT(J);
580 LPRINT NEXT J
590 LPRINT LPRINT:LPRINT:LPRINT
610 LPRINT 'TABLE 2: COMPONENT OF SOLAR RADIATION AS EVALUATED ON THE 21ST
620 LPRINT 'MONTH DIFFUSE DIRECT GLOBAL'
630 LPRINT
640 LPRINT
650 FOR J=1 TO 12
660 LPRINT J;TAB(10);RD(J);TAB(20);RD(J);TAB(30);RD(J);TAB(55);R(J)
670 NEXT J
680 LPRINT LPRINT:LPRINT
690 LPRINT 'TABLE 3: COMPONENT OF SOLAR RADIATION AS EVALUATED AT THE SOLAR
700 LPRINT 'OF THE 21ST DAY OF THE MONTH
710 LPRINT
720 FOR J=1 TO 12
730 LPRINT J;TAB(10);RB(J);TAB(20);RN(J);TAB(30);RB(J);TAB(55);R(J)
740 LPRINT RDN(J);TAB(60);R1(J)
750 NEXT J
760 PRINT 'SPECIFY THE TYPE OF WALL (INT. FROM 1 TO 8):': INPUT H
765 PRINT 'ENTER FLOOR AREA (MULTIPLE OF 44 SQ. METER) ': INPUT HF
770 FOR J=1 TO 12
780 W(J)=.92/.943*9.271*KT(J)+.021*KT(J)*KT(J)
790 B(J)=-4.345+8.853*0.01*KT(J)-3.602*KT(J)*KT(J)
800 C(J)=.17-.306*KT(J)+2.936*KT(J)*KT(J)
805 D(J)=TE-(5.42*UH(J)-TA(J))
810 IF D(J)<0 THEN D(J)=0
820 FOR r=1 TO 8
825 G(h)=5*h
830 H(J)=UH(J)*H*HF+/.3*KW(J)
840 IC(J,K)=UH(J,K)*DEL(T,J)/(.849999*KG(K))
845 AG(J,K)=IC(J,K)*(.36/1000)*(R1N(J)*RN(J)*H(J))
850 F12=(IC(J,K)+B(J)+R1(J))*C(J,K)*H(J)*KX(J,K)
855 PHI(J,K)=EXP(F12)
860 PHI(J,K)=EXP(F12)
870 NEXT K
880 NEXT J
890 K=1
900 FOR J=1 TO 12
910 C1=/.123*F*(TE-18.3)*N1(J)
915 C2=/.13*F*3.6*N1(J)
920 C1=(.849999*H(J));N1(J)
925 TM(J)=N1(J)+(C2*U1(J))/((UH(J,K)*N1(J)*.024*3.6)
926 DIF=TM(J)
930 L(J)=UH(J,J)*DD(J)*.024*3.6
940 Q(J)=L(J)-G(J)
950 GH(J)=L(J)-1-PHI(J,K)+Q(J)
960 IF GH(J)<0 THEN Q(J)=0
970 IF GH(J)<0 THEN Q(J)=0
975 IF L(J)=0 THEN F(J)=1:GOTO 990
FL(J) = (1 - Q(J)/L(J))

FZ(J) = PHI(J,K) * FL(J)

X(J) = Q(J)/L(J)

IF X(J) = 0 THEN X1(J) = 1: GOTO 1020

IF X(J) > 0 THEN X1(J) = 0

X1(J+1) = X(J) + (1 - P) * Q1 * Q2

F(J) = PHI(J) + (1 - P) * Q1 * Q2

Qm(J) = 1 - F(J) * L(J)

OG(J) = PHI(J,K) * Q1(J)

ET(J) = (L(J) * F(J)), Q1(J)

IF L(J) = 0 THEN T1(J) = TNH(J): GOTO 1078

T1(J) = TNH(J) + QA(J) / L(J) * (TE - TNH(J))

T1(J) = T1(J) + L(J) / C(J,K) * TE - Tm(J)

