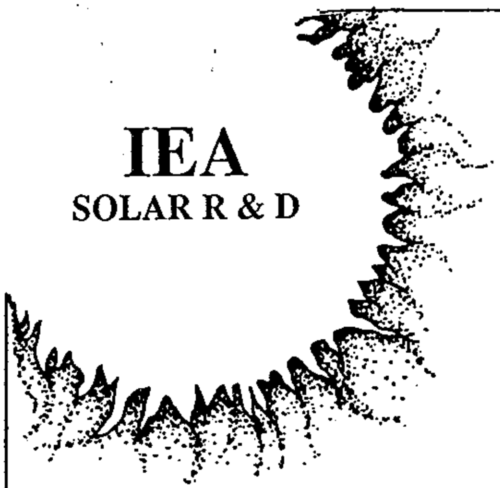

INTERNATIONAL ENERGY AGENCY
Solar Heating and
Cooling Programme

Task X

solar materials research and development

performance criteria for new solar materials (subtask A)

September1992

solar materials research and development

performance criteria for new solar materials

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Abstract:

The objective of Task X of the IEA Solar Heating and Cooling Programme was to investigate and to improve the energy efficiency performance and durability of materials used in solar buildings and solar heating systems. The purpose of Subtask A of the cooperative research, described in this report, is the establishment of performance criteria for new materials.

The principal results of the research are, first, a means of material selection for various solar applications and locations, and second, a methodology to estimate the energy benefits resulting from such selections.

The research covers two main material groups:

- spectral selective coatings on solar absorbers in solar hot water systems
- transparent insulation materials for building glazings

A step-by-step guide for material selection was developed using climatic data, system operating and boundary conditions, simulation programs and relevant material properties. A database of important material properties for the applications of solar energy was compiled to assist designers and manufacturers in selecting materials. The results, the ways and means to improve system performance and material durability, respond to the need to design and to operate systems more efficiently with respect to energy conversion, material conservation, and environmental quality preservation.

The methodology is illustrated with three different case studies on the energy benefits and degradation effects of materials.

In order to investigate the conditions effecting the durability of of spectral selective coatings within the micro-climate of solar collectors, TNO-Bouw Institute, Netherlands, developed a computer simulation model. Calculated results were compared with outdoor measured results. The degradation of system performance resulting from the changes in absorption and emission characteristic of selective solar absorber coatings was also investigated in detail by computer modeling at Waterloo University, Canada and Van Heugten Consulting Engineers, Netherlands. Finally, the material requirements and energy impacts for Transparent insulation in building were investiged through modeling of reference "shoebox" houses for several locations and orientations by researchers at Fraunhofer Institute, Germany and TNO-Bouw Institute in the Netherlands.

Key words: Climate, energy benefit, material properties, material selection, methodology, operating conditions, simulation, solar energy materials, spectral selective coating, transparent insulation.

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Availability: September 1992, see order form Annex C

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EXECUTIVE SUMMARY

The objective of Task X of the IEA Solar Heating and Cooling Programme was to investigate and improve the energy performance and durability of materials used in solar buildings and solar heating systems. The purpose of the cooperative research of Subtask A, described in this report, was the establishment of performance criteria for new materials. Researchers from Canada, Denmark, Germany, Italy, The Netherlands, and the United States participated in the Subtask.

The principal results of the research are (1) a means of material selection for various solar applications and locations, and (2) a methodology to estimate the energy benefits resulting from such selections.

The research covered two main material groups:

- spectral selective coatings on solar collector absorbers in solar hot water systems
- transparent insulation materials for building glazings.

A step-by-step guide for material selection was developed using climatic data, system operating and boundary conditions, simulation programs and relevant material properties. A data base of important material properties for the application field solar energy was compiled to assist designers and manufacturers in selecting materials. The results, a methodology for improving system performance and material durability, respond to the need to design systems which operate more efficiently with respect to energy conversion, material conservation, and environmental quality preservation.

The methodology is illustrated with three different case studies which were conducted on the energy benefits and degradation effects of materials:

- Micro-climate in Solar Collectors
- Effect of Selective Surface Properties on the Performance of Solar Hot Water Systems
- Effect of Transparent Insulation Properties on the Performance of Solar Walls for Dwellings

In order to investigate the conditions affecting the durability of spectral selective coatings within the micro-climate of solar collectors, TNO Bouw (Netherlands) developed a computer simulation model. Calculated results were compared with outdoor measured results in Switzerland. Subtask B involved a study on the degradation aspects and life time expectancy.

In the second case study, the degradation of system performance resulting from the changes in absorption and emission characteristics of selective solar absorber coatings was also investigated in detail by computer modeling at Waterloo University (Canada) and Van Heugten (The Netherlands).

Finally, the material requirements and energy impacts for transparent insulation in buildings (dwellings) were investigated through modeling of reference "shoebox" houses for several locations and orientations by researchers at the Fraunhofer Institute (Germany) and TNO-Bouw (Netherlands).

Additional Task 10 reports were prepared to document Subtask B research on accelerated life testing of solar energy materials and Subtask C research on characterization of new collector and window glazing. See Annex E.

Conclusions

- Regarding the degradation of thermal properties of spectral selective coatings of solar collectors:
    - The definition of failure of an absorber coating in most severe conditions is expressed as the performance criterion $PC = -\Delta\alpha_s + 0.25 \times \Delta\varepsilon = 0.05$. This definition corresponds to a 5% loss in efficiency.
    - The interior climate of solar collectors depends strongly on the ventilation rate (if ventilated). The time of wetness of solar absorbers can amount to as much as 3500 hours per annum in temperate climates.
- Regarding methods for estimating the influence of spectral selective coatings properties on the performance of solar absorbers in solar hot water systems:
    - The change in solar fraction due to variations in absorptance and emittance is relatively insensitive to geographical locations with solar fractions less than 0.5.
    - A 10% decrease in system performance caused by an absorptance decrease of 0.1 or an emittance increase of 0.4 may be considered a bound for most severe situations (locations and system variables).
    - A guideline for estimating the energy benefits of new spectral selective coatings is presented.
- Regarding methodology for estimating performance enhancement due to transparent insulation materials in dwellings:
    - A correlation equation was developed to express "gain utilization versus solar load ratio" with an excellent correspondence with calculated monthly gains. For the purpose of IEA Task X, this utilization function is satisfactory as a general approach to calculation of the impact of transparent insulation on the heating demand in dwellings.

  - A graphical method to estimate the energy benefits of transparent insulation on the south wall of dwellings is presented.

- Regarding material selection and evaluation criteria
  - A means of material selection for various solar applications throughout the world is provided as presented in the report of Subtask A.
  - A data base on material properties with most recent data (including the results of other subtasks) was developed. Information on ordering is provided in Annex C.

Recommendations

- Regarding material properties and degradation:
  - Research should be carried out for the total device (including edge seal and framing) in which a material is incorporated.
  - Material properties and application requirements should be specified with respect to spectral energy distribution.
  - Research on the application possibilities and the energy benefits of polymers should be continued.
  - The data bases of material properties need to be supplemented; data on the influence of environmental quality on material life expectancy, raw material contents, energy required for refining, processing, and fabricating, etc. should be added.
  - Tentative guidelines for applying materials in solar technology with respect to optimum energy conservation and minimum environmental damage are needed.

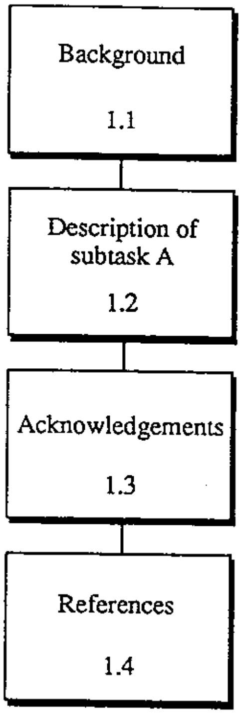
- Regarding solar collectors:
  - A study with an equivalent methodology should be carried out for other promising collector types, solar systems, and applications.
  - The study on the micro climate of solar collectors is very tentatively validated; research should be continued.

- Regarding transparent insulation:
  - Research and development should concentrate not only on material development, but also on reliable methods to assess the performance and the long-term stability of materials.
  - Since the overheating problem is a dominant obstacle to the economical use of transparent insulation, the most important research and development may be on cheap and reliable shading concepts.
  - Reliable design methods should be developed to assess the different material options.

- General:
  - Based on the experience in Task X, much more attention should be paid to the usefulness of research results in practice (product manufacturing and project design).

1. INTRODUCTION

G. Brouwer



1.1 Background

Continued technological and economic development and the prodigious use of materials and fossil fuels seriously attack our environmental resources. The challenge is to balance the material/ energy/environment system, while still meeting the requirements of the consumer and the producer. To this end, solar energy, which is both renewable and "clean", should be utilized on a wider scale.

Task X of the IEA Solar Heating and Cooling Programme, "Solar Materials Research and Development," was established to carry out collaborative research supporting the development of materials which have the potential to improve the performance, durability, reliability, and cost-effectiveness of solar energy systems used for heating, cooling, and lighting in buildings.

The context of material, energy and environment, in particular, localizes this study and largely defines fundamental criteria of the content of the research.

The Task was established in 1985 and completed in 1991. The intended audience for the results of IEA Task X consists of material scientists, system engineers, product developers and manufacturers.

The need to present well-balanced and credible results in this Task which represented an overlap between material science and system performance prompted the initiation of cooperative activities between material scientists and solar system engineers.

1.2 Description of Subtask A

Within the framework described above, the following objectives were identified for Subtask A:

- Investigate how new materials or assemblies of materials can improve system efficiency and expand the application of solar systems to a wider variety of needs.
- Estimate and evaluate the energy benefits of using new materials.
- Determine the necessary and quantitative criteria for the properties of advanced materials that can yield greater system and component performance.

To accomplish those objectives, the participants in Subtask A (1) developed a means of material selection for various solar applications and locations and (2) provided a methodology to estimate the energy benefits of these potential materials.

In May 1987, Subtask A completed survey reports on the state-of-the-art for selecting materials in the followings:

- selective absorbers
- collector and window glazing
- heat transfer media
- thermal storage media

The reports (Working Documents) include the compilations of existing data on performance levels and evaluation criteria and on material properties (ref. 1 and 2).

After a re-organization of the Task along material category lines in 1987, Subtask A focussed its effort on performance criteria for the following solar materials:

- spectral selective coatings on solar absorbers
- transparent insulation materials in buildings.

The first material category coheres with Subtask B (establishment of service-life prediction methods on solar absorbers) and is related primarily to active solar water system applications.

The second category coheres with Subtask C (development of methods of testing on optical, thermal and electrical properties and durability for new glazings) and is most primarily related to passive solar heating and daylighting systems.

Both Subtasks B and C, which were very material science-oriented, posed a challenge to the system engineers of Subtask A, who are mostly concerned with performance benefits. In turn, the material requirements compiled by system engineers in their continuous struggle for cost-effective systems, were comprehensive with respects to physical properties and service-life. The system engineers and the material experts have to match advanced physical science and simplicity of concept to deal with the low energy density of the solar flux.

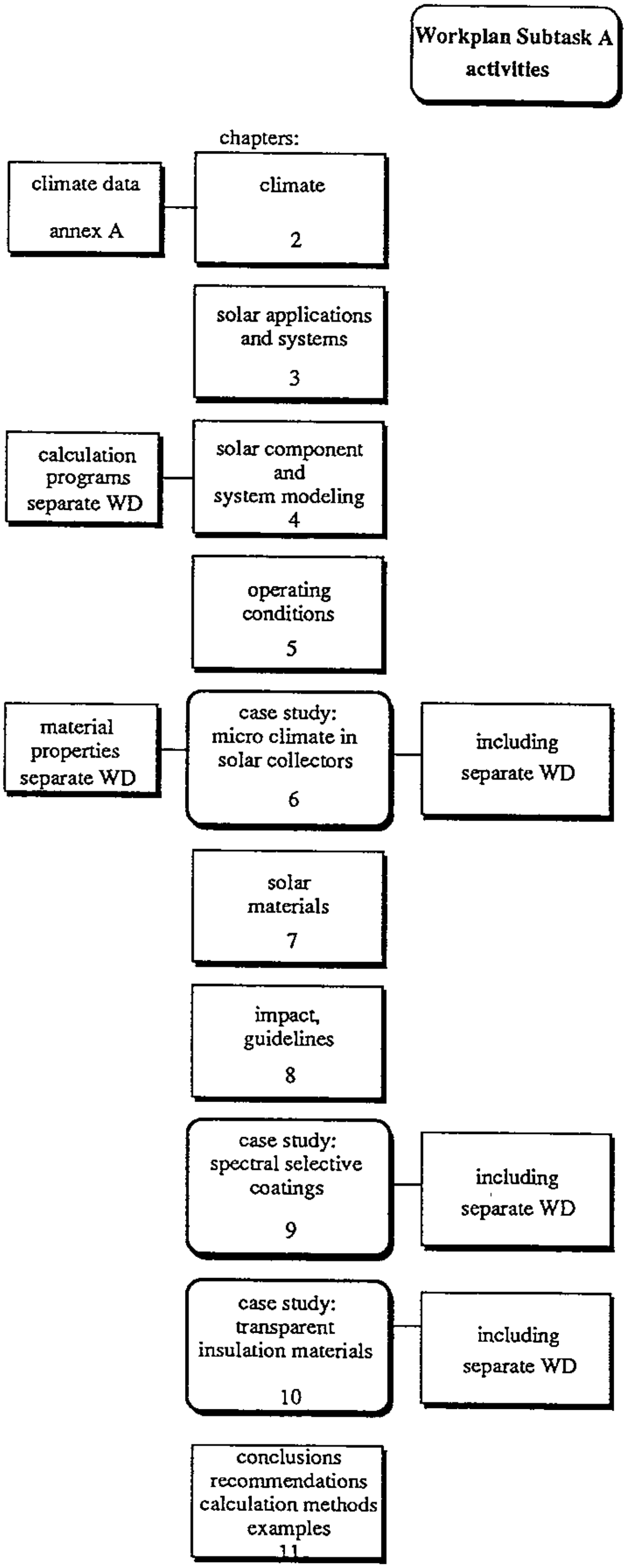
Each improvement that increases the benefits has many secondary problems such as esthetics, standards, approvals, guarantees, and return on investment. On one hand, scientific advances in physical science opens possibilities for new materials and systems. On the other hand, simplicity is the essence of many passive solar systems and is key to their acceptance in suitable climates.

However, physical science does not ignore simplicity and vice versa. The two must come together to meet the difficult challenges of those problems as the Task 10 researchers attempted to do.

Because of the broad field of research and the multiplicity of related activities in other IEA projects, the scope of Subtask A was frequently re-assessed and compressed. This led to omissions or restrictions in climate types, simulation codes, application categories, solar systems and costs. However, by following the procedures outlined in the report, some estimates can be derived for differing situations.

A survey of this research and a guideline for selection materials are presented in Fig. 1.1.

A database of material properties important for the application of solar energy was developed and presented in a separate Working Document to aid designers and manufacturers in selecting materials. However, a material must be considered in the context of its utilization, i.e., as a constituent of some specific structure or component.



GUIDELINE (stepwise) for material selection:

- Define climate data and criteria
- Select application and system
- Select simulation tool
- Establish operational conditions (actual,max.,min.)
- Consult material database and select materials
- Establish energy performance
- Concern degradation effects (include results Subtask B and C)
- Conclude on
  - . evaluation criteria
  - . lifetime prediction and
  - . energy benefits

  for selection materials

WD = Working Document IEA

Fig 1.1 Workplan Subtask A activities and guideline material selection

Therefore, evaluation criteria must be relevant to the complete system or structure. This implies that possible incompatibilities between a particular material and others used in the device have to be considered in the material selection process.

The technical results of Subtask A, a methodology to improve system performance and material durability, respond to needs to design systems which operate more efficiently with respect to material conservation, energy efficiency, and environmental quality.

We hope this report will prove useful in defining future IEA activities and that the knowledge gained from this collaborative research will be widely communicated.

1.3 Acknowledgements

Thanks are due to all those who participated during the six years of IEA Task X, particularly the Subtask A participants, the Subtask leaders and the Operating Agents. Their devotion and their great efforts dedicated to the successful accomplishment of the Subtask A activities, deserve our greatest appreciation.

Special appreciation is also extended to Mrs. A. Jansen of Holland Solar and the typists of Van Heugten for secretarial work and typing the manuscript respectively, and to Mrs. M.L. Mennen and Mrs. S. Blum for the final corrections of the English translation.

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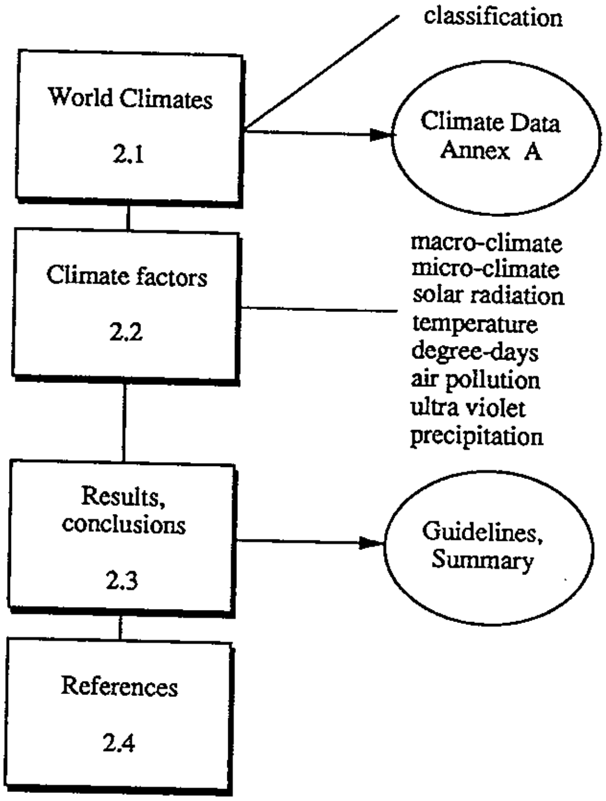
2. AMBIENT CLIMATE

G. Brouwer



2.1 World Climates

The recognition of differences and similarities between climate types has prompted climatologists to identify and to classify them according to their particular properties.

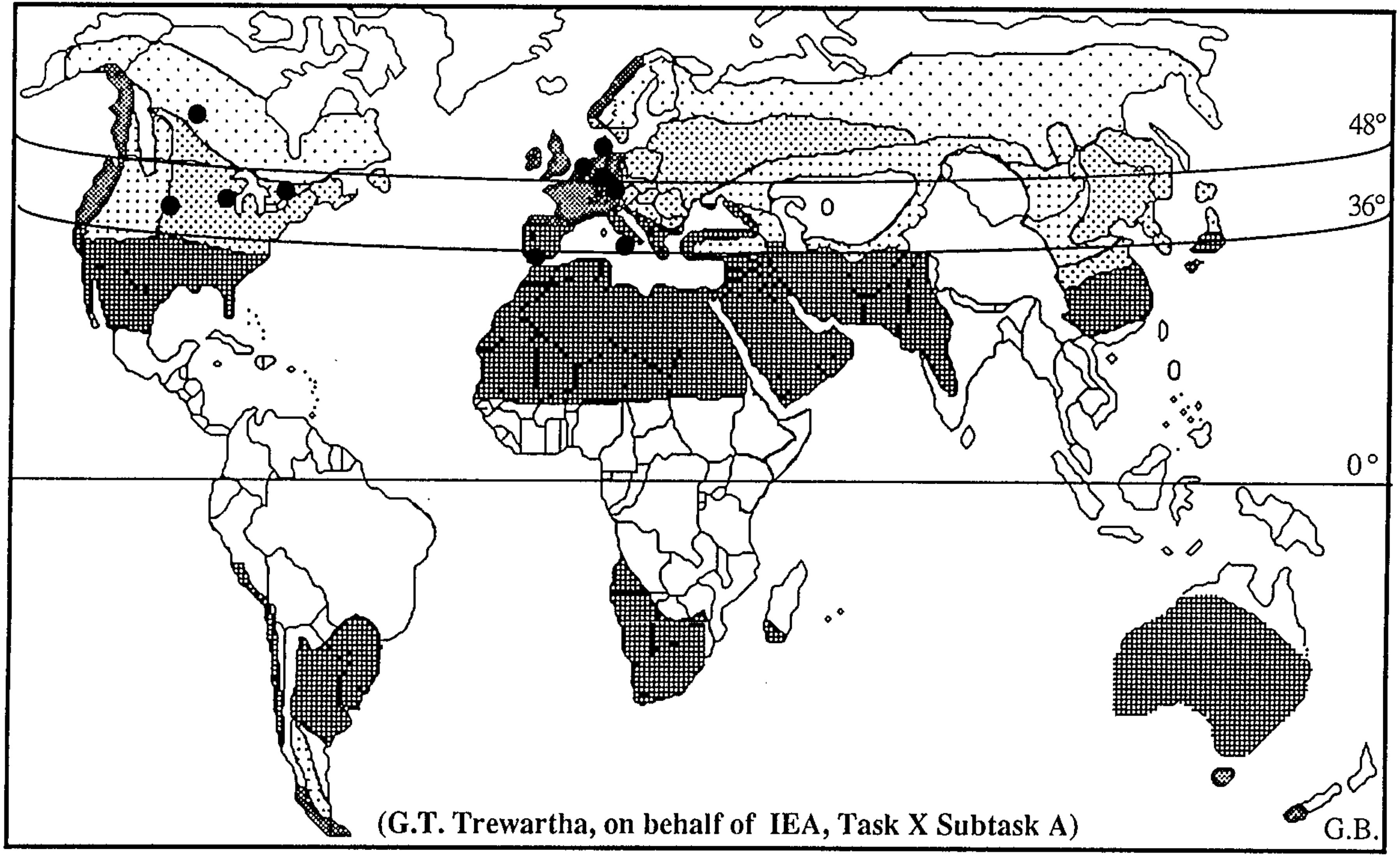
In the beginning of the 20th century, Köppen modified earlier classifications which are found in many publications of physical geography, especially those published in Europe and U.S.A. G. T. Trewartha, one of the leading American climatologists, produced a number of modifications of the Köppen classification (ref. 1, 2). Because of its relative simplicity and usefulness the Trewartha's classification is used here as a base for this part of the IEA study.

The rough climate classification is as follows :

Tropical humid, Subtropical, Temperate, Boreal, Polar, Dry and Highland.

Fig. 2.1 WORLD CLIMATES

▨ temperate continental
▨ temperate oceanic
▨ subtropical
▨ temperate semi-arid
▨ boreal



(G.T. Trewartha, on behalf of IEA, Task X Subtask A)

Note: Tropical, polar and highland climates not specified.

- ● Designated climates

The criteria to classify climate types for research on solar energy applications have emphasized ambient temperature and solar radiation. These variables have the primary effects on the system performance. Also important with respect to the durability of materials are the pollution in industrial and urban areas, the ultra violet radiation and the precipitation. Because of the application categories considered in this IEA research, viz., solar heating and solar hot water systems, the temperate climate is very important. The temperate climate, with 4-7 months over 10°C, is subdivided in two types: *Temperate Oceanic*, with coolest month above 0-2°C, rain in all seasons with autumn-winter maximum; and *Temperate Continental*, with coolest month below 0°C, rain in all seasons, and winter snow cover.

The *Temperate Semi-Arid Climate* in the dry region (evaporation is greater than precipitation) where less than 8 months are over 10°C is a climate type which in our study is considered to be equivalent with the *Temperate Continental Climate*. In the *Temperate Climate*, heating during the winter period is self evident. Another climate type may be added especially for Solar Hot Water Systems: the *Subtropical Climate*, in which 8-12 months temperatures are over 10°C, while the summer half of the year is dry. The *Boreal Climate* is the last designated climate type. Only 1-3 months are over 10°C and winters are severe, but the solar radiation is higher than in the *Temperate Oceanic Climate*. Fig. 2.1 which is based on ref. 1 shows the following climate regions:

> Subtropical, Temperate Continental, (= Temperate Semi-arid), Temperate Oceanic and Boreal.

As mentioned above, the energy benefits of using new materials are strongly affected by two phenomena related to solar radiation:

- solar radiation produces energy or heat gain
- solar radiation degrades solar exposed materials.

Energy benefits obviously also depend upon ambient temperature and energy demand. To make a selection of climate types for the IEA Task X investigations, local meteorological data for the classified climate regions were needed. Variables to be considered were :

- mean ambient temperature;
- solar radiation and/or sunshine hours;
- heating degree-days below a base temperature.

Also, the data on duration of ambient temperature combined with solar exposure are needed to estimate the material temperatures and their degrading influence on performance during the life time of the materials. For example: How many hours per year can stagnation temperatures over 90°C be expected in normal operation and in minimum operation?

Climate data were received from the participants for the following locations. They were compiled in a consistent tabular format and presented graphically (see Annex A).

Location	**Climate classification**
Denver, Colorado U.S.A.	Temperate Continental/Highland
Madison, Wisconsin U.S.A.	Temperate Continental
Rapperswil, Switzerland	Temperate Continental/Oceanic
Toronto, Canada	Temperate Continental/nearly Boreal
Edmonton, Canada	Boreal
Messina, Italy	Subtropical
Huelva, Spain	Subtropical
Freiburg, F.R.G.	Temperate Continental Oceanic
De Bilt, Netherlands	Temperate Oceanic
Copenhagen, Denmark	Temperate Oceanic

Table 2.1 presents the annual totals of several important variables for these climates.

Other degradation causes, such as pollution, ultra-violet radiation and precipitation, were discussed in a general way by the participants. See paragraph 2.2 Climate factors.