IF T1(J) = 0 THEN X(J) = 1: GOTO 1085

PRINT "ENTER PRINT INDEX(1 HARD COPY, 0 ANOTHER RUN)"

INPUT PII

IF PII = 0 THEN 1406

LPRII = TE, AG(K), AF, AG(K), LCI

LPRIII = TE, AG(K), AF, AG(K), LCI

FOR J = 1 TO 12

LPRII = J; T1(J); T2(J); U(H, J, K); T(J)

LPRIII = J; T1(J); T2(J); U(H, J, K); T(J)

NEXT J

PRINT "ENTER PRINT INDEX(1 HARD COPY, 0 ANOTHER RUN)"

INPUT PII

IF PII = 0 THEN 1406

LPRII = TE, AG(K), AF, AG(K), LCI

LPRIII = TE, AG(K), AF, AG(K), LCI

FOR J = 1 TO 12

IF G(J) = 0 THEN G(J) = 0

LPRII = J; T1(J); T2(J); U(H, J, K); T(J)

LPRIII = J; T1(J); T2(J); U(H, J, K); T(J)

NEXT J

FOR J = 1 TO 12

LPRII = J; T1(J); T2(J); U(H, J, K); T(J)

LPRIII = J; T1(J); T2(J); U(H, J, K); T(J)

NEXT J

PRINT "ENTER PRINT INDEX(1 HARD COPY, 0 ANOTHER RUN)"

INPUT PII

IF PII = 0 THEN 1406

LPRII = TE, AG(K), AF, AG(K), LCI

LPRIII = TE, AG(K), AF, AG(K), LCI

FOR J = 1 TO 12

LPRII = J; T1(J); T2(J); U(H, J, K); T(J)

LPRIII = J; T1(J); T2(J); U(H, J, K); T(J)

NEXT J
1398 FOR J=1 TO 12
1399 LPRINT J;TAB(10);TE;TAB(30);TNH(J);TAB(40);TI(J);TAB(50);ETA(J)+100;
1400 LPRINT TAB(60);DIF(J);
1405 NEXT J
1406 FOR J=1 TO 12
1410 Q(J)=0;L(J)=0;Q(I)(J)=0;Q(A)(J)=0;Q(A)(J)=0;
1420 FZ(J)=0;ETA(J)=0;TNH(J)=0;DIF=0
1430 NEXT J
1440 PRINT"WOULD YOU LIKE ANOTHER RUN FOR DIFFERENT GLAZING AND SAME MATE.
1450 PRINT"ENTER 1 FOR YES 0 FOR NO":INPUT RI
1455 IF RI=0 THEN 1480
1460 IF RI=1 THEN K=K+1
1465 PRINT"K=";K
1470 IF K<8 THEN 900
1480 FOR K=1 TO 8
1490 FOR J=1 TO 12
1500 UAH(J,K)=0;AG(K)=0;IC(J,K)=0;XC(J,K)=0;PHI(J,K)=0
1510 NEXT J
1520 NEXT K
1530 PRINT"WOULD YOU LIKE TO RUN THE PROG. FOR ANOTHER MATERIAL?"
1540 PRINT"ENTER 1 FOR YES 0 FOR NO":INPUT RI1
1550 IF RI1=1 THEN 760
1560 END
10 DIM HO(12), M(12), HTS(12), HTN(12), TA(12), ND(12), N(J), NN(12)
20 DIM Q(12), TRS(12), TRC(12), QLS(12), QLC(12), G(12), QT(12), FS(12), FC(12)
30 DIM ETA$ (12), EFFS(12), EFFC(12), THNS(12), THNC(12), QWSX(12), QWUXC(12)
40 DIM TS(12), TIC(12), XX(12), QEX(12), QDS(12), 000(12)
50 DIM DCS(12), DCC(12)

200 FOR J = 1 TO 12
210 READ HO(J), H(J), HTS(J), HTN(J), HTE(J), TA(J), ND(J), N(J)
220 DATA 22.39, 18.7, 15.34, 0.65, 7.56, 15.4, 9.1, 31
230 DATA 32.31, 20.9, 12.09, 0.86, 8.44, 17.5, 9.9, 28
240 DATA 35.43, 22.7, 6.91, 0.86, 9.50, 18.6, 9.0, 31
250 DATA 36.31, 24.8, 0.86, 6.48, 10.4, 21.6, 8.6, 21
260 DATA 36.10, 24.8, 0.86, 6.84, 9.59, 24.7, 8.8, 30
270 DATA 33.79, 24.8, 0.86, 6.48, 10.4, 22.2, 7.3, 31
280 DATA 36.64, 24.8, 1.29, 2.16, 9.41, 21.6, 8.7, 31
290 DATA 36.14, 23.8, 6.91, 0.86, 9.50, 18.6, 9.0, 30
300 DATA 38.21, 24.8, 0.86, 6.48, 9.41, 21.6, 8.7, 31
310 DATA 38.10, 24.8, 0.86, 8.64, 9.94, 22.7, 8.8, 30
320 DATA 37.93, 24.8, 0.86, 6.48, 10.4, 21.6, 8.6, 21
330 DATA 37.69, 24.8, 0.86, 6.48, 9.41, 21.6, 8.7, 31
340 DATA 32.39, 18.7, 15.34, 0.65, 7.56, 15.4, 9.1, 31
350 NEXT J