Climate locations		Yearly, averaged climate data		
		average temperature °C	total horizontal solar radiation Wh/m2.day	total heating degree-days (below 18-19 °C) Kd
Canada	Toronto	8.9	3617	3646
Canada	Edmonton	2.4	3451	5713
Denmark	Copenhagen	7.6	2782	2918
F. R. Germany	Freiburg	10.4	3033	3123
Italy	Messina	18.4	4753	327
the Netherlands	de Bilt	9.3	2591	3131
Switzerland	Rapperswil	10.1	2625	3848
U. S. A.	Denver	10.1	5316	3343
U. S. A.	Madison	7.3	3749	4294
Spain	Huelva	17.0	4884	1202

Table 2.1 Climate data

2.2 Climate Factors

Climate factors affect, on the one hand, heat gain from solar systems and, on the other hand, they influence degradation which may decrease the heat gain. In this chapter the climate factors are described in the context of both effects.

The use of solar radiation in an optimal way is the principal objective of each system for a particular applications. The climate factors are divided in two groups: the macro-climatic and the micro-climatic factors. The macro-climatic factors are generally well-known in weather forecasting and from climate atlases. The micro-climatic factors differ more or less from the macro-climate and reflect the local situation.

Macro-climatic factors have a direct influence on solar heating, cooling and hot water systems. Typical sources of climate data are the climatic atlasses such as the *European Solar Radiation Atlas* (ref. 3). A list of typical climate factors is as follows:

a. Temperature (annual, seasonal and daily)
b. Solar radiation (annual, monthly, daily, hourly)
c. Wind or air movement (direction, velocity, frequency)
d. Relative humidity
e. Rainfall, snow and hail.

Micro-climate factors are those of specific interest for an individual building, site, and immediate surroundings. Climatic characteristics become more relevant at this scale and may be tempered or exaggerated by local features, creating weather characteristics unique to the site. These characteristics may be influenced by its topography, landscaping and proximity to surrounding buildings, hills, water surfaces or open plains. The following characteristics should be considered at this scale.

a. Shading - time, duration and season of occurrence are important for heating as well as cooling
b. Air movement (direction, velocity, frequency)
c. Atmospheric quality (fog, haze) and direct vs. diffuse solar radiation
d. Relative humidity

The development of performance levels and selecting criteria for materials can be simplified by taking into account only a selected number of climate areas, representing with a certain accuracy most regions on earth (see previous paragraph).

The following climatic factors will be described below :

- Solar radiation
- Temperature
- Heating degree-days
- Air Pollution
- Ultraviolet Radiation
- Precipitation (rain, snow, hail)

2.2.1 Solar Radiation

Daily Radiation

Solar spectral irradiance strikes terrestrial surfaces hemispherically with a beam component and a diffuse component. Both are dependent on the instantaneous cloudiness, air-turbidity and air-mass. The direct terrestrial normal solar spectral irradiance is available from Standards (ref. 16). The diffuse terrestrial spectral irradiance varies considerably due to the atmospheric turbidity or amount of clouds in the air.

In general, averaged (over the total solar spectrum) values of the direct and the diffuse solar radiation are used. These values are also used in most of the energy conservation calculations.

The values of solar absorption, transmission and reflection in handbooks, data sheets, etc., are generally those measured in the N-H mode; which means that normal incident radiation and the detection of all (hemispherically) transmitted or reflected solar radiation.

For translucent materials mostly the H-H mode, which means diffuse (hemispherical) incident solar radiation and diffuse (hemispherical) detected transmitted solar radiation is used.

As the thermal and optical properties of new materials become more critical with respect to their spectral behaviour, the spectral distribution needs to be strongly emphasized in performance calculations.

Solar radiation, the main climatic parameter in this research, has a maximal intensity on the horizontal surface of 1.2 kW/m^2. Under ideal conditions the solar energy received by 1 square meter equals 6-8 kWh per day. The latitude of the regions usually considered for solar energy applications lies between 15° and 65°. In general, the solar radiation decreases with latitude while the gradient of the isolines is weaker in summer than in winter.

A comparison of the daily solar radiation on a clear day for various latitudes is indicated in Fig. 2.2.

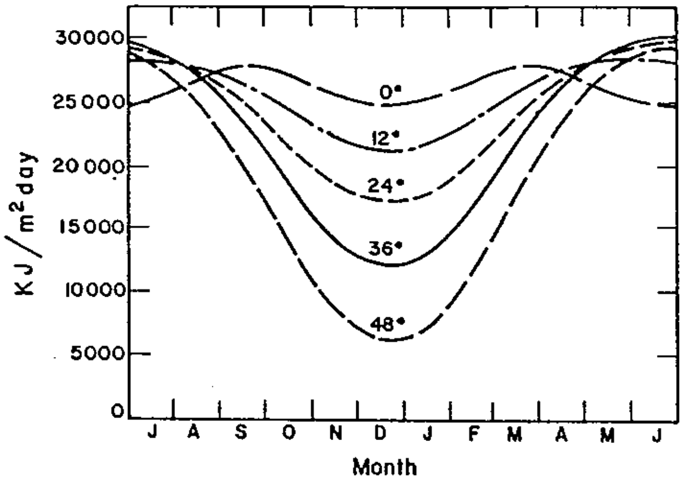


Fig. 2.2 Clear day solar radiation on a horizontal plane for various latitudes (ref. 13)

World maps with average mean daily solar radiation data (direct and diffuse radiation) are useful in areas of potential solar energy applications. As these maps do not show local, physical or climatological conditions, which greatly affect the solar energy availability, local radiation data are needed. Where these are lacking, it is possible to estimate radiation data from hours of sunshine by using empirical relationships.

In Annex A, the monthly average daily total radiation data are presented of 10 world locations (participating countries).

Diffuse Radiation

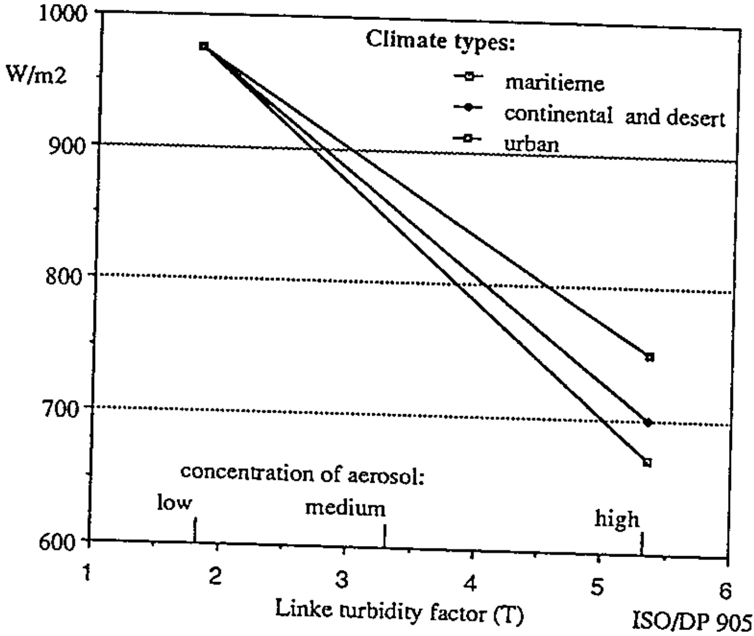
Of local importance is the ratio of the daily diffuse radiation to the daily total radiation affected by cloudy weather, e.g. in temperate maritime regions. Relevant figures are found again in ref. 13. The monthly average daily diffuse radiation can be estimated by the use of the climate data tables for a specific location (See Annex A).

Aerosol Particles

The influence of aerosol particles in the air also affects the direct solar radiation.

The direct solar radiation derived from data in ref. 14 is given in Fig. 2.3 as a function of the concentration of aerosol (Linke turbidity factor, T) for different climate types.

World map data or regional radiation data and the diffuse ratio of and direct solar radiation, as calculated above, can be used to make an estimate of the real total solar radiation for local situations.



ISO/DP 9059 SC1 N67 modified

Fig. 2.3 Turbidity effect on direct solar radiation (ref. 14)

Spectral Distribution

In addition to the solar radiation, direct and diffuse, it is useful to know the spectral distribution of this radiation in order to evaluate material properties. The behaviour of materials with regard to solar energy of specific direct and diffuse spectral magnitudes determines its performance. The coherent properties justify certain applications ranging from concentrating solar collectors to window glazing, etc. In the thermal analysis of this study, the Standard Curve of the ASTM E891 (ref. 16) of the solar spectral irradiance (Air mass 1.5) is very useful. Fig. 2.4 plots the Standard Solar Spectral Irradiance.

Other data come from Mecherikunnel and Richmond (ref. 17) and Moon (ref. 18).

For the measurement and evaluation of solar spectral properties either the weighted ordinate method (Standard Curve) or the method of 20 selected ordinates is used, Table 2.2. The last method, where averaged wavelengths represent equal energy amounts for an airmass 1.5, has a preference (ref. 16, ASTM 891).

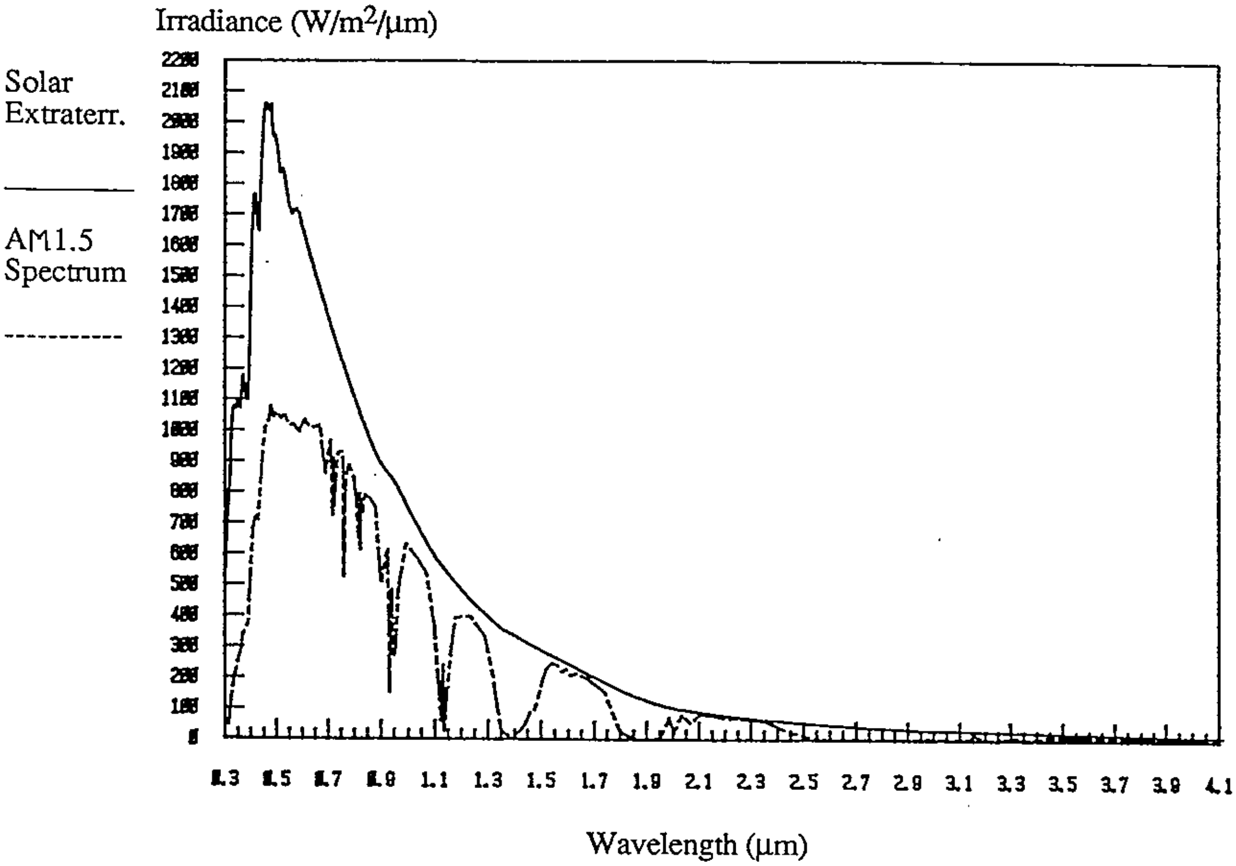


Fig. 2.4 Direct normal irradiance - US.STD Atmosphere

Table 2.2
Selected ordinates (nm):

389.8	555.4	707.0	896.7	1253.5
446.0	592.6	750.5	979.0	1524.3
483.3	629.5	795.4	1041.4	1700.1
519.1	666.7	844.8	1144.4	2322.0

2.2.2 Temperature and Heating Degree-Days (HHD).

To conduct analyses of solar systems in summer as well as in winter applications, the daily temperatures for each month of the year are needed. These are required to calculate monthly heat demand (heating purposes) and to calculate the heat losses of solar systems.

Ambient temperatures are also needed to calculate the number of hours during a year that components are exposed to specific temperatures. Mostly they affect materials in combination with solar radiation.

It can be said that climatic data are required to assess whether or not the building room or material is in "danger" of overheating.

The degree-day figures (°C days), which are used for the estimation of the heating load, are based on the balance point temperature, 17 - 19°C (T_{DD}). Heating is not used (degree days are zero) until outdoor temperature (T_a) falls below this balance point.

$$HDD = N_d\,(T_{DD} - T_a) \qquad (2.1)$$

where N_d = number of days per month or per year.

Larger internal gains, high insulation, or low infiltrations rates will lower this balance temperature. Most countries publish commonly accepted degree day base temperatures.

The Tables and Graphs of Annex A show the ambient temperatures and the degree day per month from participating countries in Task X. However, in the case studies more accurate (hourly) climatic data were used.

From IEC TC75 (ref. 20) an approximation of the "mean of many years' extreme values" was derived for some climatic zones of the earth. See Table 2.3.

Table 2.3

Type of Climate	Designated Climate Type	Low Temp., °C	High Temp., °C	Highest Temp. with Relative Humidity > 95%, °C
Extreme Cold	-	-65	+32	+20
Cold	Boreal	-50	+32	+20
Cold Temperate	Temperate Oceanic	-33	+34	+23
Warm Temperate	Continental and Semi-Arid	-20	+35	+25
Mild Warm Dry	Subtropical	-5	+40	+27
Warm Dry		-20	+40	+27
Extremely Warm Dry	-	+3	+55	+28
Warm Damp	-	+5	+40	+31
Warm Damp, Equable	-	+13	+35	+33

2.2.3 Air Pollution

Obviously, the exposure of solar materials to pollutants strongly depends upon the location. Each entry in Table 2.4 represents an annual average concentration of a pollutant in an urban environment of the U.S.A. where the concentration of that pollutant was particularly strong. For example, the concentrations of hydrocarbons (HC), ozone (O_3), and total oxidants (TOX) are given for Los Angeles, where many automobiles and abundant sunshine exist in a closed air basin, resulting in photochemical smog. Any one location would not have all the pollutants present in the concentrations listed, but a solar collector should be able to withstand exposure to any or all of the concentrations listed.

Concentrations are given in parts per million of volume (PPM) and micrograms per cubic meter (ref. 4-6). For three of the pollutants, a typical outdoor range considered in corrosion studies for copper and silver is also listed (ref. 7).

Table 2.4
Annual Average Concentrations of Pollutants in selected Urban Environments in U.S. (during 1965 - 1974)

Pollutant	CO	HC	NO_2	O_3	SO_2	TOX
Conc PPM (vol.)	5.6	4.8	0.03	0.023	0.03	0.04
Conc g/m^3	6440	3200	56	45	79	80
Range g/m3			2-160	10-90	3-185	
Los Angeles						
Conc PPM (vol.)	3.2	4.8	0.03	-	0	0.04

Symbol definitions: CO carbon monoxide, HC hydrocarbons, HO hydrogen oxide, NO_2 nitrogen dioxide, O_3 ozone, SO_2 sulfur dioxide, TOX total oxidants.

The most important air pollutants for durability research conducted by other subtasks are SO_2 and NO_2. Global average values and extreme values of these pollutants are needed. From ref. 21 we derived average values for SO_2 between 5 and 185 g/Nm^3 and a maximum value of 2500 g/Nm^3, which occur within a reasonable time period (day) in some industrial areas. For NO_2 the average concentrations amount to 2-160 g/Nm^3 and the maximum is 1500 g/Nm^3. Measuring methods are the Griess-Saltzmann Method and the TGS - ANSA Method.

2.2.4 Ultraviolet Radiation

Existing data on the ultraviolet radiation received at the surface of the earth are incomplete, but the following information has been assembled from several sources (ref. 4, 8-10, 16). The spectral distribution of solar energy reaching the earth's surface varies with time of day, season, latitude, and cloud cover. The approximate average fractions of the total insolation in the ultraviolet, visible, and infrared regions of the spectrum at the surface of the earth are:

	wavelength (nm)	fraction
Ultraviolet	280 - 380	5%
Visible	380 - 750	43%
Infrared	750 -	52%

Due to the absorption by the ozone in the upper atmosphere, the flux of solar ultraviolet radiation rapidly decreases with decreasing wavelength. At air mass one, the flux at 290 nm is less than one millionth of the flux at 315 nm. The small amount of radiation at wavelengths less than 315 nm is important because it is more damaging to materials and biological specimens than radiation at longer wavelengths. Therefore, the solar ultraviolet is often classified as being in two ranges (the UVA range extends slightly into the visible region):

range	wavelength (nm)
UVA	315 - 400
UVB	280 - 315

The shortest wavelength reaching the surface of the earth near the equator is 280 nm, and the shortest wavelength increases by approximately 5 nm for each 30° of latitude away from the equator. The ozone layer of the atmosphere is thinner at the equator, permitting greater transmission of the ultraviolet. However, the tropical air has greater turbidity, causing greater scattering. Therefore, at times of equal solar elevation angle (or air mass), the ultraviolet flux reaching the ground is approximately independent of latitude.

On a clear day, the total ultraviolet flux on a horizontal surface is maximum at noon and falls to low values in the morning and evening. The variation with time-of-day is much greater for the shorter than for the longer wavelengths. The beam and diffuse components are approximately equal at noon. The diffuse component is significantly greater than the beam component at times more than two hours from solar noon. On average, 40% of the UVB radiation is contained in the beam and 60% is contained in the diffuse component.

Clouds decrease the flux in all parts of the spectrum but water vapor absorbs the infrared more than it absorbs the UV. Therefore, the ultraviolet fraction of the total radiation may be larger when clouds are present.

The beam component of the UV increases with altitude above sea level because of the reduced absorption in the remaining air mass. However, the diffuse component of the UV decreases with altitude because the scattering is decreased. A few measurements indicate that the combined beam and diffuse flux on a horizontal surface increases by 15% per km in the Alps, and the beam radiation at wavelengths less than 313.2 nm increases by 35% per km at an altitude of 3 km in the U.S.A.

Air pollution can strongly reduce the UV radiation. Over a period of several years, the ratio of integrated radiation at wavelengths below 400 nm to integrated total insolation was 2.5% for Washington D.C. and 4.6% for Rockville, Maryland. Rockville is a suburban community located approximately 25 km from the large city of Washington.

Since global data for the ultraviolet are not available, examples of the available data are given here in order to provide a means for estimating the exposure of materials to the ultraviolet. These data are for horizontal surfaces.

Because much of the ultraviolet radiation is diffuse, the ultraviolet received by a surface tilted toward the equator is probably within a factor one-half to two of the ultraviolet radiation incident on a horizontal surface.

The ratio of the ultraviolet component between 290 and 315 nm to the total solar fluence was measured at Washington D.C., U.S.A. (elevation 100m, latitude 38.9°) for an 8-year period, with the results shown in Table 2.5. An approximate value of the UVB fluence at another mid-latitude location can be obtained by multiplying the total horizontal insolation by the factor for the appropriate month from Table 2.5.

This table shows the integrated monthly horizontal fluence of radiation with wavelength less than 313.2 nm in Washington, based on a 3-year experiment.

Table 2.5 Ratio of UVB to Total Insolation

Month	Ratio	Month	Ratio
1	3.45 x 10-4	7	10.08 x 10-4
2	4.26 x 10-4	8	9.88 x 10-4
3	5.85 x 10-4	9	9.37 x 10-4
4	7.44 x 10-4	10	6.87 x 10-4
5	8.90 x 10-4	11	4.40 x 10-4
6	9.75 x 10-4	12	2.90 x 10-4

Table 2.6 gives the annual fluence in spectral bands as measured at three locations (ref. 9). Each band is 5 nm wide, and centered on the indicated wavelength. The table also gives the sum of fluences for all wavelengths less than, and including, those of each band. The entries in this table are derived from graphical data, and are, therefore, approximate.

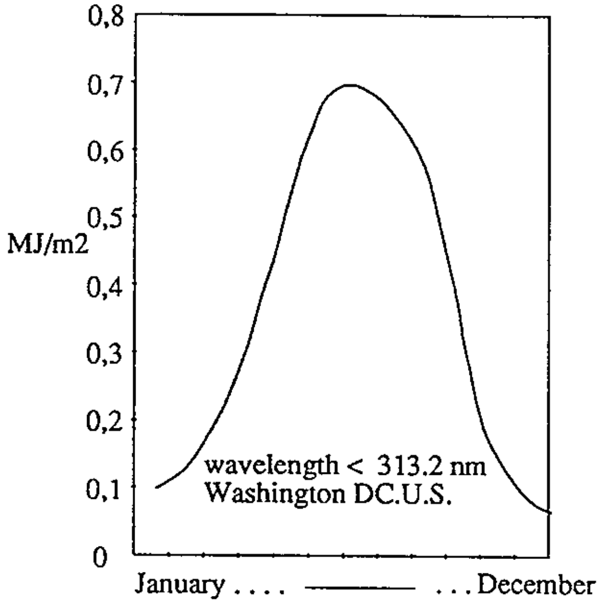


Fig. 2.5 UVB radiation

Table 2.6 Energy Fluence in 5 nm Bands and Fluence Sums: MJ/m2 year

	Balboa, Panama		Rockville MD, USA		Barrow AK, USA	
Latitude	9°N		39°N		71°N	
Band Center nm	Band Fluence	Sum	Band Fluence	Sum	Band Fluence	Sum
290	0.00009	0.00009	-	-	-	-
295	0.02	0.02	0.003	0.003	-	-
300	0.27	0.29	0.06	0.06	0.0006	0.0006
305	2.3	2.6	0.44	0.5	0.2	0.2
310	7.4	10	2.0	2.5	0.7	0.9
315	9.9	20	4.7	7.2	2	2.8
320	14	34	7.2	14	3.5	6.3

2.2.5 Time of Wetness

The wetting of surfaces is caused by dew, rain and melting hail or snow. In the estimation of degradation effects the environmental wetness and the influence of the relative humidity are combined in the total time of wetness.

In ISO TC 156 (ref. 19) these environmental conditions were characterized for different climatic zones (see Table 2.7). Note that the actual time of wetness is influenced by the type and surface structure of the material, the shape, mass and orientation of the device and the deposits on the surface.

For this calculation of the time of wetness the following conditions are applicable: relative humidity > 80% and ambient temperature > 0°C.

Table 2.7 Time of wetness

Type of Climate	Designated Climate Type	Time of Wetness hours/year*
Extreme Cold	-	0-100
Cold	Boreal	250-2500
Cold Temperate Warm Temperate	Temperate Oceanic Continental and Semi-Arid	2500-4200
Mild Warm Dry Extremely Warm Dry	Subtropical -	10-1600
Warm Damp Warm Damp, Equable	- -	4200-6000

* The wetness times include periods of condensation and precipitation

2.2.6 Hail

A detailed study (ref. 11, 12) concluded that there is little probability of damage by hail to solar collectors covered by tempered glass 4.8 mm thick. Investigators who wish to estimate the damage to materials by hail may use the following information.

The specific gravity of hailstones varies from 0.6 to 0.9 with a mean near 0.7. An approximate relationship for the terminal velocity, V in m/s, of a hailstone with diameter between 20 and 70 mm is

$$V = 9.8 + 0.4D \qquad (2.2)$$

where D is the hailstone diameter in mm.

For hailstones with diameters larger than 60 mm, the terminal velocity would be approximately

$$V = 43 + 0.21D \qquad (2.3)$$

Thin films are punctured by impact of about 38 mm hail stones or larger. Fiberglass reinforced plastics (1 mm thickness) will withstand impact by a 47 mm stone with slight crazing. Cracking results from impact by stones 54 mm or larger. It is quite clear that 4.8 mm tempered glass will experience a negligible breakage rate.

2.3 Results, Conclusions

- Main purposes of the collection of climatic data

The climatic data, presented in this chapter and in Annex A, are useful:

a. to calculate the energy benefits of solar materials during their lifetime in selected applications (see Chapter 3) and
b. to estimate the prospects of improvements in new materials for individual situations and locations.

In Chapter 8 both matters were described in the framework of the Subtask A objectives.

- Designated climate types

Because of the application categories considered in this IEA research, viz., heating and domestic hot water systems, the designated world climate types, that are expected to be most promising, are:

- Temperate climate (Oceanic and Continental)
- Subtropical climate
- Boreal climate

- Climate factors

The main climate factors affecting the performance or the degradation of materials and systems described in this chapter are:

- solar radiation, turbidity effect, spectral distribution
- temperature
- air pollution
- ultraviolet radiation
- time of wetness, precipitation, relative humidity.

Average values as well as extreme values were stated in support of evaluation criteria of materials.

- Some main climate factors of different climate types were presented on a yearly and a monthly basis in Annex A (see also ref. 3 and 22).