500 PRINT "ENTER THE STORAGE FLOOR AREA IN (SQ. M.)": INPUT FA
510 PRINT "ENTER AC": INPUT AC
520 PRINT "ENTER TC": INPUT TC
530 GS = 1.47 * FA
540 GC = 3.36 * AC * FT
550 G1 = 12 * HTS
560 GR = 3.89 * FT
570 UAS = GS + GC + GR
580 UAC = GC + GR
590 NS = 0.24 * 3.6
600 BS = UAS + MC
610 BC = UAC + MC
620 FOR J = 1 TO 12
630 Q(J) = 1.3 * 3.6 * N(J) * AP
640 TRS(J) = TC - Q(J) / (UAS + N(J) * NS)
650 TRC(J) = Q(J) / (UAC + N(J) * NS)
660 QLS(J) = Q(J) / (UAC + N(J) * NS)
670 QLC(J) = Q(J) / (UAC + N(J) * NS)
680 G(J) = 1.47 * MTS
690 G(J) = 1.47 * MTS
700 Q(J) = Q(J) / (UAS + N(J) * NS)
710 FS(J) = 1.75 * (Q(J) / QT(J))
720 FC(J) = 1 / (FS(J) + 1)
730 IF FS(J) = 0 THEN FS(J) = 0
740 IF FC(J) = 0 THEN FC(J) = 0
750 IF FS(J) = 0 THEN FS(J) = 4
760 IF FC(J) = 0 THEN FC(J) = 4
770 ETAS(J) = (1 - EXP(+-N(J) / TC)) * (1 - EXP(+-N(J) / TC))
780 ETA$ (J) = (1 - EXP(+-N(J) / TC)) * (1 - EXP(+-N(J) / TC))
790 EFRS(J) = 1 - FS(J) * ETAS(J)
800 EFFC(J) = 1 - (1 - FC(J) * ETA$ (J))
810 IF EFFS(J) = 1 THEN EFFS(J) = 1
820 IF EFFC(J) = 1 THEN EFFC(J) = 1
830 IF EFFS(J) = 1 THEN EFFS(J) = 1
840 IF EFFC(J) = 1 THEN EFFC(J) = 1
850 IF EFFS(J) = 1 THEN EFFS(J) = 1
860 IF EFFC(J) = 1 THEN EFFC(J) = 1
870 THNS(J) = TA(J) + ((Q(J) + QT(J)) / (UAS + N(J) * NS))
880 THNC(J) = TA(J) + ((Q(J) + QT(J)) / (UAC + N(J) * NS))
1070 QAUXS(J)=QLS(J)-EFFS(J)*QT(J)
1080 QHUXC(J)=QLC(J)-EFFC(J)*QT(J)
1090 TIS(J)=TNHC(J)+(QAUXS(J); QLS(J); *T(J)+TA(J))
1100 TIC(J)=TNHC(J)+(QHUXC(J); QLC(J); *(T(J)+TA(J))
1110 HT(J)=11.6*XG(J; B+8.499999)*XTS(J)
1120 XX(J; *T(J)+TA(J))/MT(J)
1130 IF QAUXS(J)>0 THEN QCS=QCS+QAUXS(J)
1140 IF QHUXC(J)>0 THEN QHC=QHC+QHUXC(J)
1150 IF QAUXS(J)<0 THEN QCS=QCS+QAUXS(J)
1160 IF QHUXC(J)<0 THEN QHC=QHC+QHUXC(J)
1170 IF (TIS(J)-TC)<0 THEN QEXS(J)=0: GOTO 2000
1180 QEXS(J)=(UAS; NSNIL(J;)*TIS(J;)-TC)
2000 IF (TIC(J)-TC)<0 THEN QEXC(J)=0: GOTO 2030
2010 QEXS(J;)*(UAS; NSNIL(J;)*TIC(J;)-TC)
2030 IF QEXS(J)>QT(J) THEN QDS(J)=QT(J): GOTO 2060
2040 IF QEXS(J)=0 THEN QDS(J)=0: GOTO 2060
2050 QCS(J; QTC(J;)-QEXS(J)
2060 IF QEXS(J)>QT(J) THEN QDS(J)=QT(J): GOTO 2090
2070 IF QEXS(J)=0 THEN QDS(J)=0: GOTO 2090
2080 QDC(J; QTC(J;)-QEXC(J)
2090 QDC(J; QTC(J;)-QEXC(J)
2100 DCS(J; DCS(J;)/QT(J)
2260 PRINT J; TAB; QLS(J; TAB; W(J; TAB; 25); QAUXS(J; TAB; 35; J)
2290 PRINT TAB; 45; FS(J; TAB; 55; EFFS(J; TAB; 65; TC-TA(J)
2325 PRINT
2330 PRINT
2340 PRINT
2345 PRINT
2350 PRINT TAB; 5; TIS(J; TAB; 15; TAB; 25; TAB; 25; TAB; 35; TAB; 35; QEXS(J;)
2360 PRINT TAB; 45; QDS(J)
2370 ET=ST=ETS+ETAS(J)
2371 NEXT J
2374 GOTO 4040
2380 LPRINT"TC; ETAS; W; TTC; MC; MF; "
2390 LPRINT TC; TAB; 5; ETAS; 12; TAB; 15; TAB; W; TAB; 25; TAB; 35; TAB; 45; MC; 2450 LPRINT
2455 QHS=QHS 1000; QCS; QCS/1000; QHC=QHC 1000; QCC=QCC 1000
2460 LPRINT"MONTH TI; TI-TC; TC-TA; DELT; HT; F; EFF"
2470 LPRINT"(C); (C); (C); (C; SQ; P; H)
2480 LPRINT
2490 FOR J=1 TO 12
2500 LPRINT J; TAB; 5; TIS(J; TAB; 15; TIS(J; TAB; 25; TC(TA(J); TAB; 35)
2510 LPRINT TAB; 50; FS(J; TAB; 60; EFFS(J; TAB; 70; DCS(J)
2520 LPRINT
2530 LPRINT TAB; 5; TIC(J; TAB; 15; TIC(J; TAB; 25; FA(J; TAB; 30; EFFS(J;)
2540 LPRINT TAB; 70; DCS(J)
2550 LPRINT
2560 NEXT J
2570 LPRINT"MONTH; LOAD; SOLAR; AUX; DUMP; EN"E
2580 LPRINT ST; CON; ST; CON; ST
2590 LPRINT (GJ/MONTH; (GJ/MONTH; (GJ/MONTH;
2600 LPRINT
2610 FOR J=1 TO 12
2620 LPRINT J; TAB; 5; QLS(J; QLC(J; TAB; 35; QT(J; TAB; 45; QAUXS(J; QAUXC(J)
2650 LPRINT
2630 LPRINT TAB(55);QDS(J);QCC(J)
2640 LPRINT "-------------------------------------------------------------"
2650 NEXT J
2660 LPRINT "ANNUAL HEATING COLLING TOTAL"
2670 LPRINT TAB(25);QHS;TAB(35);QCS;TAB(45);QHS-QCS
2680 LPRINT TAB(25);QHC;TAB(35);QCC;TAB(45);QHC-QCC
2700 LPRINT "-------------------------------------------------------------"
4040 QCS=0;QCS1=0;QHS=0;QHS1=0
4050 QCC=0;QCC1=0;QHC=0;QHC1=0
4060 ET=ST=0
5010 PRINT "ANOTHER RUN(RI=1),STOP(RI=0)";INPUT RI
5020 IF RI=1 THEN 515
5030 END
10 DIM NL(12), TA(12), ND(12), NN(12), DO(12), N(12), H(12), H0(12)
11 DIM UX(9), RD(9), CP(9), U9(9), K(9), D(9)
15 DIM KT(12), DEC(12), H(12), OL(12), ABS(12), RBN(12), RBE(12), RNB(12)
20 DIM RDH(12), RS(12), RN(12), RE(12), RH(12), RBN1(12), RBN2(12), RTN(12)
30 DIM RDNH(12), RN(12), RL(12), HTS(12), HTN(12), HTE(12), MTH(12), T(12), E(12)
35 DIM D1(12), TR(12), G(12), QT(12), DL(12), F(12), ETAS(12), EFF(12), QUA(12)
40 DIM RDH(12), RS(12), RN(12), RBE(12), RNB(12), RBN1(12), RBN2(12), RTN(12)
45 DIM TNLH(12), TL(12), NH(12), ABSS(12), DE(12), DELT2(12), DELT3(12)
50 DIM XT(12), XS(12), XA(12), XH(12)