- The calculation of the energy benefits sometimes requires the spectral distribution of useful energy. The method of 20 selected ordinates is recommended.

2.4 References

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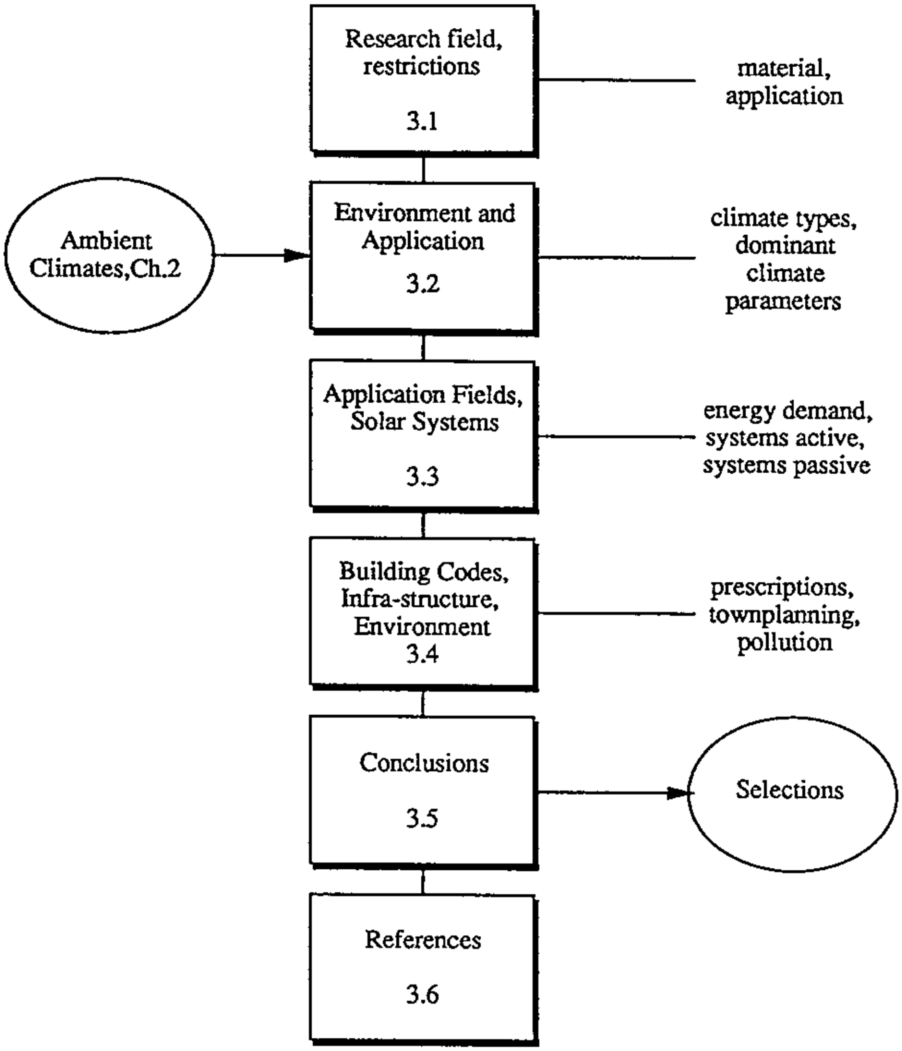
3. SOLAR ENERGY APPLICATIONS AND SYSTEMS

G. Brouwer



3.1 Research Fields

The realisation of a solar energy system occurs within a context of technical, legal and institutional requirements that increase in scope from the application (e.g. building) for which the system is designed, to the site, to the region and its climate, up to the goals of national energy policy. Regional climate conditions may exert a strong influence on thermal performance, on the choice of components and systems, and even on material selection.

In active solar systems the quality and the "capacity" of the collector absorber and the collector glazing (if applicable) are the most significant parameters for the energy gain. In passive solar systems the greatest significance is often attached to glazing materials for windows and walls (transparent insulation). Absorber and glazing materials are the focus of this report by Subtask A, and also the subject of Subtasks B and C respectively.

Some specific case studies, extracted from these research areas, were performed and described in Chapters 6, 9 and 10 respectively:

- Case study I Collectors: Description of the microclimate in solar collectors
- Case study II Collectors: Degradation effects of absorption and emittance of solar collector absorbers on the thermal performance
- Case study III Wall Glazing: The energy benefits of transparent insulation materials

Ultimately, the thermal performance and the economic feasibility determine whether realisation in a specific application field is justified or not. The annual local climate conditions (solar radiation), the specific annual heat or cooling demand, and the governmental rules and codes (health, safety, fire resistance) restrict a specific solar energy application and are fundamental first evaluation criteria to be satisfied before considering components and materials in a more technical way.

The primary evaluation criteria may be broken down in more detail:

a. Climatic factors include:

   Solar radiation, ambient temperature, hours of exposure, humidity, air pollution and ultra violet radiation (see Chapter 2). Annual variations of these data have to be considered.

b. Energy demand in different application fields include:

   Annual pattern of heat demand, operating temperatures demand, heat transfer medium, integrated heating or cooling systems, passive or active systems, standard dimensions of systems.

c. The local and national building codes and standards include:

   Attention to physical hazards and toxicity, structural safety, fire resistant, aesthetics, environmental pollution effects.

The selection of materials for a specific application in a more technical way, based on engineering properties in a specific field involves considering the operating conditions and the boundary conditions. These conditions will be estimated from a wide range parameter study and optimisation process.

3.2 Environment and Application

Energy conservation links the environment (climate) directly with the energy demand, which is in turn related to the application. Ambient temperature and solar radiation are the most important parameters of the operating environment (climate) in thermal solar applications.

Material degradation, which inevitably decreases the energy conservation benefits, depends upon climate factors as U.V.-aging, high temperature exposure, humidity and pollution.

The climate factors are divided in two groups (see par. 2.2): the macro-climatic and the micro-climatic factors. The macro-climate is generally well-known from weather forecasting institutes. The micro-climate factors differ slightly from the macro-climate because of local situations. In fact, most of the deviations from the macro climate will be of no direct significance for the selection of materials.

In Chapter 2 and in Annex A, monthly values of the most important climate factors are presented for some locations around the world. Table 2.1 summarizes these climate parameters in annual totals.

Looking at the most promising prospects of materials with respect to energy benefits priorities can be allocated to climate types for specific applications. The results of this research from Round Robin tests (Subtasks B and C) and from simulation programs (Subtask A) can be easily converted on behalf of other climates. Before performing this procedure a description and a classification of the pattern and the amount of the energy demand in each application is needed.

3.3 Application Fields and Solar Systems

A very important consideration in the economical application of solar energy is the temporal relationship between the demand for energy and the availability of the solar resources. Obviously, the simultaneous occurrence of energy demand for any application and solar radiation is most advantageous, e.g., solar drying systems perform very well by using solar energy directly.

Year-around direct use of solar energy is also applicable to solar water heating systems in all climate types considered. If the time shift between energy demand and solar resource exceeds a period of some days (absence of simultaneous occurrence) in, e.g., space heating the energy storage capacity has to be enlarged. Of course space heating demand exists by the grace of the "absence" of ambient solar (particularly in oceanic climates). In intermediate periods during the year (spring, autumn) the useful energy gain for heating remains attractive. However, in temperate continental climates and boreal climates with abundant solar energy during winter (low ambient temperature), promising prospects for the direct use of solar energy exist.

Solar collectors for swimming pools, used in summer, are mostly unglazed resulting in low material temperatures of the absorber. Cooling systems, also used in summer, require more efficient collectors to produce the high temperatures required to drive cooling machines which results in high collector material temperatures. Climate types and the different application fields with their specific system and material temperatures require an adaption of the component, the device, or the solar system.

Figure 3.1 shows the temperature levels associated with some active and passive applications of solar energy. The most important system parameters of each application category is briefly described hereafter.

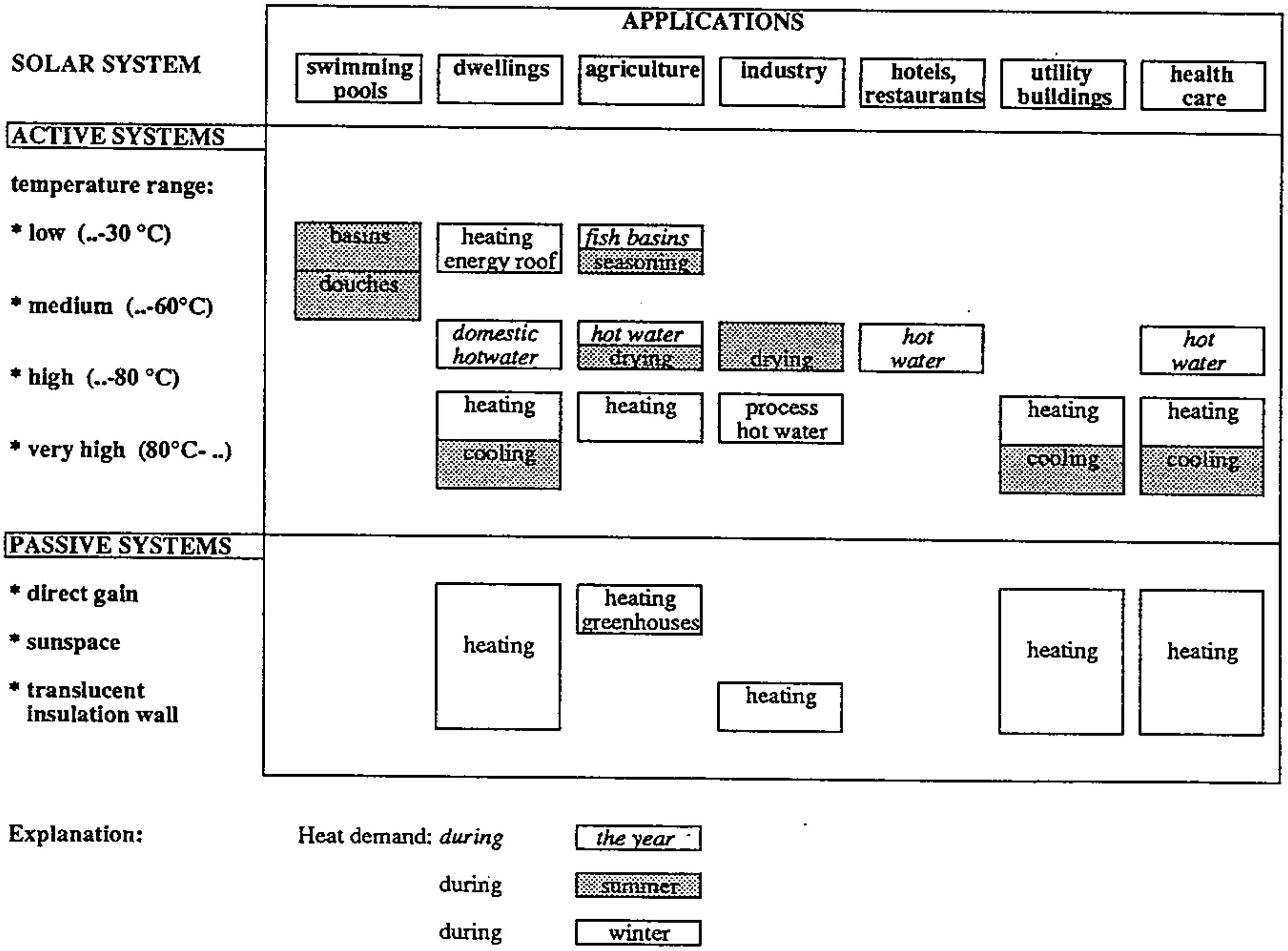


Figure 3.1 Solar Applications.

3.3.1 Application Categories

SWIMMING POOLS

- There is a large demand for heating of outdoor swimming pools that, in northern countries, are used only in the summer. The water temperature in swimming pools normally varies between 21 and 26°C. Due to this relatively low temperature requirement, low-temperature solar collectors are economic in systems for pool heating. The collectors with large dimensions, generally made of plastic and are situated in the neighbourhood of the swimming pool that acts as the load and heat storage of the system.

- Higher temperature water for shower (about 35-40 degr. C) requires better collectors and an additional heat storage tank.

DWELLINGS

- For heating during winter system temperatures from 30 to 80°C are required. Very simple collectors (uncovered, unisolated) can be used in combination with a heat-pump since the collector system temperature is very low. Low temperature heat from solar radiation and ambient air is transformed into usable heat at a temperature of about 50°C.

- Domestic water heating requires temperatures of about 60 to 70°C throughout the year. Solar heat is stored for 1 or 2 days.

- Due to the lack of solar heat during the period of space heating, attention must be paid to the storage of solar heat. In spring and autumn short time storage (some days) and in winter long term storage (some months) can be considered. In general, to achieve better collector performance low-temperature heating systems are much more appreciated in comparison with high temperature systems.

- Solar heat driven cooling systems require a high temperature (about 80°C). These systems are generally economical only in warm sunny countries where abundant solar energy can be captured.

- Passive solar heating is achieved by capturing solar radiation through windows of dwellings, in conservatories (serres), and through transparent insulation materials covering opaque walls. Best results are expected at locations with a sunny climate during winter (temperate continental and boreal climates).

AGRICULTURE

- Solar energy systems for fish basins are similar to solar energy systems for swimming pools. Depending on the fish culture the temperature of the basins will differ (eel 25°C, tarbot °C).
- Seasoning of products or drying require the same temperatures.
- In the livestock sector, hot water is needed for food preparation, cleaning of equipment and drinking. During the year water temperatures from 40 to 80°C are desired.
- Solar drying is practised in countries with sunny climates. The relationship between the parameters concerning the energy requirement for the different products in a drier is relatively complex since the process temperatures determine the product quality. The heat storage can be avoided. Air collectors are usually used.
- Potential applications for solar energy in livestock house conditioning are mostly in pig and poultry rearing.
- Greenhouses generally have to be cooled in southern countries (summer) and to be heated in northern countries (winter). Most important is the balance of a high solar light transmission for plant growth and the captured heat.

INDUSTRY

- Solar drying requirements are similar to those in agriculture.
- The food industry requires large amounts of hot water with temperatures from 40 to 100°C throughout the year.
- Transparent insulation materials covering opaque walls and roofs will capture solar heat for building heating purposes.

HOTELS, RESTAURANTS

- For kitchens in restaurants and for rooms, kitchen and laundry in hotels, hot water with a temperature of about 60 to 70°C is used throughout the year.

UTILITY BUILDINGS

- Heating, mostly during winter, requires temperatures of about 30 to 80°C. As already mentioned for heating of dwellings, the storage of heat is more complex.
- Heating as well as cooling is needed for climatisation. Cooling, mostly during sunny periods, with absorption cooling machines requires heat with a temperature of about 80°C or more.
- Passive solar energy systems can be used for heating. Good results can be expected capturing solar heat through windows and through transparent insulation materials covering opaque walls.

HEALTH CARE BUILDINGS

Applications in this category are similar to those in the hotel, restaurant and utility buildings categories.

3.3.2 Types of Solar Systems

The analysis of active solar systems results in a general scheme (Fig. 3.2), in which all current systems are incorporated, e.g., compact (integrated) systems, air- and liquid collector systems, direct and indirect heating, gravity and forced circulation, etc. The survey shows the large number of possibile applications in which components and materials have to withstand different operational conditions.

The research of this report focusses on the components that use the designated materials: solar collector glazing and absorbers (especially the absorber coatings).

Only one group of applications was selected for further research as indicated in Fig. 3.2, viz., solar water heating systems.

A general scheme for the analysis of passive solar systems was developed (Fig. 3.3), in which some of the techniques of passive solar heating are incorporated (Fig. 3.3a).

The research in this report focusses on the glazing materials (especially transparent insulation materials).

The emphasized application category is space heating for dwellings. The main selection criteria were shown in Fig. 3.3.b.

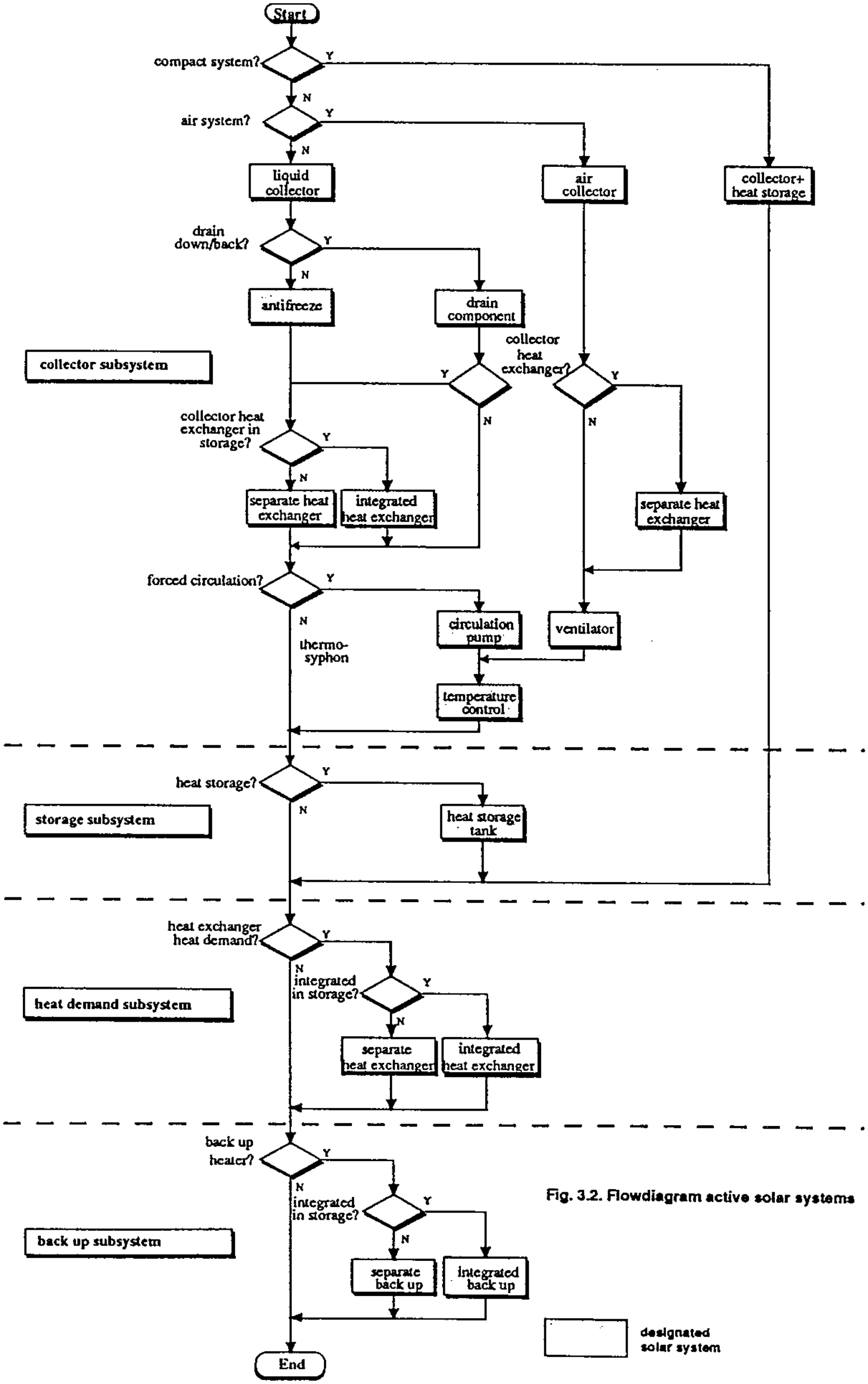
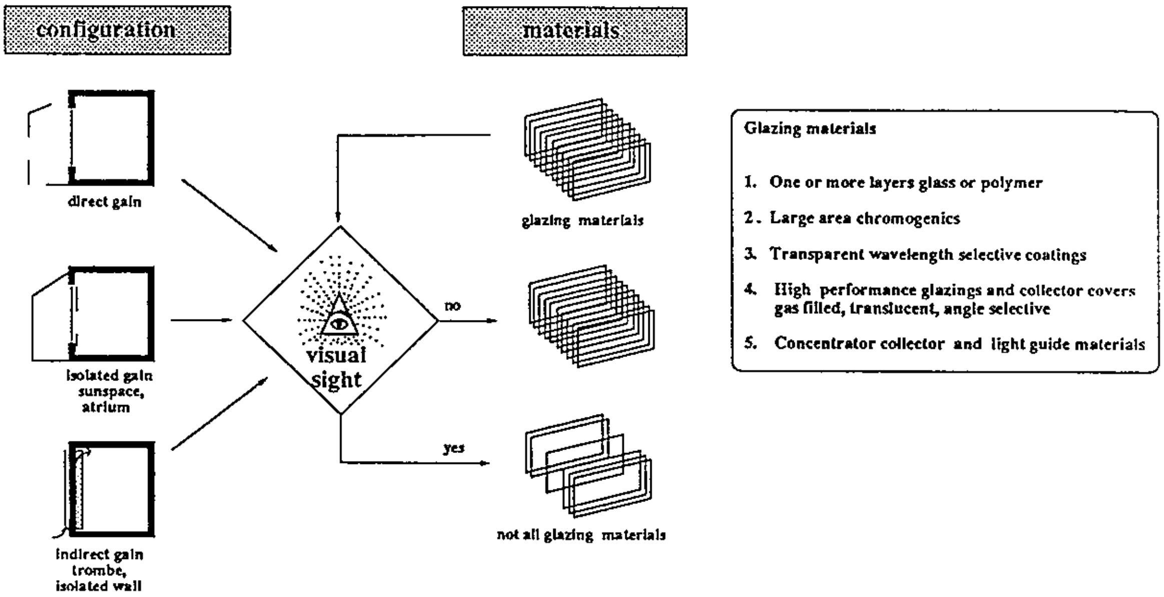


Fig. 3.2. Flowdiagram active solar systems

a. First selection glazing material



Glazing materials

1. One or more layers glass or polymer
2. Large area chromogenics
3. Transparent wavelength selective coatings
4. High performance glazings and collector covers gas filled, translucent, angle selective
5. Concentrator collector and light guide materials

b. Second selection glazing material

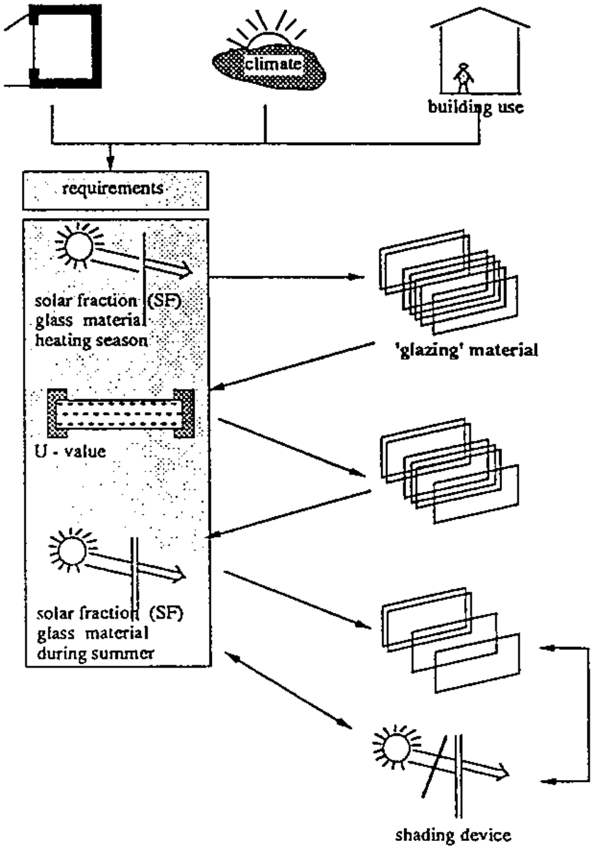


Fig. 3.3 Selection Glazing Materials.

3.4 Building Codes, Infrastructure and Environmental Aspects Affecting Solar Applications

Due to non-technical and somewhat technical reasons, local governmental institutes prohibit the application of some materials, components or solar systems.

Some factors that are covered by special codes or acts may include:

- Density and growth of development - in consideration of solar rights, shading, glare, obtrusive installations.
- Building materials and architectural character - consideration of mass and geometry or prevalent building types.
- Building codes - to the extent that they constrain solar applications.

The justification of applications of solar systems must also take account of the following natural factors:

- Sun altitude and declination - for consideration of collector aperture tilt and shading, etc.
- Orientation - to determine orientation and building geometry.
- Topography - for consideration of building into slopes, earth berming, and otherwise maximizing southern exposure and minimizing others.
- Altitude - for the effects of atmospheric pressure and density.
- Vegetation - as it effects shading, reflection and air movement.
- Ground temperature - as it effects ground water temperature and earth exchange cooling.
- Water table height - for considerations of excavation, burying of storage elements, earth contact housing, and wetting insulation.
- Water quality - its mineral content, pH, etc., when used for heat transfer fluid or thermal storage.

The environmental pollution, material recylcing and material waste are still in global discussion. In future research these issues have to be strongly emphasized. The knowledge of material requirements depends upon ongoing research, where the feasibility of materials and devices has to be proved. However, the importance of pollution, recycling and waste has to be underlined.

3.5 Conclusions

- Materials and applications

The occurrence of so many types of solar energy applications and solar systems with different solar loads and solar fractions, means components and materials have to match in an extensive set of operating conditions.

Research on performance aspects of solar materials should be focussed on a particular application category by considering the strict mutual relation of material and application.

- The selection of climate types and applications

Regarding the general goal of this task (to evaluate the energy benefits obtained by using new materials in different solar energy application) specific climate types emerge as most promising in a certain application.