40 LPRINT "MONTH TA ND SOLAR ENERGY FALLING ON HOUSE WALLS"  
41 LPRINT " (MJ/SQ.M DAY )"  
42 LPRINT " HORIZ SOUTH NORTH EAST WEST"  
50 FOR Jul TO 12
60 READ NL(J), TA(J)
70 DATA 31,15.4,28,17.5,31,18.6,30,19.6,31,21.6,30,22.7,31,22.2,30,21.8
75 DATA 30,18.9,31,16.5,30,15.1,31,13.9
80 NEXT J
90 FOR Jul TO 12
95 READ ND(J)
100 DATA 9,9,9,9,9,9,9,9,9,9,9,9,9,9,9,9,9,9
105 NN(J)=24-ND(J)
110 NEXT J
107 FOR Jul TO 12
108 READ HA(J), H(J), H0(J)
120 DATA 15,18.7,28.93,47,20.9,32.31,74,22.7,35.43,105,24.1,37.6,135,24.6
130 DATA 166,24.8,38.1,196,24.8,37.98,227,24.8,37.69,258,23.8,36.14,268
140 DATA 319,19.8,29.67,349,18.4,27.93
150 NEXT J
151 FOR H=1 TO 8
152 READ UX(H)
153 DATA 1.47,1.29,3.36,0.72,5.3,1.29,2.9,1.9
154 NEXT H
155 FOR H=1 TO 9
156 READ RO(M), CP(M), U(M), K(M), D(M)
157 DATA 1520,837,2.26,0.465,0.140
158 DATA 1520,837,2.10,0.465,0.135
159 DATA 1520,837,1.83,0.465,0.111
160 DATA 2110,897,2.11,1.745,0.199
161 DATA 2110,897,2.72,1.745,0.126
162 DATA 2110,897,10.3,1.919,0.155
163 DATA 2110,897,7.72,1.745,0.215
164 DATA 2110,897,2.86,1.745,0.125
165 DATA 1700,897,2.30,2.271,0.350
166 UK(M)=(8.3*K(M))/(K(M)+D(M)*6.3)
167 TT(M)=RO(M)*D(M)*CP(M)*COS(0.001/X(M))
168 NEXT M
169 L=(3.142/180)*15: COSL=COS(L): SINL=SIN(L): TANL=TAN(L)
170 FOR J=1 TO 12
171 KT(J)=HA(J)*H(J)
190 DEC=(25.45)*SIN(3.142/180)*(360/365)*(N(J)+284): DEC(J)=DEC
200 DCI=(3.142/180)*DEC: COSD=COS(DEC): SIND=SIN(DEC): TAND=TAN(DEC)
210 XL=TAND*TANL: X2=ATN(X1/SQR(1-X1*X1))+1.5708: W(J)=(180/3.142)*X2
220 DL(J)=(180/3.142)*(2/15)*X2
230 FOR H=1 TO 13
240 HA=(3.142/180)*15*((5.5Y)-12.5): COSH=COS(HA): SINH=SIN(HA)
250 X3=COSD*COSL*COSH+SINL*SINH*SIND
260 S1=X3/SQR(1-X3*X3)
270 X4=COSD*SINH*COSL/SIND
271 IF X4<=4.1 THEN 290
280 S2=X4/SQR(1-X4*X4)
231

IF SIN(SAL)=0 THEN 310

300 RS=COS(SAL)*(COS(SAZ)/SIN(SAL))

301 RN=RS

302 RE=COS(SAL)*ICOS(SAZ)/SIN(SAL))

303 RW=RE

304 IF RS.0 THEN RS=0

305 IF RS.3 THEN RS=3

306 IF RN.3 THEN RN=3

307 IF RN.0 THEN RN=0

308 IF RE.3 THEN RE=3

309 IF RE.0 THEN RE=0

310 IF RW.3 THEN RW=3

311 IF RW.0 THEN RW=0

320 RTS=RTS+RS

321 RTN=RTN+RN

322 RTE=RTE+RE

323 RIS=RTS/RN

324 RTS=RTS/DL(J)

325 RTN=RTN/DL(J)

326 RTE=RTE/DL(J)

327 RW=RW/DL(J)

360 KGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

370 KCH(J)=1.0045+0.04349*KT(J)-3.1422*KT(J)+2.4325*KT(J)*KT(J)-3.11*KT(J)*KT(J)

380 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

390 RCH(J)=1.0045+0.04349*KT(J)-3.1422*KT(J)+2.4325*KT(J)*KT(J)-3.11*KT(J)*KT(J)

400 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

410 RS=RS+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

420 RTN=RTN+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

430 RGH(J)=1.0045+0.04349*KT(J)-3.1422*KT(J)+2.4325*KT(J)*KT(J)-3.11*KT(J)*KT(J)

440 RCH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

450 RGH(J)=1.0045+0.04349*KT(J)-3.1422*KT(J)+2.4325*KT(J)*KT(J)-3.11*KT(J)*KT(J)

460 RGH(J)=1.0045+0.04349*KT(J)-3.1422*KT(J)+2.4325*KT(J)*KT(J)-3.11*KT(J)*KT(J)

470 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

480 RTN=RTN+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

490 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

500 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

510 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

520 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

530 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

540 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

550 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

560 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

570 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

580 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)