This leads to the following selection of materials, applications, systems and climates for case studies:

a. Absorber Coatings and Substrates
  - hot water production
  - solar water heating systems (liquid, forced circulation, drain back system, heat storage with one heat exchanger and a separate auxiliary heater)
  - subtropical climate (Messina, It) or temperate continental climate (Denver US).

b. Transparent Insulation Materials
  - space heating of dwellings
  - solar-radiated masonry walls covered with transparent insulation material (controlled air ventilation, vertical south faced)
  - temperate continental climate (Denver or Madison, US) or boreal climate (Edmonton, Ca).

The impact of the thermal properties of the designated materials on the thermal performance is described for these situations in Chapter 8. Relationships were developed for other climates (locations) and systems in Chapters 9 and 10, to which Chapters 2 (Climates) and 5 (Operating Conditions) contribute.

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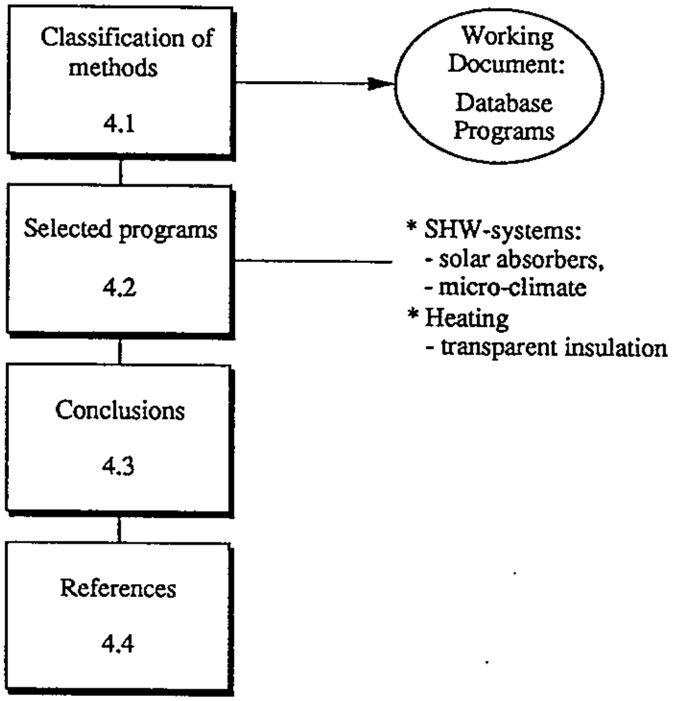
4. COMPONENT AND SYSTEM MODELING

G. Brouwer



4.1 Classification of Methods in Component and System Modeling

One of the aims of activities in Subtask A is the estimation of the energy yield of solar energy systems due to improved or new materials. The modeling of these systems by thermal network programs is very useful in this regard. In this chapter some simulation programs that were used in the case studies of Subtask A are presented. Prior to that, some basic classifications of existing programs, that address performance attributes of solar component and system design are discussed.

Calculation programs were developed from instantaneous or time integrated energy balances with periods up to a year for buildings and solar systems. Instantaneous energy balances were used more often for components and its materials. These programs allow the effects of material properties to be considered more explicitly. Programs for the calculation of annual energy balances can be used for the research on energy benefits of materials. In these programs the results of the instantaneous balances can be included, e.g., by means of correlation formulas, to minimize computing time.

In the IEA work two more or less independent major classification schemes are presented, namely by calculation principle and by complexity.

a) Classification by Physical Principle

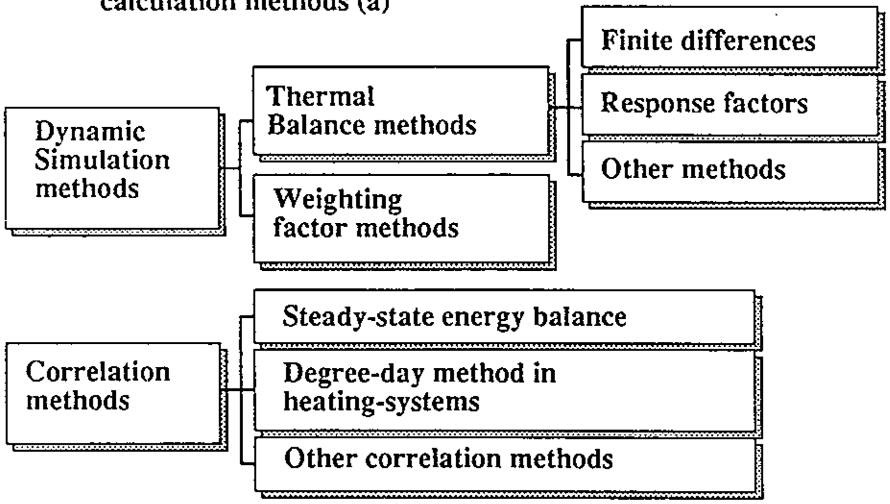
In general two main categories of methods to calculate annual energy balances in buildings and solar systems can be distinguished (ref. 1): dynamic simulation methods and correlation methods.

Dynamic simulation methods are based on the solution of more or less detailed thermal models of the building, system or device in short time steps, e.g., hour by hour.

Correlation methods, give the energy balance without taking into account the specific time influences. Correlation methods calculate e.g., the energy consumption with a simple relationship between the thermal losses of the building and averaged weather data for longer periods or calculate in detail the energy balance in steady state situations (instantaneous energy balances). The classification which is based on calculation principles is summarized in Fig. 4.1.

According to the main goals of Subtask A, a) to evaluate the energy benefits of new materials in most promising situations, and b) to deliver guidelines and design tools for material selection, both calculation methods were considered.

Fig. 4.1 Classification of calculation methods (a)



b) Classification by Complexity

Another classification scheme for passive solar heating and for active solar systems has two categories: the detailed method and the simplified method.

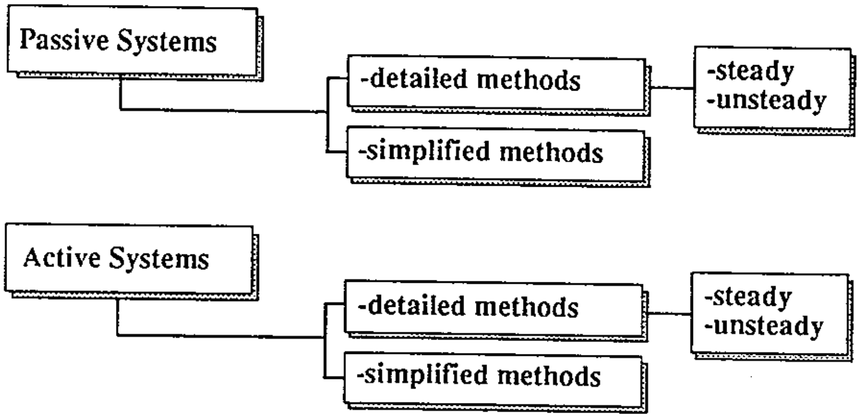
In detailed methods the thermal aspects of components, systems or buildings are modeled in detail. Instantaneous (or steady state) and dynamic (unsteady state) calculations, can be distinguished.

Simplified methods, however, use very simple relationships for system modeling as well as for dynamic effects.

The classification, which is based on the complexity of the models, is presented in Fig. 4.2.

This classification of methods was used in the categorisation of available computer programs for thermal analysis of buildings and solar systems. See working document, "Solar System and Component Modeling. Database of Calculation Programs" (Annex C).

Fig. 4.2 Classification of calculation methods (b)



4.2 Selected Programs

Based on the main goals of Subtask X activities and the availability of calculation tools for IEA participants the following guidelines in the selection procedure of simulation programs were established:

- Task X activities shall not emphasize the development of new programs.
- The results from other IEA-Tasks (Solar Heating and Cooling Programme) and IEA-Annexes (Energy Conservation in Buildings and Community Systems Programme) on simulation tools shall be used.
- Case study participants who are carrying out the calculations must be familiar with the selected simulation tool.
- The selected calculation programs will emphasize the designated material and its thermal properties.

The main interest in IEA Task X is in glazing materials (Subtask C) for active and passive systems and in materials for absorbers of solar collectors (Subtask B) for active solar systems. During the period of the Subtask A activities a large number of computer programs that could be used for the assessment of the energy benefits of material properties come to the attention of the participants. Therefore, literature research on reports from IEA Tasks and Annexes and on reports from CEC was carried out which resulted in a comparison of characteristics of some selected programs (Table 4.1).

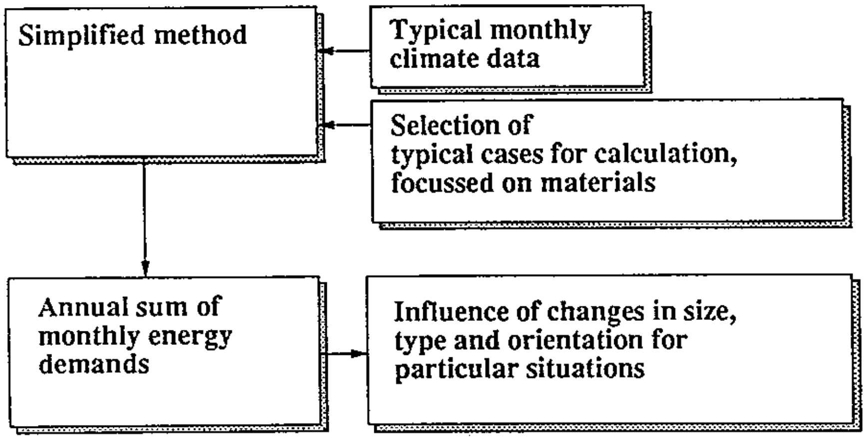
The programs were briefly described in the working document. For some programs that were used frequently in Subtask A activities a program description was added. For glazing systems in buildings, especially the transparent insulation materials (passive solar heating) the "SIMHAUS" simulation tool was used (ref. 1). The simulation tool "WATSUN" was used for active solar-systems analyses, especially for the case study: "degradation effects of the collector absorber in solar domestic hot water systems".

The "CNDNS" programs was partly developed in support of the calculation of the micro-climate in solar collectors. These programs are all of the 'detailed' and 'unsteady state' types and belong to the type 'dynamic simulation methods' class. Parametric studies were performed between certain main variables.

Based on these results correlation or simplified methods were developed for the estimation (with reduced, but sufficient accurate) of results for many other situations.

See, for example, Fig. 4.3 (ref. 2). Guidelines and design tools derived in the particular case study will be presented in the corresponding chapters.

Fig. 4.3 Selected sensitivity study
using the simplified method



4.3 Conclusions

From a number of frequently used computer programs, see working document, "Solar System and Component Modeling. Database of Calculation Programs", that cover the thermal performance analysis of buildings and solar systems, some simulation programs were selected that are:

- applicable in the designated case studies of materials
- well known by the end-user participants of the case studies.

The selected simulation programs are:

- SIMHAUS for calculations on thermal performance of transparent insulation materials in buildings,
- WATSUN for calculations on degradation effects on the thermal performance of the collector-absorber in solar domestic hot water systems,
- CNDNS for calculations on micro-climate in solar collectors.

Detailed as well as simplified simulation tools were used in the evaluation process of the case studies. They were helpful in the analyses of the final results.

TABLE 4.1 Type of Calculation Program	Calculation programs described in Working Document (see Annex C)																				
	1. DOE	2. DYWON	5. ESP	8. PASSIM	9. SERI-RES (Suncode)	10. SIMHAUS	11. SPECTRUM	12. SUPERLITE	13. TCM-HEAT	16. VISION	18. WINDOWS	20. GWERT	21. TABS	3. EMGP2	4. ESM	6. EURSOL	7. HEUSOL	14. ZBOIL/ZVI	15. TRNSYS	17. WATSUN	19. CNDNS
PASSIVE Solar Systems	o	o	o	o	o	o		o	o												
Components							o			o	o	o	o								
detailed	o	o	o	o	o	o	o	o		o	o	o	o								
simplified									o												
steady							o	o	o	o	o	o	o								
unsteady	o	o	o	o	o	o															
ACTIVE Solar Systems														o	o	o	o	o	o	o	
Components												o	o								o
detailed												o	o	o	o		o	o		o	o
simplified				o										o	o	o			o		
steady												o	o	o	o				o		o
unsteady				o										o	o	o	o	o		o	o
REFERENCES																					
IEA Task VIII	o		o		o																
IEA Annex III	o	o																			
IEA Annex XII	o	o		o	o				o		o										
CEC			o						o					o	o	o					
Literature (see WD)			o				o	o		o	o	o	o	o		o	o	o	o	o	o
Used (o) and Selected (O) Programs for Case Studies																					
* Transparent Insulation		o			o	O			o												
* Absorbers α/ε																	o			O	
* Collectors micro-climate																					O
Remarks							1)	2)		1)	1)	4)	4)								3)

1) Window model 2) Daylight model 3) Microclimate model 4) TIM wall, window and collector model
O Selected program

Table 4.1 Calculation Programs.

4.4 References

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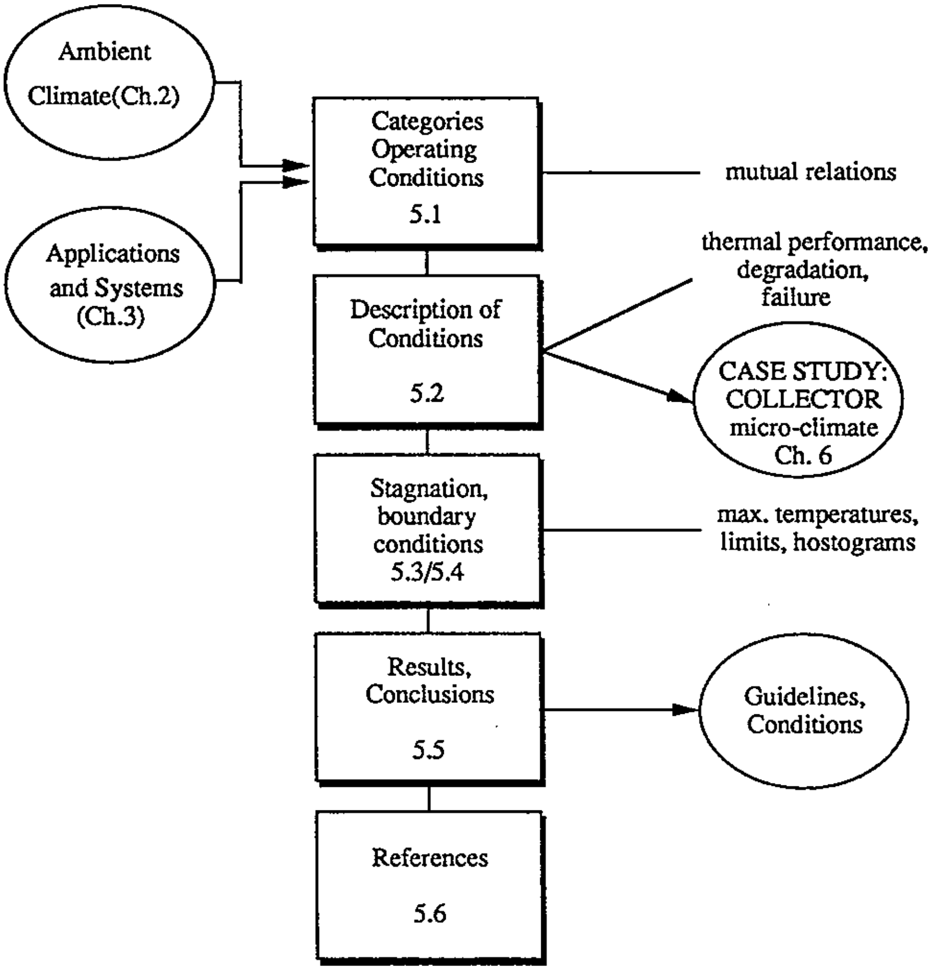
5. OPERATING CONDITIONS

G. Brouwer



5.1 Categories

Operating Conditions not only justify the application of solar systems in particular local regions, they also constrain the selection of materials. Operating conditions and material properties reflect the technical evaluation criteria for selection. In Chapter 3 the application categories and the preferred type of solar systems were presented. It was shown how solar materials have to match in an extended set of operating conditions. Climates, type of heat demand and system design, all yield numerous changing parameters that result in a multitude of differing operating characteristics. Since performance prospects of materials are closely related to applications, ongoing research on materials was narrowed to some specific application fields and some thermal evaluation criteria as previously described.

Correlated with degradation is the measure of deterioration during the lifetime of the material. High temperatures and radiation levels for long periods, climate pollutants such as sulphur dioxide, ultra violet radiation, and high humidity do accelerate this degradation as discussed in Chapter 2. Subtask B of this Task X focusses on the prediction of service life. A methodology based on accelerated aging tests was developed. The quantitatively effective stresses on the absorber material caused by high humidity and condensation were characterized in the prediction of service life. Chapter 6 describes a study on service life predictions carried out by some Task X participants, coordinated by J. Havinga (the Netherlands): "Micro-climate in solar collectors".

Operating conditions are categorized as follows:

a. Thermal performance conditions
- solar radiation, including spectral distribution
- ambient operating temperature
- system operating temperature
- maximum attainable temperature (c.q. due to a slight heat demand).

b. Degradation conditions
- solar ultra violet radiation
- air impurities (SO_2, NO_x, salts, chemicals)
- high temperature exposure
- temperature cycling, temperature shock
- air humidity, moisture

c. Failure conditions
- structural exposures to wind, snow, hail
- external source loads (during transport, vandalism etc.)

All operational modes of solar systems need to be considered in the evaluation of operating conditions as discussed briefly below.

Only effects on the thermal performance were considered for the degradation and failure conditions. Simultaneous occurrence of severe conditions (simultaneous stresses), e.g., SO_2 pollution and high temperatures, can accelerate deterioration in some situations.

5.2 Description

5.2.1 Thermal Performance Conditions

These environmental and operational conditions directly affect the energy benefit of the applied device (glazing, absorber). Solar radiation and ambient temperature on the one hand and the system design and application on the other hand determine the operating temperatures as well as the thermal performance.

Active solar systems are likely to be exposed to conditions where there is no working fluid flow or no heat demand either during operation, installation, or maintenance periods. Under these more or less stagnant conditions the materials are severely attacked with respect to degradation (see 5.2.2). Extended exposure to these conditions will result in continuously decreasing performance. The normal and extreme temperature affecting glazings and absorber material in the active and passive solar applications identified in Chapter 3 are listed in Table 5.1. In the material property databases the maximum and minimum service temperatures are usually cited. They specify the temperature range in which the material is designed to operate. The minimum service temperature is usually the ambient temperature. However, nocturnal radiation from sky-faced surfaces and/or evaporative cooling will slightly depress the material temperature. The maximum service temperature will generally occur when the collector or the building structure is exposed to maximum solar radiation at maximum ambient temperature and there is no heat withdrawal. Usually this is called stagnation temperature. See section 5.3.

5.2.2 Degradation Conditions

A main requirement for solar materials is that they shall not be affected adversely by exposure to environmental factors to an extent that will significantly impair their function during their design lives. The effect on thermal performance of changes in material properties from their initial values during their lifetime due to degradation, can be expressed in a percentage of the system's yearly performance. This loss of performance may be estimated by the use of system performance simulation programs. To estimate this degradation or, conversely, the durability of materials, by means of prediction and accelerated testing (Subtask B for absorber materials), the durations of the particular conditions have to be formulated. The current environmental data for U.V. radiation, air pollution and air humidity, can be extracted from National Statistical Data Handbooks for each particular region.

Moisture appears to have a deleterious effect on some absorber coatings and polymer glazings, e.g., poly carbonates (PC) become more brittle when aged in a humid environment at elevated temperatures (ref. 7) and nickel-pigmented aluminium oxide coatings on absorbers are vere susceptible to moisture and condensation (Subtask B results). The operating conditions for glazing materials (window, wall, and collector) including the highest ambient temperature with RH ≥ 95% and time of wetness were characterized according to ISO TC 156 (ref. 9) in Chapter 2 (Table 2.7).

TABLE 5.1	Operating Conditions of Temperatures (*) (indicative values)			
Application categories: (see fig. 3.1)	Components	Normal operating temperatures °C	Maximum temperature(**) °C	Remarks
ACTIVE SYSTEMS Solar Collectors				
1. low temperature (uncovered collector) - swimming pools - energy roofs	absorber	10 to 30	Ta + 50	not applicable in subtask A
2. medium temperature (single covered, normal black collector) - hot water in dwellings restaurants agriculture (drying)	cover absorber	10 to 30 10 to 60	Ta + 50 Ta + 100	
3. high temperature (double cover, normal black or single cover, selective coated collector) - hot water in dwellings restaurants industry - heating	outer cover inner cover absorber	10 to 50 10 to 60 10 to 80	Ta + 50 Ta + 120 Ta + 200	 if applicable
4. very high temperatures (as 3 with extensive improvements as vacuum, honeycombs etc.) - heating - cooling	outer cover inner construction absorber	10 to 50 10 to 60 10 to 100	Ta + 50 Ta + 120 Ta + 350	
PASSIVE SYSTEMS				
- direct gain	window glass	10 to 40	Ta + 30	
- sunspace	window glass	10 to 40	Ta + 30	
- translucent insulation material wall	outer cover inner structure	10 to 50 10 to 60	Ta + 40 Ta + 80	

* from calculations of different participants
** depending on local climate Ta = ambient temperature

The operating conditions for absorbers depend not only on the ambient climate but also on the ventilation rate, the temperature gradients, and the humidity in the collector.

For the quantative assessment of absorber coatings durability in Subtask B a cooperative case study was performed and is presented in Chapter 6: "The micro-climate in solar collectors". The study includes the development of a simulation program for characterizing the microclimate and the validation of the code with measured results from exposed collectors.

No comparable study was conducted of the performance loss of passive systems due the degradation of wall, window and collector glazing materials.

Components and building elements also have to withstand the stresses induced by thermal shock and thermal cycling. These conditions were not considered in this study, however, ref. 5 and 6 describe approved international standards.

5.2.3 Failure Conditions

Operating conditions, which cause tremendous changes in the functioning of solar systems or which exceed the limits (e.g., stresses, decolouration, deposits, corrosion or interference with other materials) that components can withstand, are called failure conditons. The particular failure effects in which thermal performance limits are exceeded, were already discussed under degradation conditions.

In Chapter 9 a performance criterion was derived for failure of the absorber coating. This criterium corresponds to a 5% loss in annual efficiency.

All previously mentioned operating conditions shall be determined in accordance with the existing or continuing standard methods of testing solar devices and materials of each national authority. (See ref. 5 and 6).

5.3 Stagnation, Maximum Boundary Conditions

The designated materials (window, wall and collector glazing and the collector absorbers) should be capable of withstanding continuous exposure of a certain duration to stagnation temperatures. The maximum service temperatures may severely affect the structural and thermal properties of the material. High solar radiation at maximum ambient temperature and no heat removal may elevate material temperatures to more than 200°C. However, the heat capacity of the device reduces the stagnation temperature in short-term exposures and can limit deterioration of the material.

For solar collectors the instantaneous heat balance is expressed as:

$$Q_u = A_c\,(\eta_o.G - U_L(T_p - T_{amb})) \qquad (5.1)$$

Q_u = useful heat gain (W)
A_c = collector area (m^2)
η_o = optical efficiency ($\alpha\tau$)
G = irradiance (W/m^2)
U_L = heat loss coefficient (W/m^2K)
T_p = temperature absorber plate (°C)
T_{amb} = ambient temperature (°C)
τ = cover transmittance
α = absorber plate absorptance

In stagnation the heat gain is zero, so the stagnation temperature of the absorber plate for a particular collector will be.

$$T_{stagn.} = T_p = T_a + \eta_o G/U_L \qquad (5.2)$$

If the collector efficiency is described by

$$\eta = \eta_o - a_1\,T^* - a_2 G\,(T^*)^2 \qquad (5.3)$$

where a_1 and a_2 are known constants and $T^* = (T_p - T_a)/G$

which means that $U_L = a_1 + a_2\,(T_p - T_a)$ the stagnation temperature equals:

$$T_{stagn.} = T_a + [-a_1 + (a_1{}^2 + 4a_2\eta_o G)^{1\ 1/2}]\ /\ 2a_2 \qquad (5.4)$$

The stagnation temperature of the absorber was calculated for typical collectors with a selective absorber and one glass cover plate (ref. 4) and plotted as a function of the irradiance G in Fig. 5.1. Varied parameters were: the absorptance (α), and the emittance (ε) of the absorber plate and the transmittance (τ) of the coverplate.

The main fixed parameters are:

ambient temperature	T_a = 10°C
inclination angle	β = 45°C
absorption coefficient of absorber plate:	α_p = 0.90
emission coefficient of absorber plate:	ε_p = 0.15
transmission coefficient cover:	τ_g = 0.85
heat resistance of isolation:	R_w = 2 m2K/W
emission coefficient of cover:	ε_g = 0.85

It appears that the maximum stagnation temperature of the absorber plate of the selective collector amounts to about 150°C over ambient. The stagnation temperature of the (single) collector glazing, derived from ref. 3, will amount to about 40°C over ambient.

For a typical flat black collector with one glass coverplate the stagnation temperatures over ambient amounts to 100°C for the absorber and 40°C for the glazing.

Generally, in passive solar systems, there is no active heat withdrawal. Stagnation temperatures of glazing materials equal the maximum operating temperatures. They strongly depend on the air and the surface temperature at the backside. The analogy between stagnating solar collectors and window and wall glazing may be used to estimate the stagnation temperature of other glazing constructions.

Under the conditions previously described for solar collectors, a double glazed construction placed before a black absorption structure (e.g. transparent insulation wall) will reach temperatures over ambient: 40°C for the outer cover and 80°C for the inner cover.

5.4 Histogram of Operating Temperatures Solar Collector

In the previous paragraph the operating conditions of temperatures for solar collectors were discussed. The level of these temperatures will be strongly affected by whether a system is in use, partly used, or (in the worst case) not used at all. The occurrence of temperatures was calculated and expressed in a histogram for a normal operating system with a specific standardized load demand, and for a stagnating system (the solar collector is without heat storage). As an example, Fig. 5.2. shows the presentation for a spectral selective collector in a solar domestic hot water system exposed to the Dutch climate (ref. 10).

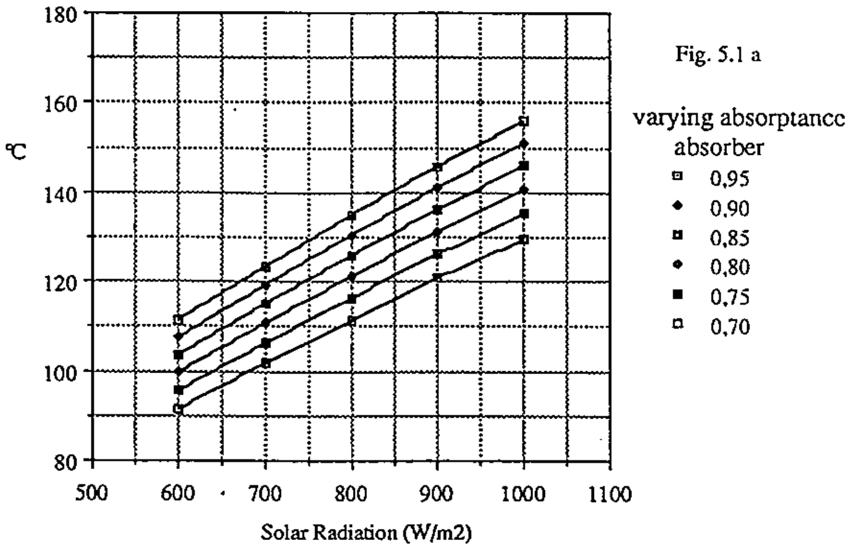


Fig. 5.1 a

varying absorptance absorber

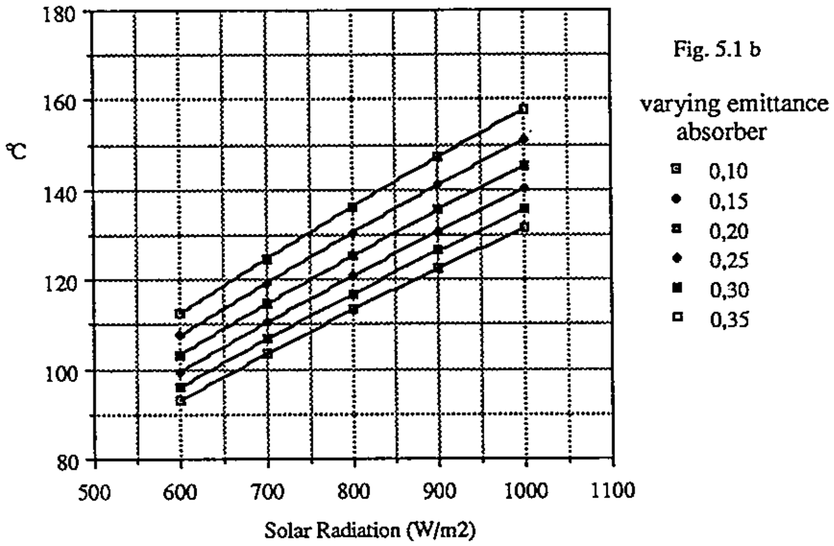


Fig. 5.1 b

varying emittance absorber

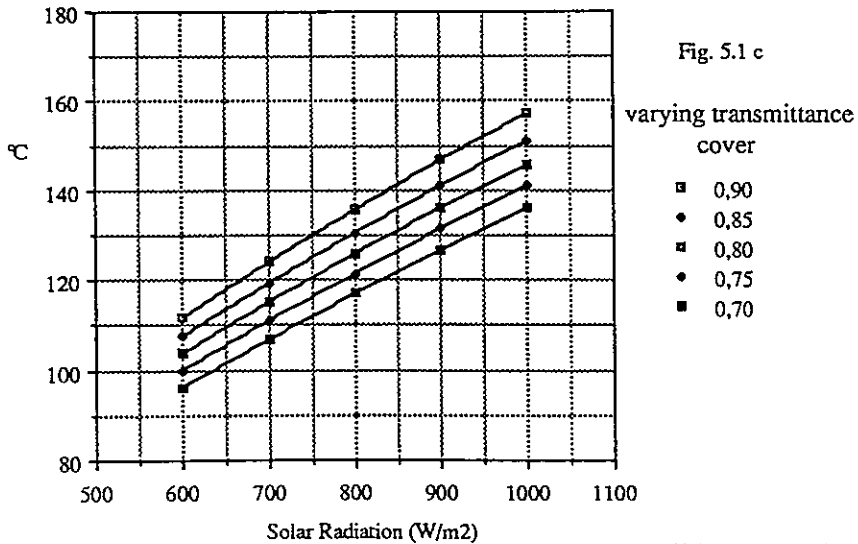


Fig. 5.1 c

varying transmittance cover

Source: TNO-TPD, Delft, 1986

Fig. 5.1 Stagnation temperature absorber

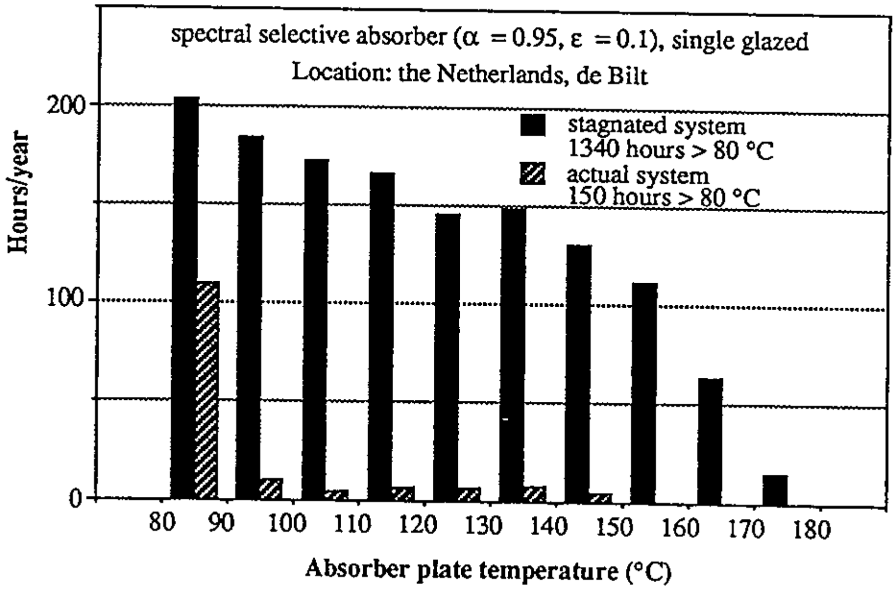


Fig. 5.2 Histogram absorber temperature

For a system operating normally, the plate temperature will exceed 80°C for only about 150 hours per year, but if the system is allowed to stagnate about 1350 hours above 80°C will be experienced.

Temperature calculations were carried out from the climate data in Appendix A. For a normal operating system with the same system size and load demand, 80°C will be exceeded for 100 - 1000 hours per year in the climates described in Appendix A. For a stagnating system, the absorber temperature will exceed 80°C for 1300 to 2000 hours per year.

Both operating and stagnation temperatures durations above 80°C are minimum in Copenhagen, Denmark and maximum in Denver, U.S.A. In Denver, the temperature of the absorber in a stagnating system will actually exceed 160°C for about 600 hours a year.

Table 5.2 Operating conditions

Operating conditions	**Indicative values**		**Affecting:**			Reference
	Overall range of operating values	Boundary values	outer panel	inner glazing	absorber (glazed)	
THERMAL PERFORMANCE CONDITIONS:						
- Solar radiation (W/m2)	0 - 900	max. 1100	o		o	Ch. 2
- Solar spectral distribution (nm)	320 - 2500		o	o	o	Ch. 2
- Ambient temperature (°C)	-20 - +30	-50, +40				Ch. 2
- Service operating temperature (°C)	10 - 50		o			table 5.1
of material	10 - 60			o		table 5.1
	10 - 100				o	table 5.1
- Service stagnation temperature (°C)	80	90	o			table 5.1
of material	150	160		o		table 5.1
	130 - 380	390			o	table 5.1, fig.5.1
- Thermal spectral distribution (nm)	200 - 5000		o	o	o	table 2.2
DEGRADATION CONDITIONS:						
- Solar UV radiation (%)	3.5 - 5	9	o			Ch. 2
UVB radiation (%)	0.03 - 0.1	0.5	o			Ch. 2
- Air impurities (µg/m3) - SO2	3 - 185	2500	o	o	o	Ch. 2
- NO2	2 - 160	1500	o	o	o	Ch. 2
- Time of high temperature exposure (hours/year)						
standardized SDHW system >80 °C	100 - 1000	1300 - 2000			o	Ch. 5
>160 °C	-	0 - 600			o	Ch. 5
- Temperature cycling			o	o	o	5
- Temperature shock			o	o	o	5
- Relative humidity ambient air (%)	20 - 90		o	o	o	Ch. 6
- Time of wetness (hours/year)	100 - 4200	4200	o			Ch. 2
of material	100 - 3300*	3300*		o		Ch. 6
	100 - 3300*	3300*			o	Ch. 6
- Life time expectancy					o	Subtask B
FAILURE CONDITIONS:						
- Performance Criterium 5% efficiency loss					o	Ch. 9
- Structural exposure - hail, diam(mm)	20 - 50	100	o			5, 6
- wind			o			5, 6
- snow			o			5, 6

* The number 3300 is applicable for location De Bilt, Nl.

5.5 Results, Conclusions

- Evaluation criteria for selecting materials emphasize operating conditions in three categories:
  - thermal performance conditions
  - degradation conditions
  - failure conditions

- Table 5.2 lists conditions affecting glazing and absorber along with their range and influences. This chapter also contains the estimated values of operating conditions for the designated material categories (glazing, absorbers) in different applications, viz., the normal operating temperatures and the minimum and maximum (stagnation) temperatures (see Table 5.1).

- The influence of the material properties (solar absorptance and thermal emittance of the absorber plate and solar transmittance of the collector cover) on the stagnation temperature was calculated in ref. 4 and plotted in Fig. 5.1. These results are specific to each application, solar system, and climate.

- Absorber plate temperatures exceed 80°C in actual operating systems 100 - 1000 hours per year, depending on the climate. For stagnation during the whole year, 80°C will be exceeded 1300 - 2000 hours per year.

5.6 References

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6. MICROCLIMATE IN SOLAR COLLECTORS

CASE STUDY

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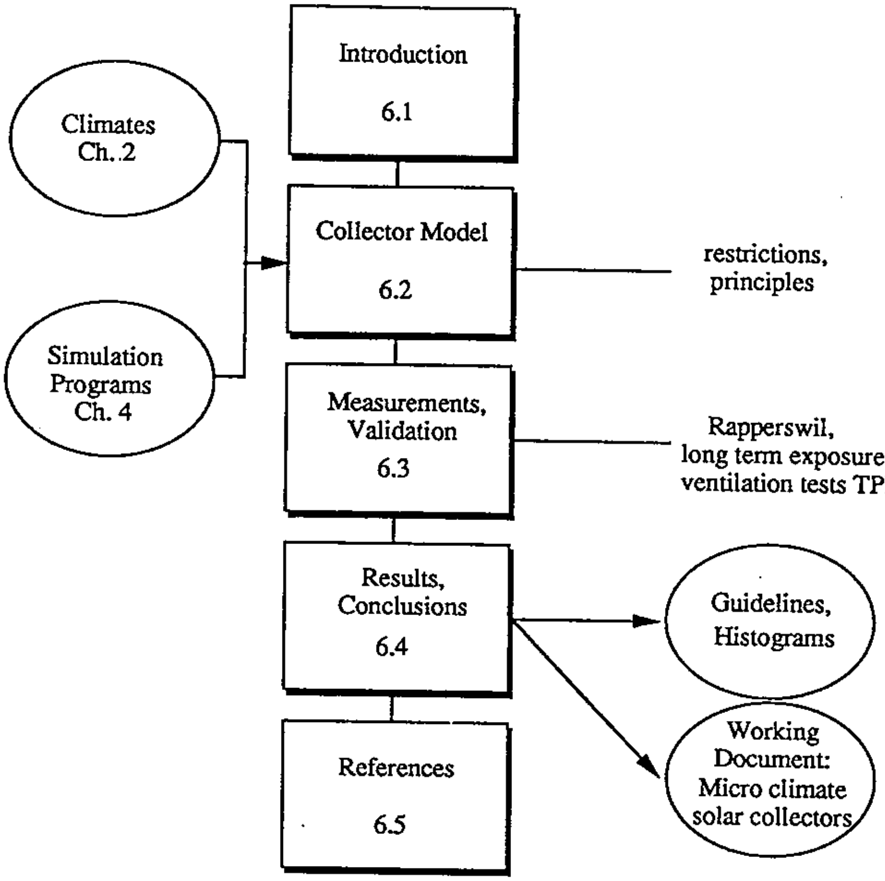

6.1 Introduction

For the prediction of the service life time of flat plate collectors information concerning the operating conditions of the components within the collector is necessary. These operating conditions are dependent from the type of system application (e.g. solar domestic hot water systems or space heating systems etc.).

There are different factors which lead to degradation of the collector components. The temperature and the collector humidity are the most important factors. The collector micro climate model is developed to provide information about the operating conditions inside a solar collector with respect to these two degradation factors. This information is used to calculate the service life time of the solar collector.

The modelling work presented here, is carried out as a part of the activities within Task X of the IEA Solar Heating and Cooling Programme, Subtasks A and B.

6.2 Description of the Collector Micro Climate Model

The developed collector micro climate model describes the humidity conditions inside the collector. A heat and mass transfer model calculates each time step the conditions of the collector micro climate.

The model assumptions are:

- Steady state process during a time step (3600 s.).
- Condensation occurs when the temperature of the collector cover or the absorber is lower than the dew point temperature of the collector air.
- Evaporation occurs when the absorber plate or the cover plate is wet and the temperature of this wet surface exceeds the dew point temperature of the collector air.
- Both surfaces inside the collector can hold a maximum of 0.1 kg/m2 water. Excess water is transported out of the collector.
- Inert collector materials. (A special version of the model is also able to take into account hygroscopic materials. These hygroscopic materials can have a large influence on the collector micro climate as measured data from a Swiss Agena collector ,which had a wooden frame, showed. The collector Relative Humidity (RH) was very stable.
- The collector ventilation is due to:
    * Density difference of the air inside the collector and the ambient air. This density diference is caused by a temperature difference between collector air and ambient air.
    * Expansion/compression of the collector air. The collector air temperature of succesive time steps varies. Therefore the collector air expands or compresses. Since the collector is not air tight these temperature fluctuations cause ventilation of the collector.
- The effect of the wind speed on the collector ventilation is not considered. However the fitting of measured data obtained from a outdoor collector test include the influence of the wind effect on the collector ventilation rate.

In order to perform an annual collector climate simulation the model requires the following input data:

- Collector dimensions.
- Collector ventilation rate coefficient.

And hourly values of the
- Ambient temperature.
- Ambient RH or the ambient water vapour pressure.
- Collector cover temperature.
- Absorber plate temperature.

6.3 Measurements and Validation

In Rapperswil, Switzerland, outdoor collector exposure tests are carried out. Test data of the Teknoterm collector (SWE) were used to validate the collector micro climate model and to determine the ventilation rate of the collector.

Fig.6.1 shows the ambient and the collector air temperature during the relevant test period of the Teknoterm collector. Since the Teknoterm collector is well ventilated the Absolute Humidity (AH) of the collector air and the ambient air are nearly identical during a large part of the test period. Identification of the collector ventilation rate during periods with an identical ambient and collector air AH is not possible. Small periods at sunrise however contained data with very different values for the AH of the collector air and the ambient air. During these small periods the condensate evaporates inside the collector due to solar radiation. This causes an increase of the AH inside the collector. Due to ventilation of the collector this sudden increase of the collector AH is temporary.

Fig. 6.2 shows one of these periods. During the period with a high collector AH water evaporates inside the collector. At the sudden drop of the collector AH all water is evaporated, but the AH is still high. Due to ventilation the AH drops to a value equal to the ambient AH. This ventilation period is used to determine the collector ventilation rate. The model predicts a ventilation rate of 0.076 dm3/s/Pa during the simulated test period.

Finally the complete condensation and evaporation cyclus is simulated. This cyclus starts at the sunset of the previous day. At this point the collector is dry. During the night, condensation occurs. At sunrise the next day the condensate evaporates. The measured and simulated cyclus is shown in fig. 6.3. The simulation of the complete test period of the Teknoterm collector can be seen in fig. 6.4.

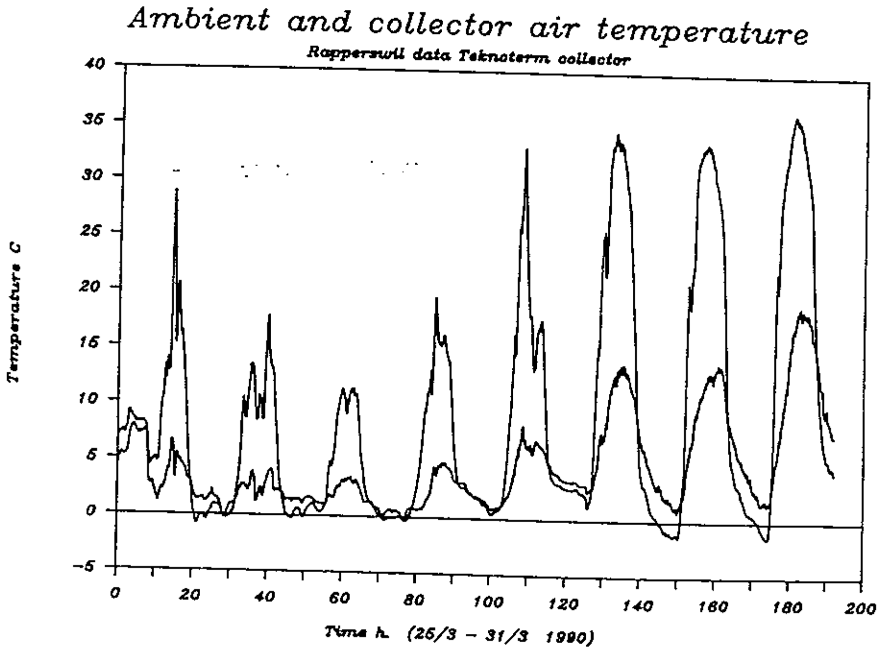

Fig. 6.1 Ambient and collector air temperature during the Teknoterm collector test

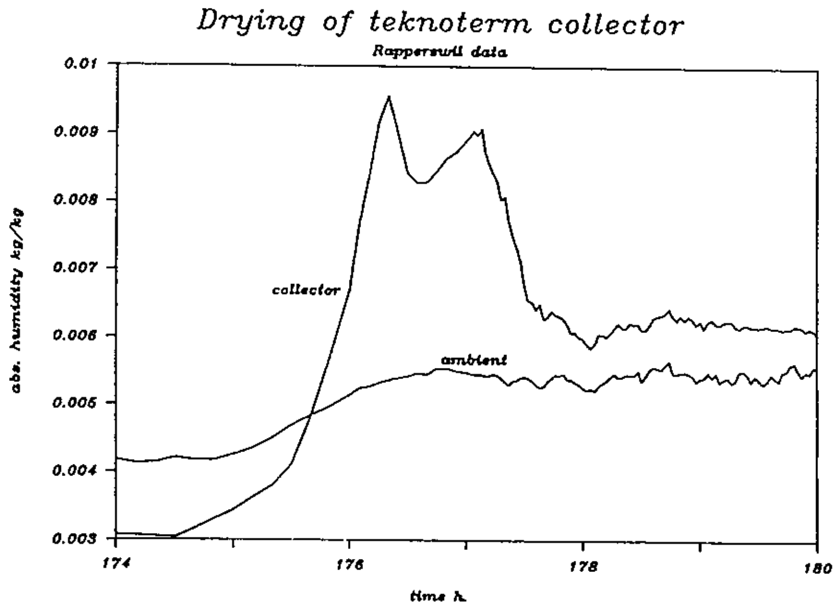

Fig. 6.2 Small period of the Teknoterm collector test during which collector and ambient Absolute Humidity vary

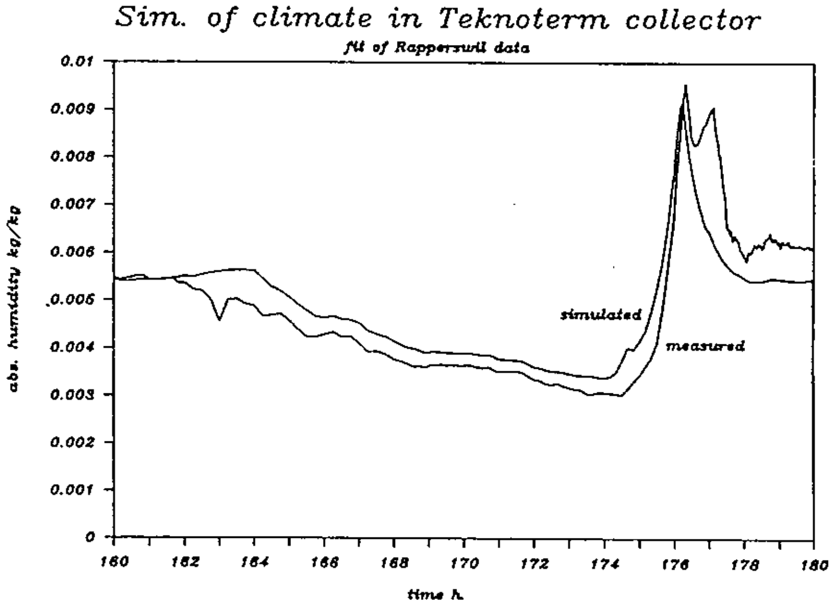

Fig. 6.3 Simulation of the Teknoterm collector using the best fit ventilation rate

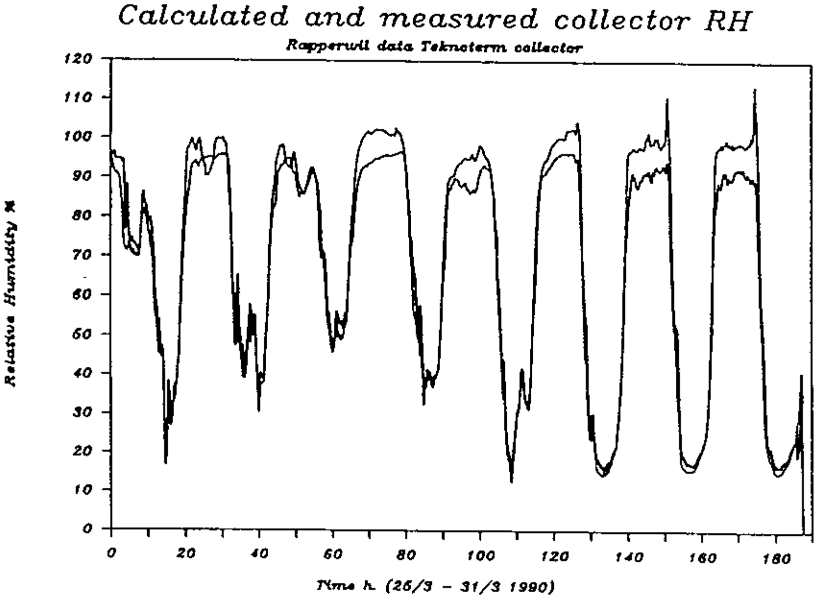

Fig. 6.4 Simulation of the complete Teknoterm collector test sequence

6.4 Results of Annual Simulations and Conclusions

Annual simulation are carried out for the Test Reference Year of De Bilt (the Netherlands) using a typical Dutch solar domestic hot water system. The collector ventilation rate is varied from 0.0 - 0.1 dm3/s/Pa. At zero ventilation rate the ventilation due to expansion/compression of the collector air remains possible.

Fig. 6.5 shows the time of wetness of the collector cover on the outside and on the collector cover and absorber inside. As can be seen, at high ventilation rates the time of wetness is nearly independent of the collector ventilation rate. A minimum time of wetness occurs at a low ventilation rate of 0.01 dm3/s/Pa. This minimum however is not very significant, it is approximately 90% of the time of wetness at high ventilation rates. A further decrease of the ventilation rate introduces an increase of the time of wetness.

These annual simulations show the importance of collector ventilation. A collector with poor ventilation, less than 0.005 dm3/s/Pa, see fig. 6.5, may suffer from a high time of wetness and is possibly a water trap. An increase of the collector ventilation rate may reduce the time of wetness and avoid the existence of large amounts of condensate.