590 RGH(J)=1.39+4.23*KT(J)+5.52*KT(J)*KT(J)-3.11*KT(J)*KT(J)*KT(J)
610 \text{UA} = G1 + G2 + G3: \text{PRINT} "UA"; \text{UA}
620 \text{NS} = 0.2 * X + 0.6
630 B = UA / AC
640 \text{FOR} J = 1 \text{TO} 12
650 Q(J) = AC * (8 * B * 8499999) * HTS(J) * N(J) * N1(J)
660 QL(J) = N(J) * N1(J) * NS * (TR(J) - TA(J))
670 F(J) = (1 - 75 * (QL(J) / QT(J)))
680 ETAS(J) = (1 - \text{EXP}(-ND(J) / TTC)) * (1 - \text{EXP}(-NN(J) / TTC))
690 \text{ETASLJr} = (TTC / ND(J)) * ETAS(J)
700 \text{IF} F(J) < 0 \text{THEN} F(J) = 0
710 \text{EFF(J)} = 1 - F(J) * ETAS(J)
720 \text{IF} EFF(J) < 0 \text{THEN} EFF(J) = 0
730 \text{IF} EFF(J) > 1 \text{THEN} EFF(J) = 1
740 \text{IF} QL(J) < 0 \text{THEN} QL(J) = QAUX(J) + QL(J)
750 \text{IF} QL(J) > 0 \text{THEN} QL(J) = QAUX(J) - QL(J)
760 TT(J) = TNH(J) + DEL1
770 \text{IF} TT(J) < TR(J) \text{THEN} TT(J) = TR(J)
780 \text{IF} TT(J) / TC \text{THEN} GOSUB 5000
790 \text{NL(J)} = (1 - TT(J) / TC) * N(J) * 24
800 \text{QE} = QE * 1000 / Q(J) * Q1(J) * 1000 : QUX(J) = QUX(J) * 1000 / Q(J) / 1000
810 QS = QUX(J) * 1000 : QUX(J) = QUX(J) / 1000
820 \text{FOR} J = 1 \text{TO} 12
830 XX = (QUX(J) / Q(J)) / (DELT2(J) / HTS(J) * G(J))
840 \text{LPRINT} J; TI(J); TA(B(10)); TI(J); (DELT3(J) / HTS(J))
850 \text{NEXT} J
860 \text{LPRINT} "------------------------------------------------------------------"
870 \text{NEXT} J
880 \text{LPRINT} "SYSTEM PARAMETERS"
890 \text{LPRINT} "AC; B; UA; TTC; TC; ETAS; LR; WIND"
900 \text{LPRINT} "------------------------------------------------------------------"
910 \text{LPRINT} "FACTOR: EFF (TR - TA) / HTS"
920 \text{LPRINT} "(SQ.M C/W)"
930 \text{LPRINT} "------------------------------------------------------------------"
940 \text{LPRINT} "ANNUAL AUX HEATING COOLING"
950 \text{LPRINT} "(GJ/MONTH)"
960 \text{LPRINT} "------------------------------------------------------------------"
970 \text{LPRINT} "ANNUAL AUX NEEDS (GJ) HEATING COOLING TOT-L"
1120 NEXT Y
1130 PRINT "WILL YOU LIKE ANOTHER RUN(1 YES, 0 NO)"; INPUT RI
1140 IF RI = 1 THEN 500
1200 END
5000 QEX = WNS*N1(J)*(T(J) - TC)
5010 IF QEX > QT(J) THEN Qh = QT(J); GOTO 5030
5020 Qh = QT(J) - QEX
5030 ABCS = QAB/QT(J)
5040 QS = (1 - ABCS)*QT(J)
5050 IF QS = 0 THEN F1 = 1; GOTO 5060
5055 F1 = (1 - QL(J)/QS)
5060 EFF1 = 1 - F1*ETAB(J)
5065 IF QAUX(J) > 0 THEN QAUX1 = QAUX(J); GOTO 5080
5070 QAUX1 = QL(J) - EFF1*QS
5080 TnH1 = TA(J) + (QS+Q1(J))/(WNS*N1(J))
5090 T11 = TnH1*(QAUX1/QL(J))*(TC-TA(J))
5095 IF T11 < TR(J) THEN T11 = TR(J)
5096 IF QAUX1 > 0 THEN QAUXH1 = QAUXH1 + QAUX1
5097 IF QAUX1 < 0 THEN QAUXC1 = QAUXC1 + QAUX1
5100 RETURN