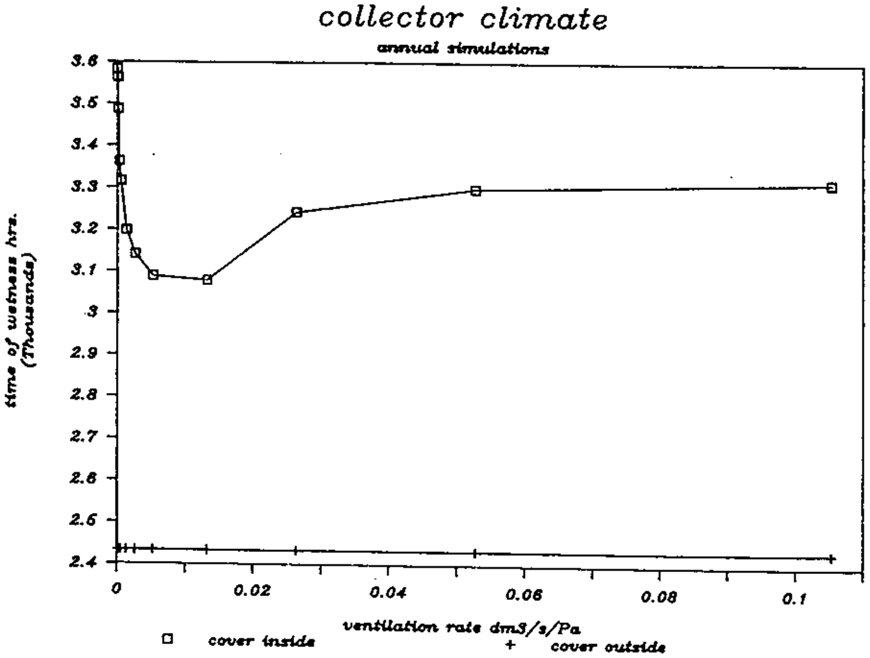

Fig. 6.5 Time of wetness of the cover outside and of the collector inside (cover as well as absorber).

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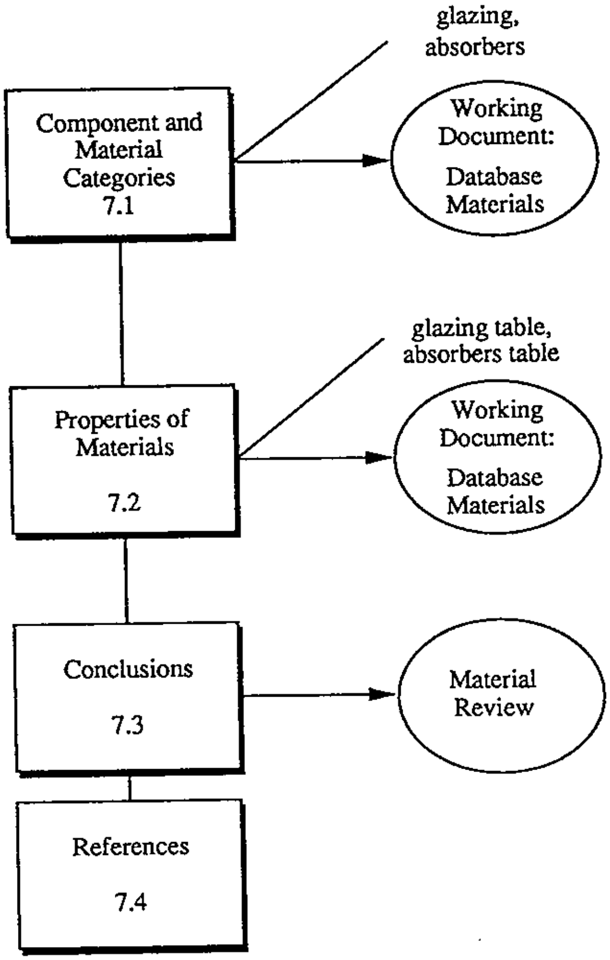
7. MATERIALS

G. Brouwer
See Working Document (Annex C)



7.1 Introduction

Climate and operating conditions for different applications attack the materials in a very complex way. The operating conditions restrict the choice of materials and products. The search for more promising and improved materials, and the increasing level of performance and quality requirements reinforce the need for accurate knowledge of solar materials.

Questions that arise include: what are the properties? how does it withstand the operational and climate conditions? what is the stability of the material with respect to its properties during its lifetime? how does the material impact the environment, etc.?

On the other hand, questions arise about the methodology and the accuracy of measurements for characterizing and evaluating material properties. Improvement of the energy benefits of solar energy system through the proper choice of materials involves clear specifications of requirements for the many different applications and application environments. Also, in the emerging solar energy market, the solar energy industry must constantly update its technology in order that it be a durable and feasible energy supplier. The interaction between material researcher and end-user of the material-assisted solar system research increases in importance because the optimisation of solar products is directly related to the achievement of energy conservation.

The selection procedure of materials requires the proper classification of materials, and application requirements. The objectives of a classification scheme for material specifications are to:

a. provide hierarchical groups of related provisions and
b. provide a basis for textual organization and indexing of the specifications.

Reflecting on the scope of this research the physical type of classification is most workable. Such a classification scheme was developed for each material group.

The classification of materials starts with hierarchical specifications. Next the particular materials are listed. New materials can be easily added. The extended schemes are included in the working document, "Database of Solar Materials".

(1) Collector, Wall and Window Glazing
(2) Collector Absorber Coatings
(3) Collector Absorber Substrates

A brief classification is shown below (Fig. 7.1). Note that solar control films and optical switchable films were not included in the database at this time.

7.2 Properties of Materials

In the preceeding section a brief classification scheme was proposed on the basis of physical and chemical characteristics. The specification of the materials presented in terms of these characteristics in the working document, "The Database of Solar Materials," deals with the following classes:

a. physical background, including the composition and kind of material
b. optical and thermal properties
c. mechanical properties
d. durability

The first class corresponds with the classification scheme and needs no further subdivision. The optical and thermal properties, which are most important with respect to energy performance calculations, are averaged data for shortwave and longwave (infra-red) radiation respectively. Temperature limits of the material are of concern. Mechanical properties are useful in the selection procedure to check the practical capability of the material in the particular solar system and application. For example, attention should be paid to the temperature-dependency on the tensile strength of polymers as shown in Fig. 7.2. The same applies to the durability factors with respect to ambient climate and operating conditions. Durability factors have not been quantified. Only a somewhat arbitrary judgement value is given in the database. The durability specifications for absorber coatings were strongly emphasized in Subtask B of Task X. See also refs. 1 and 2.

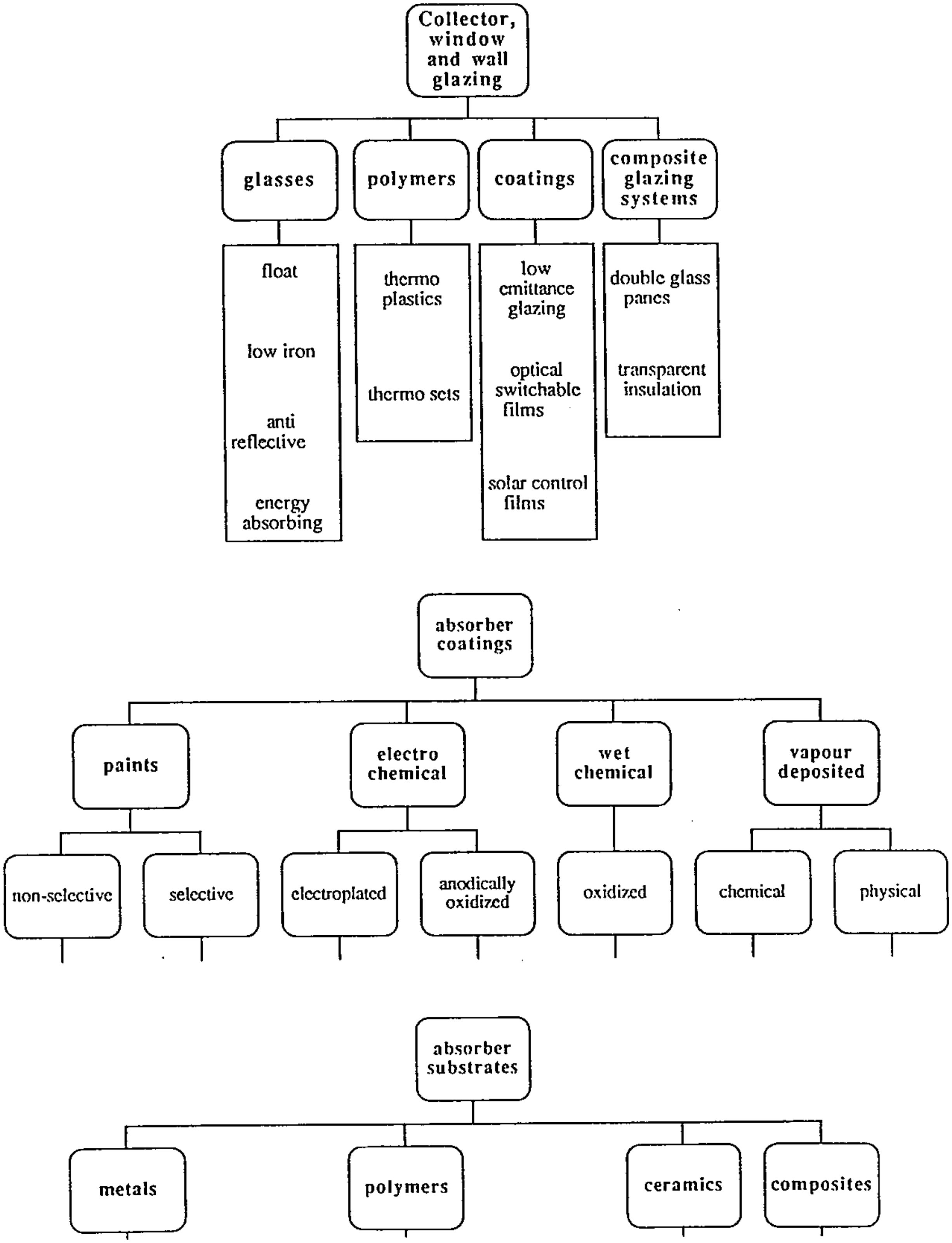


Fig. 7.1 Classification of materials

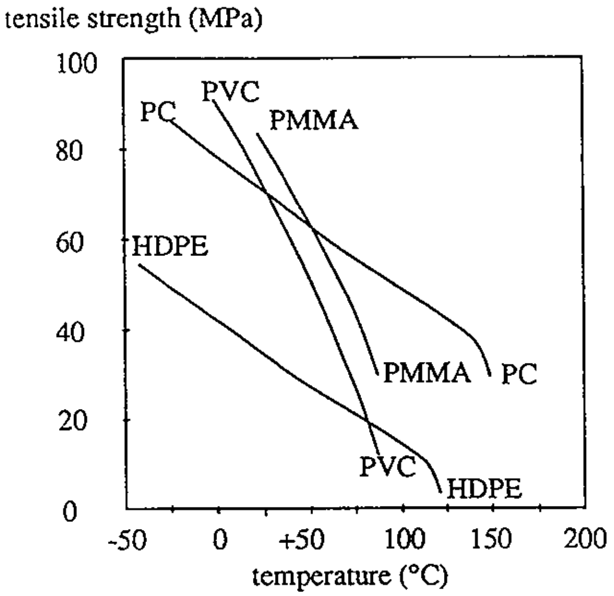


Fig. 7.2 Temperature dependence of tensile strength of polymers.

In a previous working document (Part II) of this Subtask A (ref. 4), a first set of brief material descriptions was presented. Each material group was reviewed in an editorial paper that clearly described the background in the material fields.

The selection of wall, window and collector glazing materials is made primarily on the properties of solar transmittance and heat loss coefficient (U-value). Some most promising products, that have a high solar transmittance as well as a low U-value are evacuated aerogel, honeycomb (Arel) and capillary (Okapane) constructions.

The selection of absorber materials strongly emphasizes the properties of solar absorptance and heat emittance. Some promising candidates are black chrome coatings, chemically oxidized stainless steel and some black nickels.

Fig. 7.3 and 7.4 and 7.5 illustrate the relationship between these critical material property pairs for glazings, TIMs, and absorber coatings respectively.

Fig. 7.3 Solar Transmittance (normal) and U-Value
(indicative values)

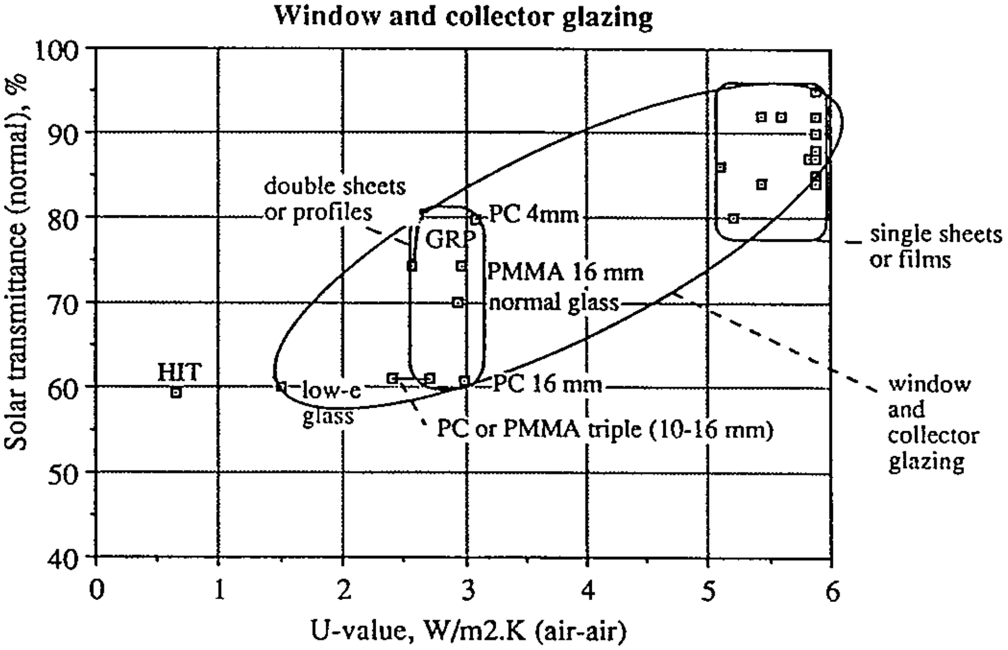
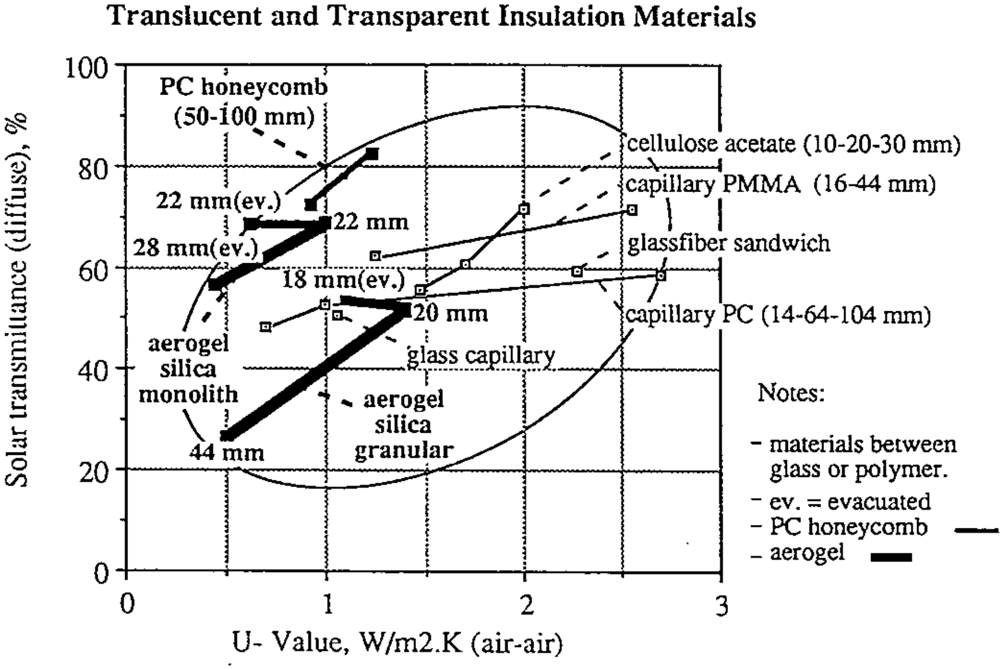
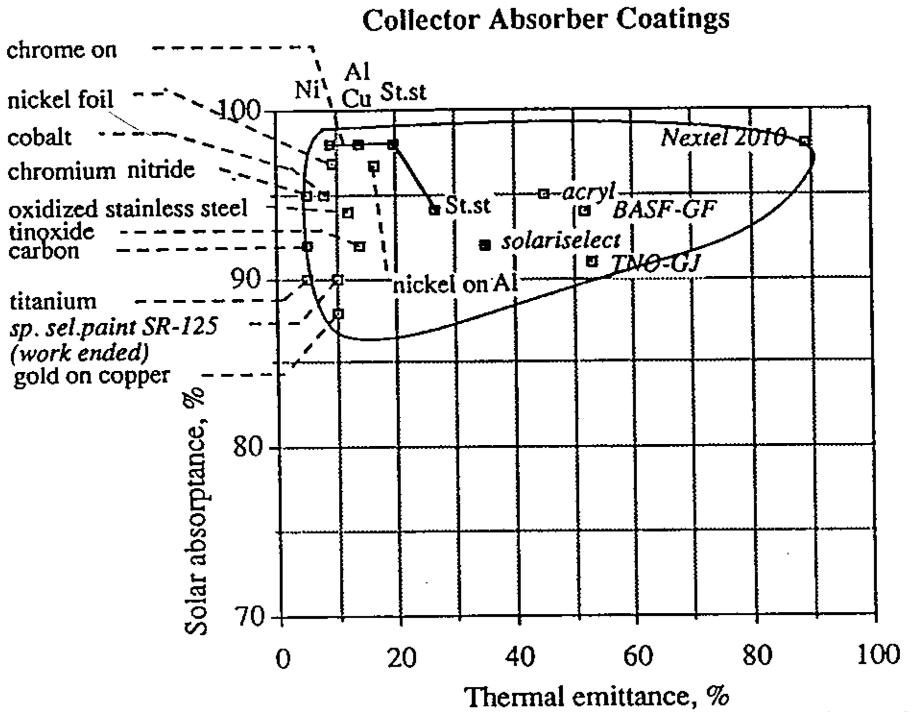


Fig. 7.4 Solar Transmittance (diffuse) and U- Value
(indicative values)





Note: paints in *italic*

Fig. 7.5 Solar absorptance and thermal emittance
(maximum and indicative values)

The increased emphasis on environmental quality requires more and more information of the material in its applications e.g.:

- energy use during the material's life cycle
- emission to earth, water and air
- failures, risks
- resource potential, degree of use, conservation
- effect on animal and plant life
- chronic, additive or delayed effects on public health
- reusability, recycling
- disposal.

Further research is needed on these attributes. Although judgements on an international scale are very tentatively at this time, basic agreement could be achieved on the following points.

a. The investigation of an ecological material database

The current database of properties has to be completed with data on:

- life expectancy,
- maintenance,
- raw material requirements,
- energy use during processing.

b. Recommendations or regulations for applying materials based on objective judgements of the environmental effects.

This information is required for the more effective use of materials with the potential of improving energy performance and environmental quality.

7.3 Conclusions

The following groups of materials were considered :

a. window, wall and collector glazing
b. collector absorbers

Clear specifications of requirements and properties, including the spectral energy distribution, are needed to optimize materials for particular systems and applications with respect to energy benefits and environmental quality.

In order to facilitate the selection of materials, a physical hierarchical classification was composed and material property data, including optical, thermal, mechanical and durability properties were listed. See working document, "Database of Solar Materials" (Annex C).

Among wall, window and collector glazing materials, evacuated aerogel, honeycomb (Arel) and capillary (Okapane) constructions are very promising because of their high solar transmittance and a low heat loss coefficient.

Promising absorber coatings with high solar absorptance and a low thermal emittance include most black chromes, chemically oxidized stainless steel and some black nickels.

On ecological grounds:

a) the current database needs to be supplemented with data on environmental quality as life expectancy, used raw materials, energy use, etc.

b) regulations for applying materials are needed.

7.4 References

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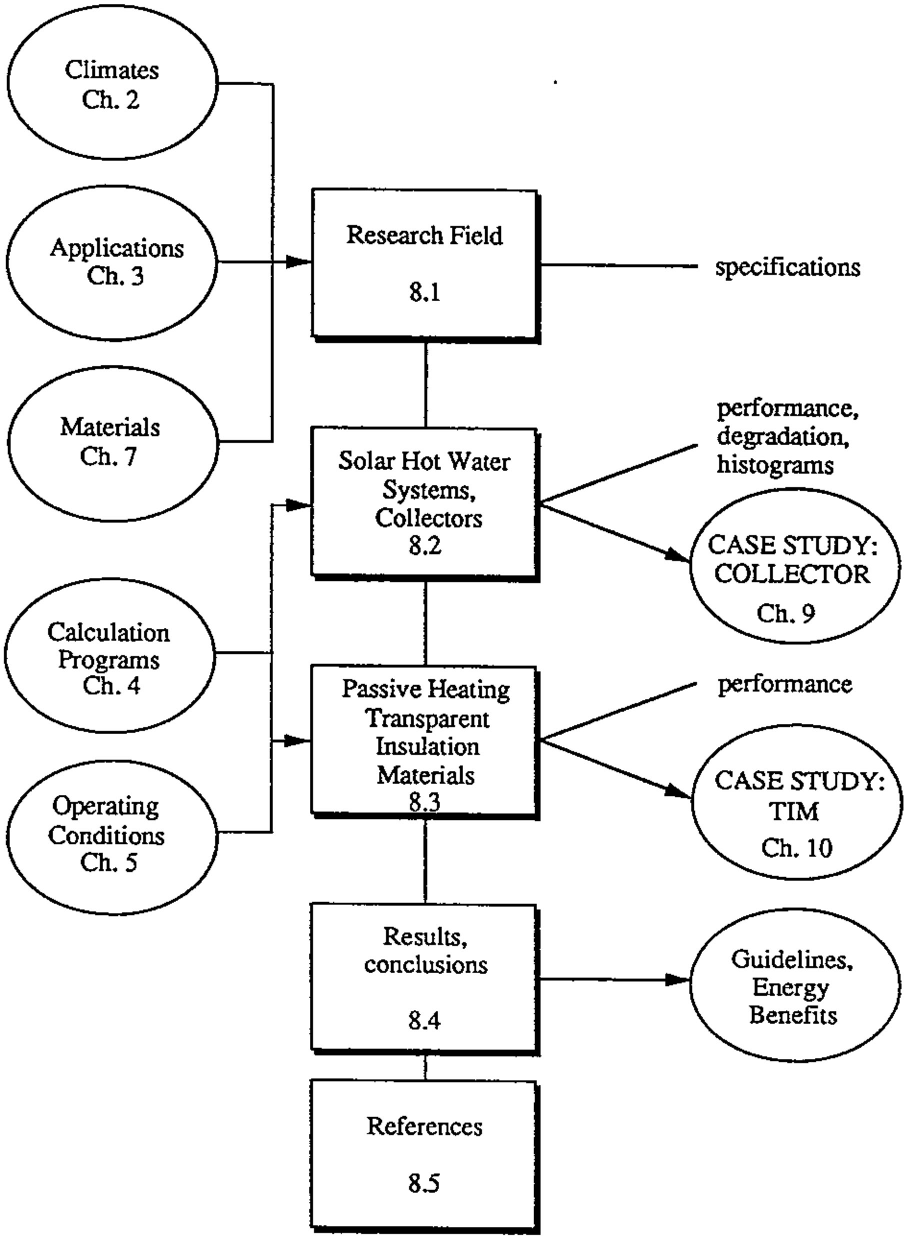
6. Brouwer G., Database Solar Materials. Working Document. Nijmegen NL, May 1991. Task X, IEA (See Annex C).

8. IMPACT OF MATERIAL PROPERTIES ON THE THERMAL PERFORMANCE

G. Brouwer



8.1 Introduction

The estimation of the energy benefits of new materials in solar energy applications is restricted here to *spectral selective coatings* on absorbers of single glazed solar collectors in solar water heater systems (forced circulation, drainback, one heat exchanger, separate back-up) in temperate continental climates and *transparent insulation materials* for space heating (passive) dwellings using solar radiated masonry walls covered with transparent insulation (controlled air ventilation) in temperate continental climates. Approaches and relationships for differing climates, systems, and applications are presented in the following chapters.

8.2 Solar Hot Water Production

The major thermal properties of spectral selective coatings on solar absorbers are the absorptance and the emittance of energy in the total spectrum (shortwave and longwave). In Chapter 7 and in the working document, "Database of Solar Materials," different materials with their particular properties were presented. Degradation during the absorber lifetime reduces solar absorptance and increases thermal emittance.

Chapter 9 describes a study on this subject carried out by some participants, coordinated by T. Hollands (Canada), "The Effect of Selective Surface Degradation on the Performance of Solar Hot Water Systems". Functional properties of materials were transformed into system performances and guidelines for performance criteria were defined. The calculations were carried out primarily with the Canadian simulation code WATSUN.

Absorptance (α) and Emittance (ε) of Solar Collectors

A very rough fundamental analysis on the instantaneous effects of the thermal material properties uses the well-known formula for the flat plate collector performance proposed by Hottel and Willier.

$$Q_u = F_r[S_{pl} - U_L\,(T_i - T_{amb})] \qquad (8.1)$$

where:

Q_u = heat collected (W/m^2)
F_r = efficiency factor
S_{pl} = instantaneous energy absorbed on the collector plate surface (W/m^2)
U_L = collector overall energy loss coefficient (W/m^2 K)
T_i = temperature fluid inlet (°C)
T_{amb} = ambient temperature (°C)

For small temperature differences between the absorber plate and the ambient, this equation can be drastically simplified into:

$$Q_u = K_1 \alpha \, \tau \, S - K_2 \varepsilon (T_i - T_{amb}) \tag{8.2}$$

where:

S	=	solar radiation (W/m^2)
K_1,K_2	=	simplified into constants
τ	=	transmittance cover(s)
α	=	absorptance absorber plate

The very rough conclusion can be derived that the degradation influence of the collector absorptance and the cover transmittance on the heat gain are of the same type. Degradation of these properties always directly affects (nearly linear) the heat gain. The influence of the collector emittance on the heat gain increases when the inlet fluid temperature increases. Chapter 8 presents a comprehensive analysis in a case study, "Effect of selective surface degradation on the performance of solar hot water systems", based on very accurate simulation codes.

Two graphs were derived from this case study. Fig. 8.1 shows fraction solar F_s versus solar absorptivity α_s with the plate emissivity ε held constant at 0.1. Fig. 8.2 shows fraction solar F_s versus plate emissivity with the absorptivity held constant at 0.95. For a typically sized solar system operating in Toronto, Canada these graphs were combined in a single plot in which the combination of absorptivity decrease ($-\Delta\alpha$) and emissivity increase ($\Delta\varepsilon$) will cause a 10% decrease in the energy delivered by the solar system. See Fig. 8.3.

Such graphs as can be developed for other climates and system variables. See Chapter 9.

Energy Saving Potential

In order to assist the selection of absorber materials with optimal energy benefits, the impact on system performance of material properties (α and ε) was estimated.
4

For a coating with absorptance = 0.95 and emittance = 0.1 as a reference, a multiplication factor for the reference fraction solar (F_s) can be used to estimate the fraction solar for other coatings. Fig. 8.4 presents this rough approach and an example for a first estimate of a specific SDHW system for a Denver location.
The slope of the lines in Fig. 8.4 was derived in the case study of a base case situation (collector area 4.8 m^2 daily draw of 350 litre at 50°C). This figure has to be used in conjunction with Fig. 7.5.

Calculations were also performed for other locations (see Chapter 9 and section 11.3). For a system with a collector area of 3.0 m^2, heat storage of 120 l and a daily draw-off of 100 l at 55°C, the energy saving potential differs slightly in other climates.

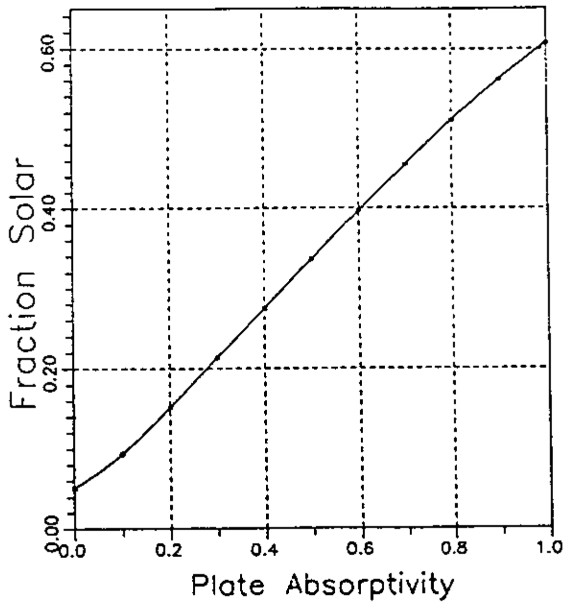


Fig. 8.1 Fraction solar versus absorptivity

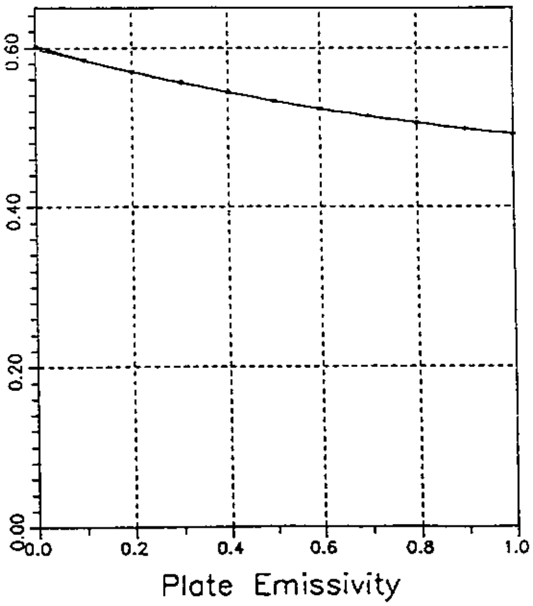


Fig. 8.2 Fraction solar versus emissivity

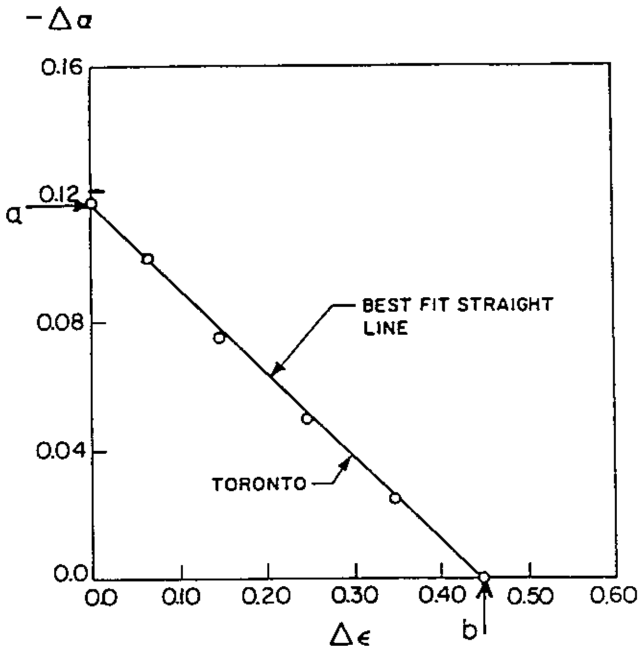
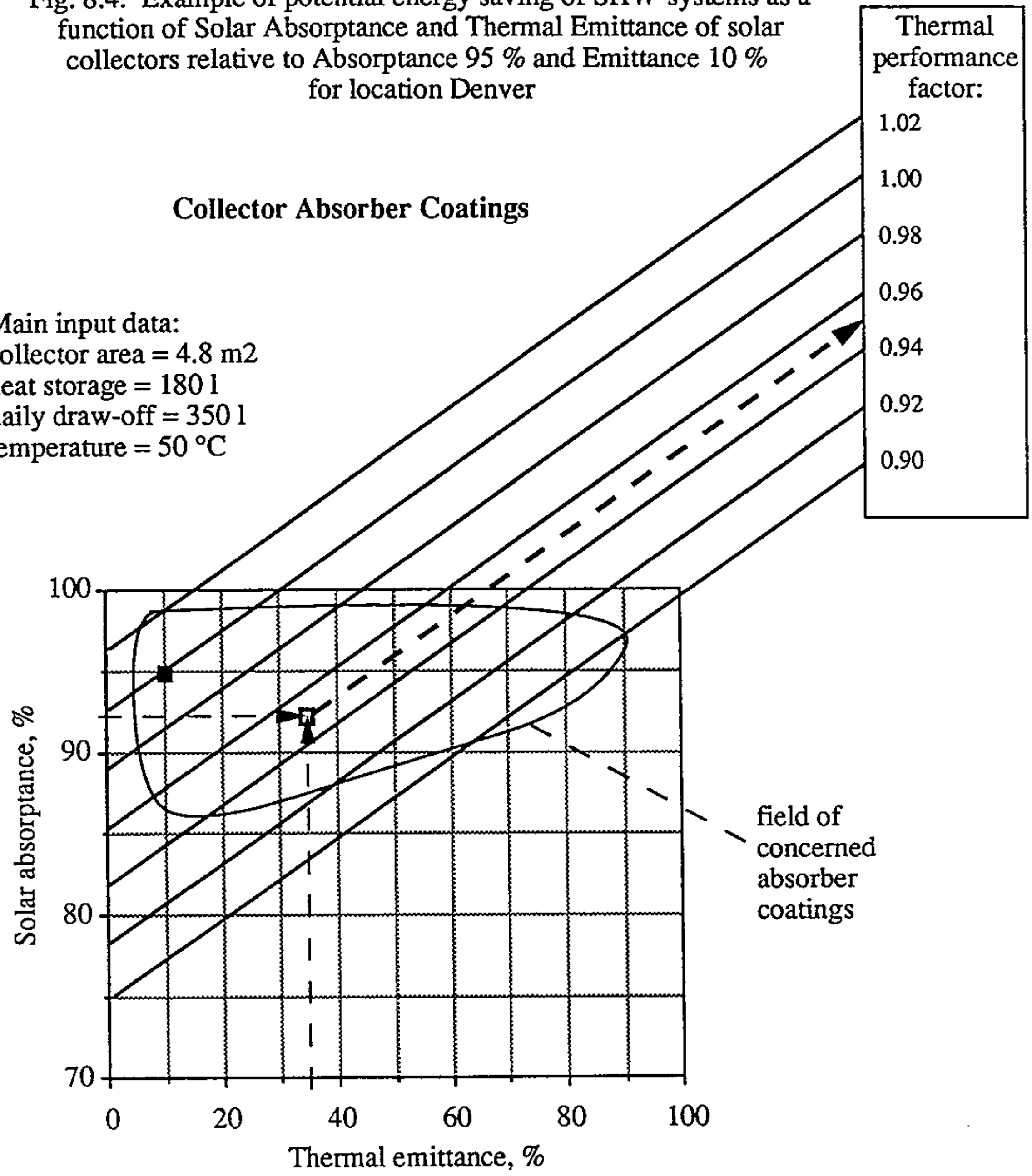


Fig. 8.3 Sample plot of changes absorptivity and emissivity

Fig. 8.4. Example of potential energy saving of SHW-systems as a function of Solar Absorptance and Thermal Emittance of solar collectors relative to Absorptance 95 % and Emittance 10 % for location Denver



Main input data:
collector area = 4.8 m2
heat storage = 180 l
daily draw-off = 350 l
temperature = 50 °C

Example for Solariselect coating
absorptance =0.92
emittance=0.35:

Solar Fraction (Solariselect) = 0.95 x Solar Fraction (0.95/0.10)

8.3 Passive Heating with Transparent Insulation Materials

The major thermal characteristics of transparent insulation materials for buildings are the solar transmittance and the heat transfer coefficient (U - value). In Chapter 7 and the working document, "Database of Solar Materials," different materials and their specific properties were presented. Chapter 10 describes the effect of these materials on the energy benefits when used in dwellings. In this study, carried out by participants coordinated by W. Platzer, Germany, the new simulation code from Fraunhofer Institute "SIMHAUS" was used (see working document, "Solar System and Component Modeling, Database of Calculation Programs", Annex C).

The tradeoff between solar energy capture and energy retention were considered for heating and cooling applications. Both material characteristics for a group of existing materials found in the field are presented in Fig. 8.5. Property data of glazing materials can be presented in a similar figure.

There are a number of thermal design tools for desk calculators, micro computers, and mini- or mainframe as well as manual methods to analyse passive solar buildings. However, the optimisation of transparent materials in a particular application requires the use of a detailed simulation code capable of modeling phenomena such as:

a) the thermal behaviour of the material and its device, viz., the angle modifier, the spectral energy distribution of the reflectance, absorptance and transmittance, the amount of air ventilation and shading in the air cavity behind the material.

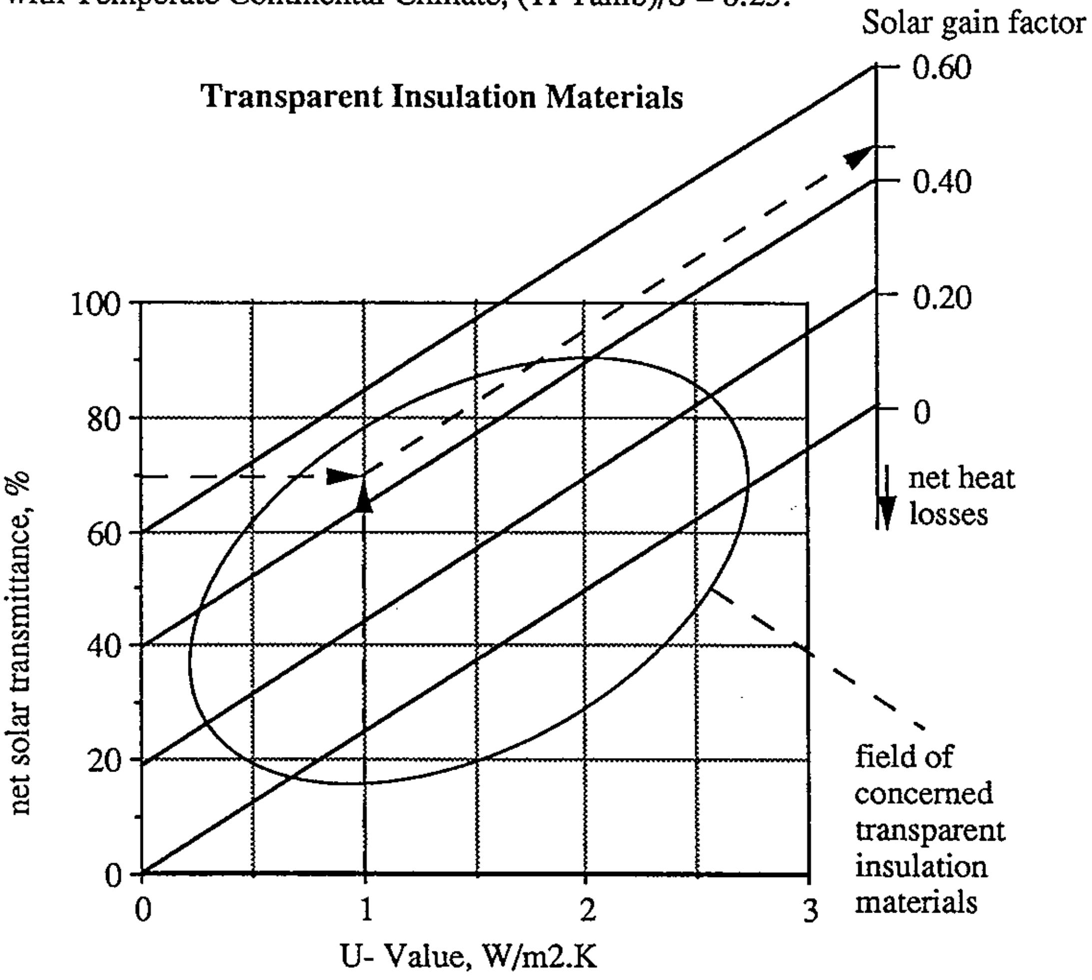
b) the energy demand, viz., the judgement of thermal comfort criteria with respect to air and radiant temperatures, overheating, temperature control.

c) the ambient climate on a hourly basis viz., temperature, direct and diffuse solar radiation (with spectral distribution).

The elaborate model SIMHAUS was refined for the purpose of this Subtask A research. A set of regression equations was derived from the results of a number of situations with the program SIMHAUS. The correlations predict annual total heating and cooling loads based on envelope (including TIM) and interior loads for dwellings. See Chapter 10.

A rough approach for the estimation of the combined effects of solar transmittance and U-value of transparent insulation materials on the solar gain of TIMs is also presented in Fig. 8.5. However, for accurate thermal performance calculations the energy absorbed within the glazing and conducted into the building has to be included. If only the solar transmittance is used in this graph the predicted net solar utilisation is too pessimistic.

Fig. 8.5 Example of potential energy saving of Windows and Transparent Insulation Materials for Solar Heating as a function of Net Solar Transmittance and U- Value without taken into account overheating for locations with Temperate Continental Climate, (Ti-Tamb)/S = 0.25.



Example for aerogel, monolth (13 mm) between glass (3 mm)
U-value = 1 W/m2K, transmittance (diffuse)= 0.7
Solar gain factor = 0.45

Ti = average indoor temperature (°C)
Tamb = average ambient temperature (°C)
S = average solar radiation (W/m2)
τ = solar transmittance (%)
U-value = heat transfer coefficient (W/m2K)

Using the basic formula:

$$\eta_{solar} = g - U_{TIM}(T_i - T_{amb})/S \quad (8.3)$$

where:

η_{solar} = solar gain factor

g = fraction of incident solar radiation (at the average angle of incidence) that is directly transmitted by the glazing and indirectly absorbed within the glazing and conducted into the building.

U_{TIM} = thermal transmittance coefficient of the TIM (W/m^2K)

T_i = average indoor temperature (°C)

T_{amb} = average ambient temperature (°C)

S = average solar radiation (incident) (W/m^2)

and considering the 5 months from November to March the following approach was derived for specific locations with Temperature Continental climate.

$$\eta_{solar} = g - U_{TIM} \times 0.25 \quad (8.4)$$

Example: Arel is more beneficial than aerogel, non evacuated, with respect to solar energy for heating. Note: no overheating was taken into account. For other locations see Paragraph 11.3.2.

8.4 Results, Conclusions

Based on simulation results the effect of changes in absorptivity and emissivity of solar absorbers on the potential energy saving of a specific solar system and a specific location can be easily established using the methodology presented in Fig. 8.4.

A rough approach for the estimation of the effect of changes in solar transmittance and U-value of transparent insulation materials on the solar gain in dwellings is presented in Fig. 8.5.

The impact of the thermal properties of transparent insulation materials on the solar gain of solar radiated walls for heating will normally be maximum at the highest value of $g - 0.25 \times U_{TIM}$ for locations in temperature continental climates.

Accurate studies were carried out on the thermal performances of spectral selective coatings on solar absorbers and transparent insulation materials for differing climates, in the case studies, described in Chapters 9 and 10.

Calculation methods and examples are described in Chapter 11 for a tentative estimation of the energy performance of spectral selective coatings and of transparent insulation materials.

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9. EFFECT OF SELECTIVE SURFACE PROPERTIES ON THE PERFORMANCE OF SOLAR WATER HEATING SYSTEMS

CASE STUDY

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A. Karagiozis, Unversity of Waterloo, Canada
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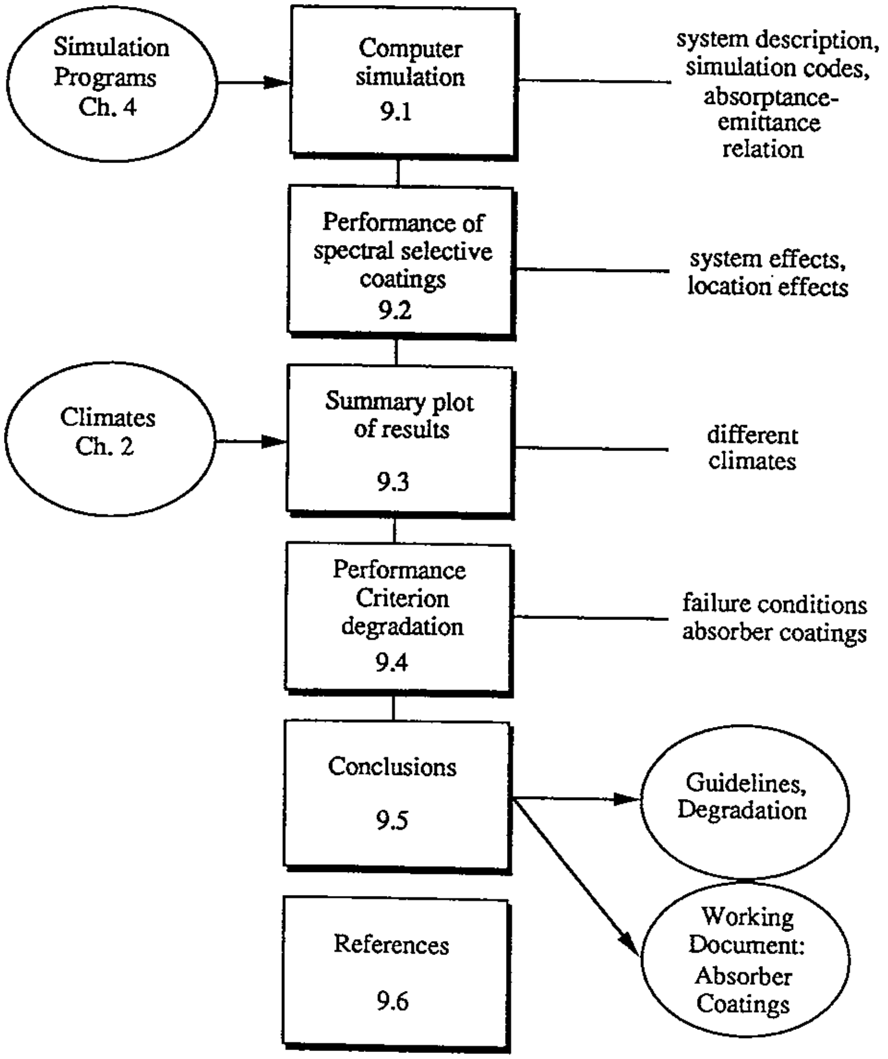
G. Brouwer, Van Heugten Consulting Eng., the Netherlands



9.1 Computer Simulations of Solar Domestic Hot Water Systems

Selective surfaces of solar collectors often degrade in the field; their solar absorptivity α_s, and thermal emittance ε change with time in service by some amount, say $\Delta\alpha_s$ and $\Delta\varepsilon$, from their starting $\alpha_{s,o}$ and ε_s. In order to project their service life, it is important to quantify the effect this degradation has on the annual fraction solar F_s. Thus when F_s has suffered a relative decrease of say 5 or 10%, the selective surface has reached the end of its service life. A given relative decrease in F_s can be caused by different combinations of $\Delta\alpha_s$ and $\Delta\varepsilon$. The objective of this study was to quantify this effect by using computer simulation of solar domestic hot water systems. The results were presented in plots of $\Delta\alpha_s$ versus $\Delta\varepsilon$ for relative decreases in F_s of 10% and 5%. The further objective was to study and interpret the nature of these plots and thier dependence on a range of solar system parameters, such as geographical location, collector area, and set point temperature of hot water.

The simulations were performed using the computer simulation code called "WATSUN" to simulate a standard solar water heating system as shown in fig. 9.1 (ref.1).

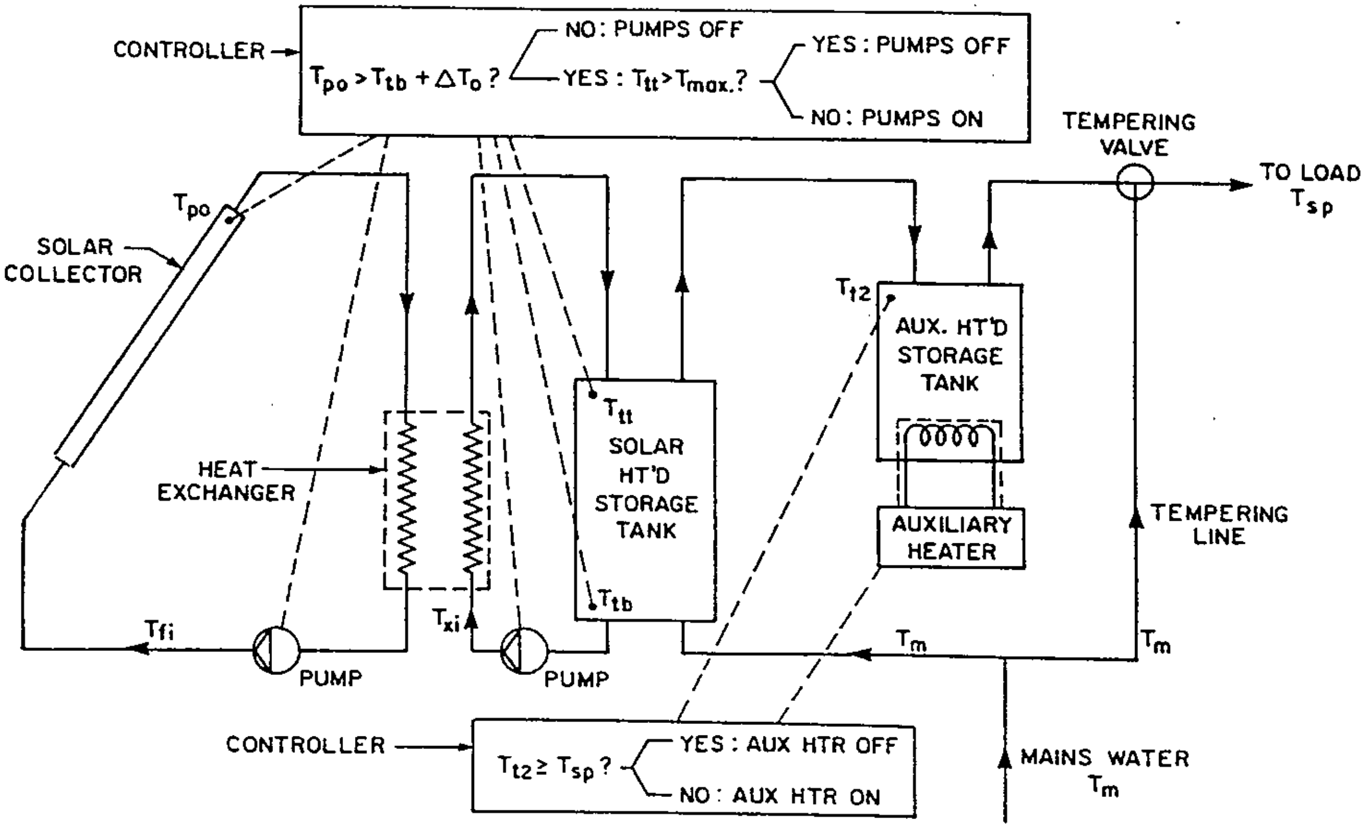


Fig. 9.1 Solar Domestic Hot Water system.

Like other similar codes, WATSUN marches through the year in hourly time-steps of simulated time. At each step it reads, form data storage, the mean weather data (solar radiation and temperature), and using modeling algorithms, calculates the mean solar irradiance on the collector for the hour, calculates the collector output and revises the status of the storage tank, and, finally, calculates the solar energy delivered to the load. Summed over the year, the latter quantity represents the annual solar energy to the load. Dividing this value by the yearly energy demand gives the fraction solar F_S. The program used is briefly described in the Working Document : Solar System and Component Modeling Database of Calculation Programs and fully documented in its instruction manual, ref. 2.

Similar calculations were performed with the computer code called "HEUSOL" also briefly described in the Working Document. As the results from this also detailed program were approximately equivalent in basic situations no additional calculations with HEUSOL were performed.

The input weather data used by Hollands et al in the simulations were typical meteorological year (TMY) data for North American cities. The data for the European cities were synthetic data created from knowledge of certain monthly means for the locations. In the case of Rapperswil, Switzerland, real data for one particular year was used.

In tables 9.1. and 9.2 the assumed values of input parameters to collector simulation program and system simulation program, respectively are presented. The remaining parameters were variations on the "base case 1 setting" given in table 9.3.

Quantity	Assumed Value
Ambient Temperature T_a,	283K
Mean Absorber Plate Temperature T_p,	308K
Back and Edge Heat Loss Coeff., $U_b + U_e$	1 W/m^2K
Convective heat transfer coefficient from cover to ambient air, h_w	15 W/m^2K
Glass cover solar transmittance τ_s	0.91
Glass cover solar absorptance $\alpha_{s,c}$	0.01
Spacing from absorber plate to glass cover	0.02 m
Bond conductance, C_b	∞
Fin efficiency parameter† $k\delta/W^2$	27.7 W/m^2
Group† $[h_{fi}(\pi D_i/W)]$	36 W/m^2K
Collector tilt angle	45deg

† These values make the fin efficiency = 0.95 and $F' = 0.86$ when $\epsilon = 0.1$.

Table 9.1 Assumed values of input parameters to collector simulation program.

Quantity	Assumed Value
Collector tilt	45 deg
Collector orientation	south-facing
Maximum allowable preheat tank temperature, T_{max}	90 deg C
Controller differential, ΔT_o	1K
Collector fluid specific heat	4200 J/kg K
Preheat tank heat loss coefficient	2 W/K
Tank room temperature	20 deg C
Heat exchanger effectiveness, ϵ_x	0.85
Heat exchanger heat capacity ratio	1

Table 9.2 Assumed values of input parameters to system simulation program.

	Base Case 1	Base Case 2
Collector area, A_c	$4.8m^2$	$3.0m^2$
Preheat Tank Vol.	180L	120L
Daily Total Load Draw-off	350L	100L
Set Point Temperature, T_{sp}	50 °C	55 °C
Heat exchanger effectiveness, ϵ_x	0.85	0.85
Collector flow rate to collector area ratio:		
High flow	0.025 kg/sm^2	0.025kg/s m^2
Low flow	0.0022 kg/sm^2	
α_{s0}/ϵ_0	0.95/0.1	0.95/0.1
F_s/F_{s0}	0.9	0.9

Table 9.3 Base case input data to computer simulations.

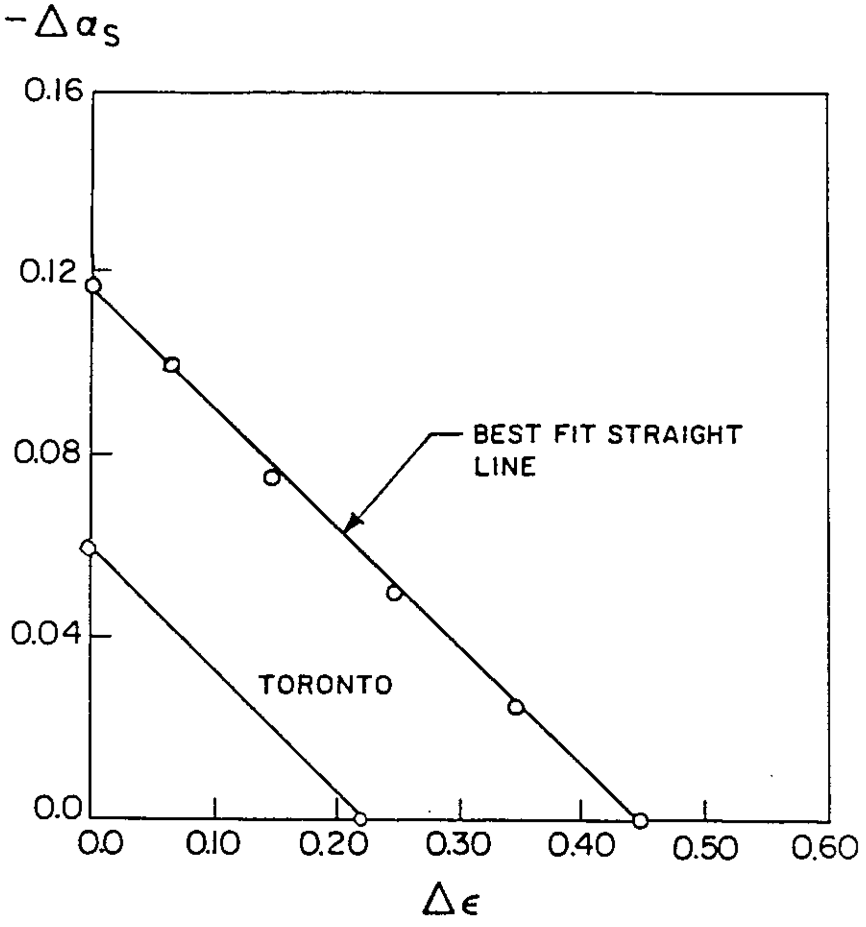


Fig. 9.2 Plots for base case 1 for 5% and 10% decrease in F_s, see table 9.3.

Fig. 9.2 shows plots of $-\Delta\alpha_s$ versus $\Delta\varepsilon$ using initial values $\Delta\alpha_{s,o} = 0.95$ and $\varepsilon_0=0.1$ and based on a relative decrease in F_s of 10% respectively 5% ($\Delta F_s/F_{so}=0.1$ and 0.05). Any point in a curve represents a combination of $-\Delta\alpha_s$ and $\Delta\varepsilon$ that will give a 10% or 5% loss in system performance. Both curves are seen to be very close to linear and can be closely matched by

$$-\Delta\alpha_s=a - \frac{a}{b} \times \Delta\varepsilon \tag{9.1}$$

were a and b are parameters that will depend on the geographical location and other system parameters. For the 10% loss in system performance the values of a and b are found to be a=0.117 and b=0.445 for Toronto and a=0.118 and b=0.498 for Rapperswil. Plots obtained by the low flow were also found to be linear.

Based on these linearities and an additional hypothetical justification it seems reasonable to conclude that the plots will always be linear. It also means that a considerable reduction in computational effort is achieved, particularly if a large range of combinations of input parameters are to be examined for effect.

9.2 Performance of Spectral Selective Coatings of Solar Absorbers

In the previous chapter (8.2.1) computer simulation was used to establish the effect of changes in plate solar absorptivity, α_S, and long-wave emissivity, ε, on the overall annual average energy delivered by a solar domestic hot water system with a single low-iron glass cover operating in Denver and in Toronto. In this chapter we extend these results to a broader range of locations and system parameters.

Firstly the effects of location, collector area and set point temperature were examined (ref. 1. Phase II). All other variables were held constant at the values used in the simulations reported on in the previous paragraph.

Secondly, calculations were performed to establish the effect of changes of α_S and ε on the solar system performance with a new setting of system parameters, chosen to be more representative of European practice (ref. 3. Phase III).

In what follows, we discuss the effect of location, collector area, set point temperature and system parameters in turn.

Effect of location

Fig. 9.3 shows the effect of the location. These plots are for the "base case condition" corresponding to a collector area A_c of 4.8 m^2 and a set point temperature T_{sp} for the water being heated at 50 °C. This area of 4.8 m^2 gives a fraction solar between about 40 to 60% for virtually all locations except Albuquerque, New Mexico and Denver, Colorado. The set point of 50 °C is quite typical.

Some sensitivity to city can be observed, but except for Albuquerque and Denver, the results are in a fairly narrow band. In practice, for Albuquerque, the collector area would probably be downsized somewhat; if the Albuquerque plot is redone for a collector area of 3.4 m^2, the line falls very close to the Stuttgart line, placing it in the "band" of the other cities.

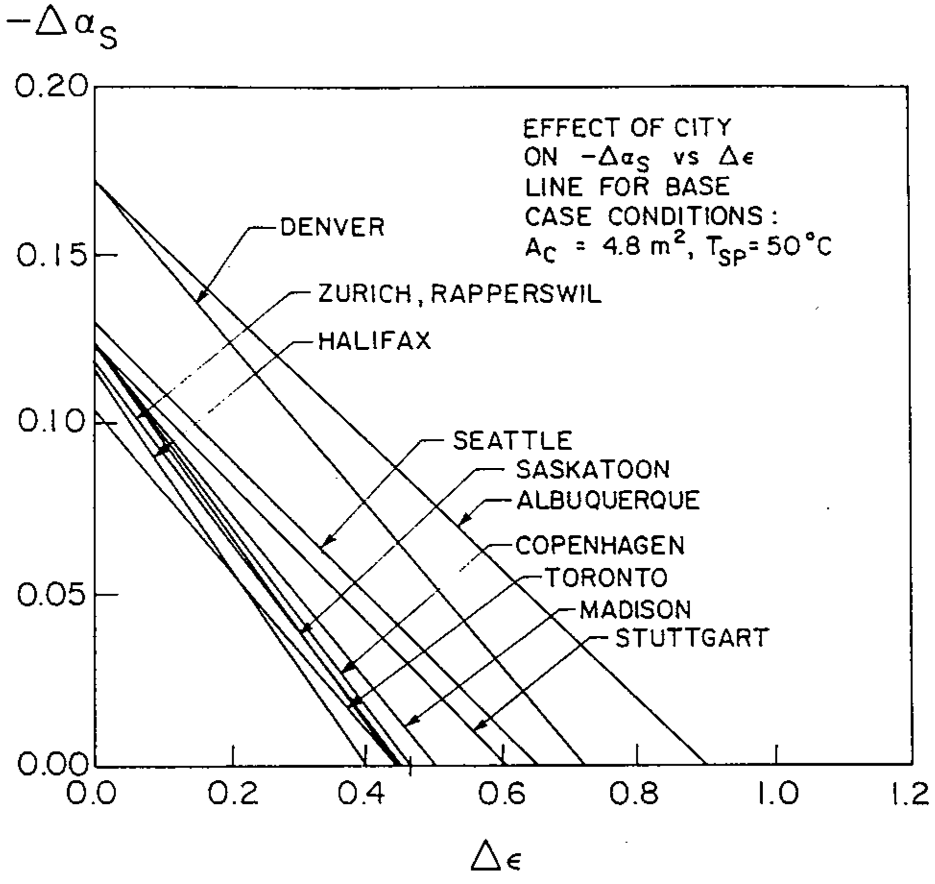


Fig. 9.3 Effect of location for 10% decrease in F_S.

Effect of collector area

Fig. 9.4. shows the effect of collector area A_c. The base value of 4.8 m^2 represents the typical value used for domestic hot water. The value of 7.2 and 3.4 m^2 are respectively 50% more and 40% less than the base area. By studying the effect of area for a fixed location, we are also studying the effect of fraction solar. The values of F_S are shown in paranthesis on the plots of the figure.

No consistent trends on the effect A_c are to be observed. Most often the largest value of A_c produces the line furthest removed from the origin. But in one case it produced the line closest to the origin.

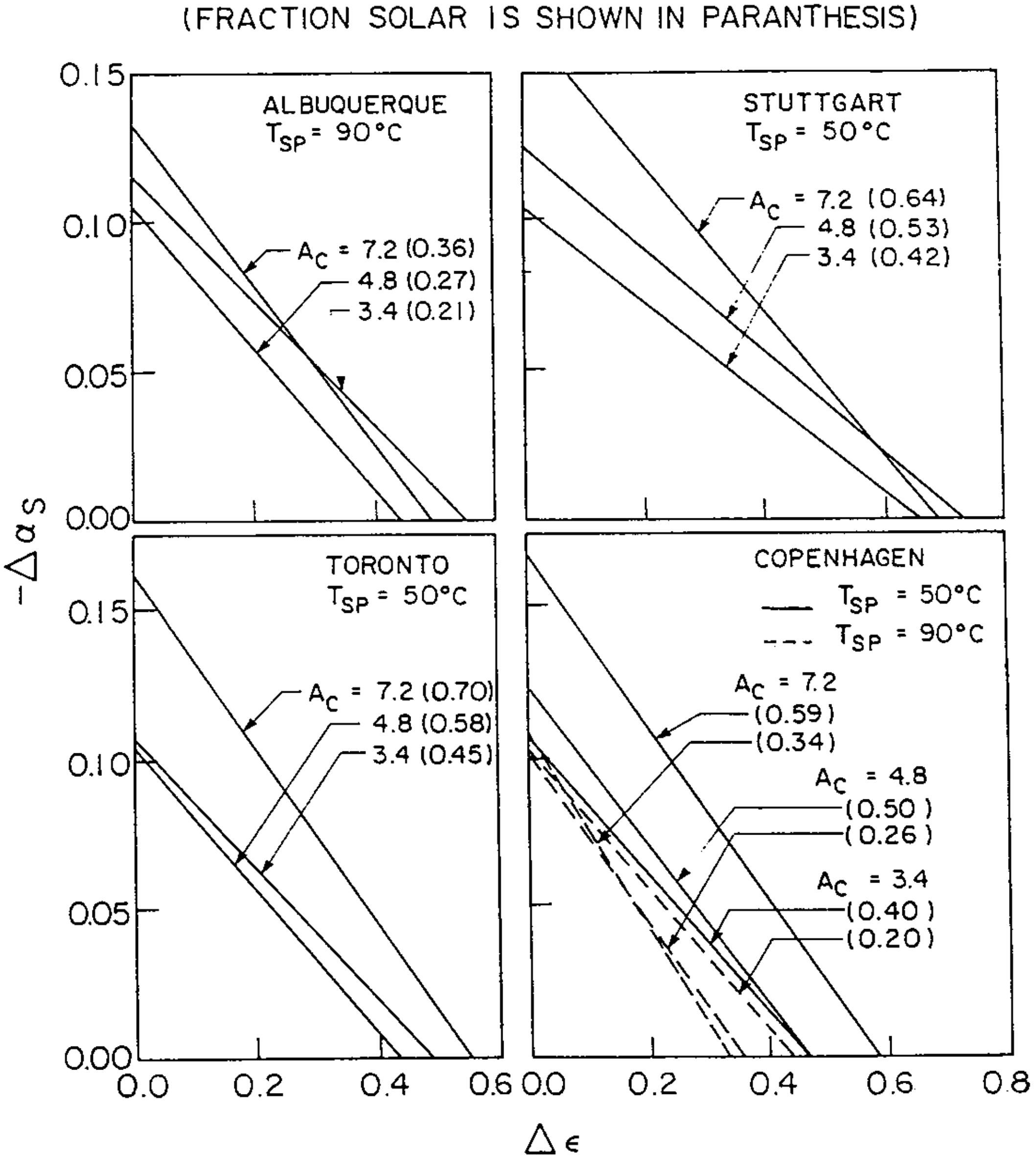


Fig. 9.4 Effect of collector area.

Effect of set point temperature for other applications

Fig. 9.5. shows the effect of set point temperature T_{sp}, the temperature to which the auxilliary heater heats the water. Values of T_{sp} of 30 °C and 90 °C, in addition to the base value of 50 °C were chosen for simulation . These figures allow for inference about some other applications of solar heat for buildings, such as swimming pool heating, active comfort heating, and active comfort cooling.

The plots show a relative insensivity to T_{sp} for $T_{sp} \geq 50$ °C. For T_{sp} of 30 °C it is dubious whether a selective surface is really required, as this is a fairly modest application. This shows up in these plots that for $T_{sp} = 30$ °C, a black ($\varepsilon = 0.9$) absorber plate would perform only 10% less well than one having a selective surface with the base value ($\varepsilon = 0.10$) for the selective surface emissivity.

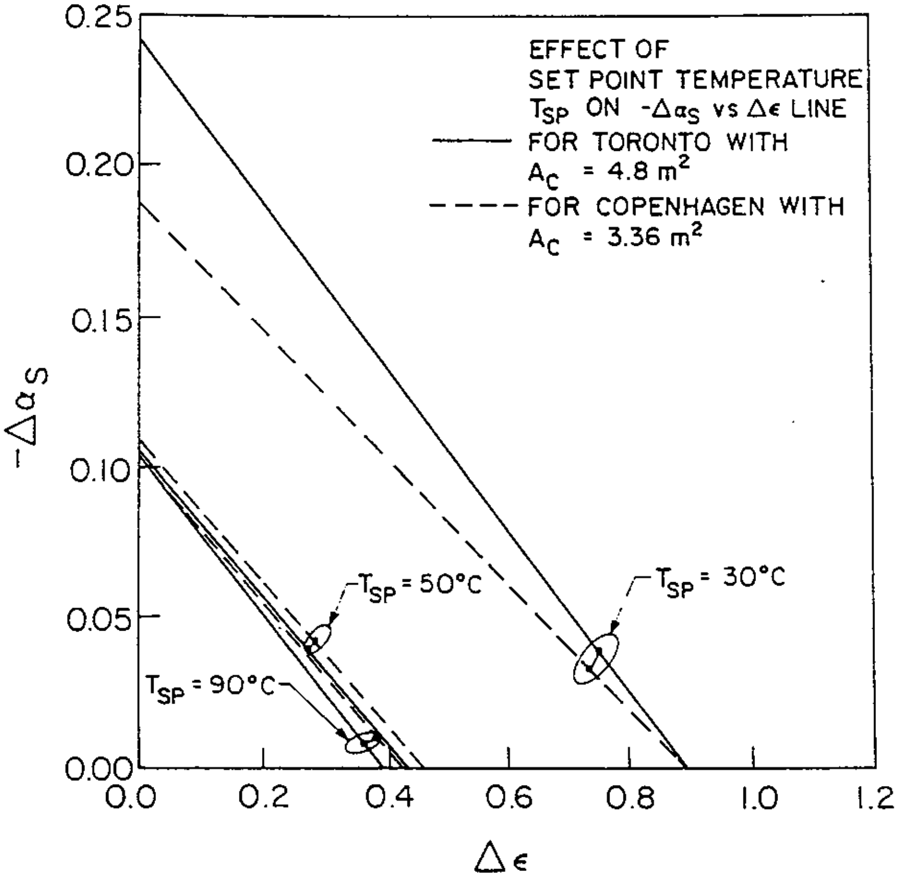


Fig.9.5 Effect of set point temperature.

<u>Effect of system parameters</u>

Fig. 9.6. shows the effect of a new setting of system parameters :
a tank volume of 120 litres, a collector area of 3 m^2, a set point temperature of 55 °C and a daily draw of 100 litres (these parameters will be referred to as "base case two", see the previous paragraph). Base case one, used in the previous effect studies was a tank volume of 180 litres, a collector area of 4.8 m^2, a set point temperature of 50 °C and a daily draw 350 litres. From an examination for different locations can be seen base case two acts quite similar to base case one.

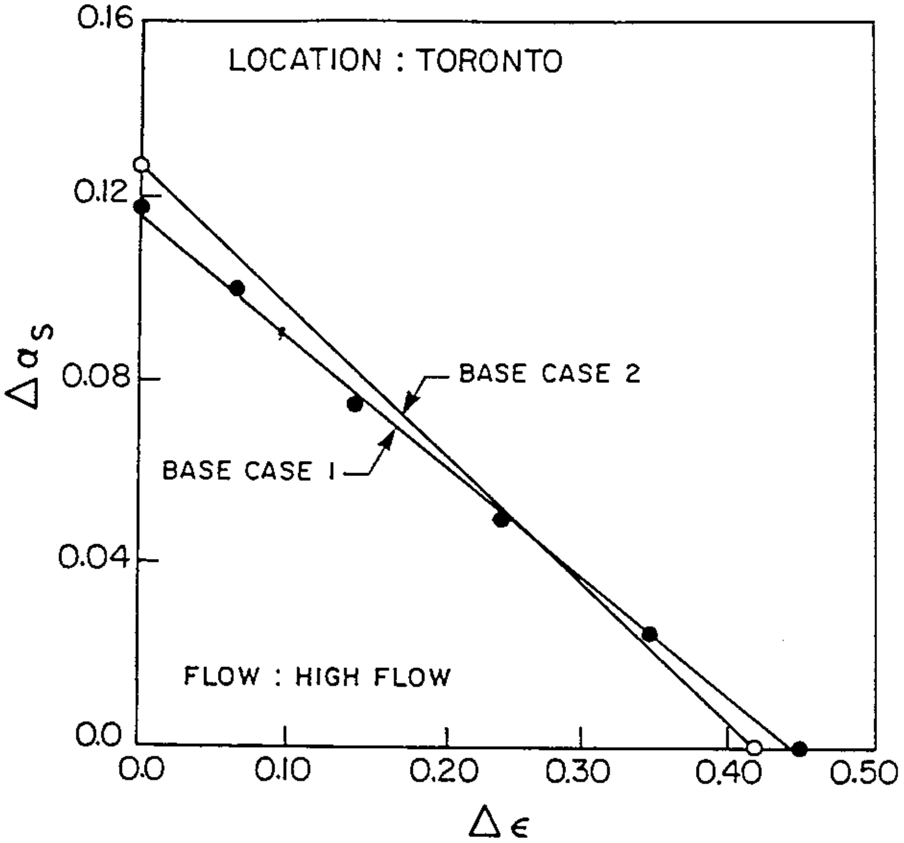
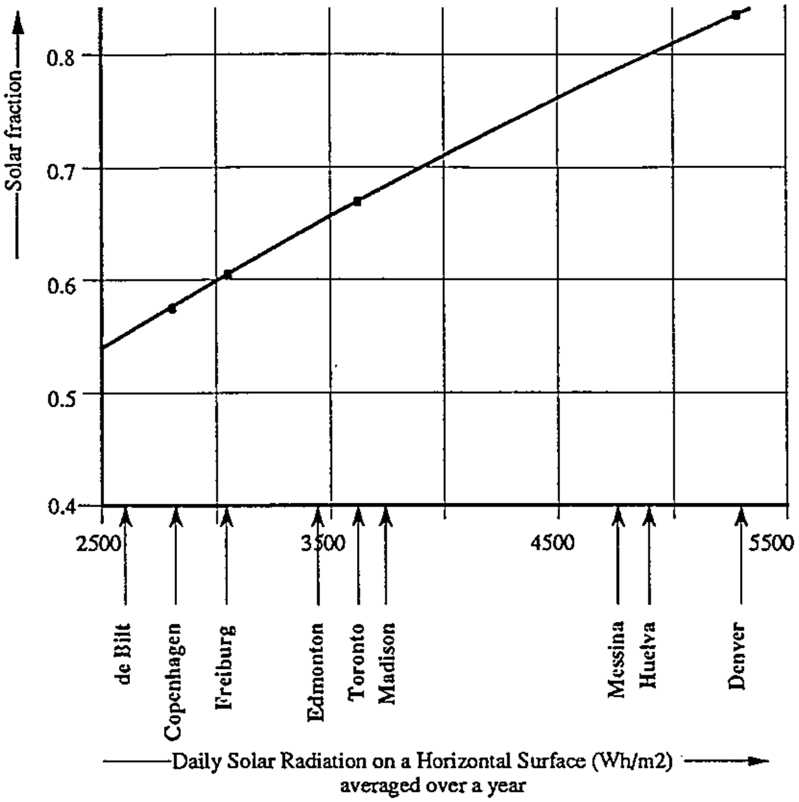


Fig. 9.6 Effect of system parameters.

For the base case condition 2 corresponding to a collector area A_c of 3 m^2 and for different locations (solar irradiance) fig. 9.7. shows the calculated solar fraction. With an equal hot water demand and solar system in base case 2 the annual solar heat gain increases from 350 kWh/m^2 collector for de Bilt (NL) to 540 kWh/m^2 collector for Denver (U.S.).



Conditions:

- Solar DHW-system
- Tank Volume = 120 liter
- Collector Area = 3.0 m2 (α =0.95 ε =0.1)
- Daily Draw = 100 l/55°C

Fig. 9.7 The Solar fraction of Solar DHW-Systems at different locations

9.3 Summary Plot of Results

Plots like that in fig. 9.2 were accordingly prepared to show the effect of various circumstances : on how the plot depends on geograpical location, on collector area, on thermostat set point temperature, on the (arbitrarily-chosen) ratio $\Delta F_s/F_{s,o}$=and the collector flowrate (See paragraph 9.2).

The resulting plots all showed a nearly constant value for the slope $k_1 = a/b$ of about 0.25, but the intercept (a) varied - from about 0.10 to about 0.20 at $\Delta F_s/F_{s,o}=0.1$.

That the parameter $k_1 = a/b$ is relatively insensitive to a wide range of system and climate variables can also be explained in theoretical terms as presented in detail in ref. 1.

To explain the variation in the intercept parameter a = k_2, the ratio $(a/\alpha_{s,o})$ / ($\Delta F_s/F_{s,o}$) was plotted against the initial annual solar fraction $F_{s,o}$ see fig. 9.8

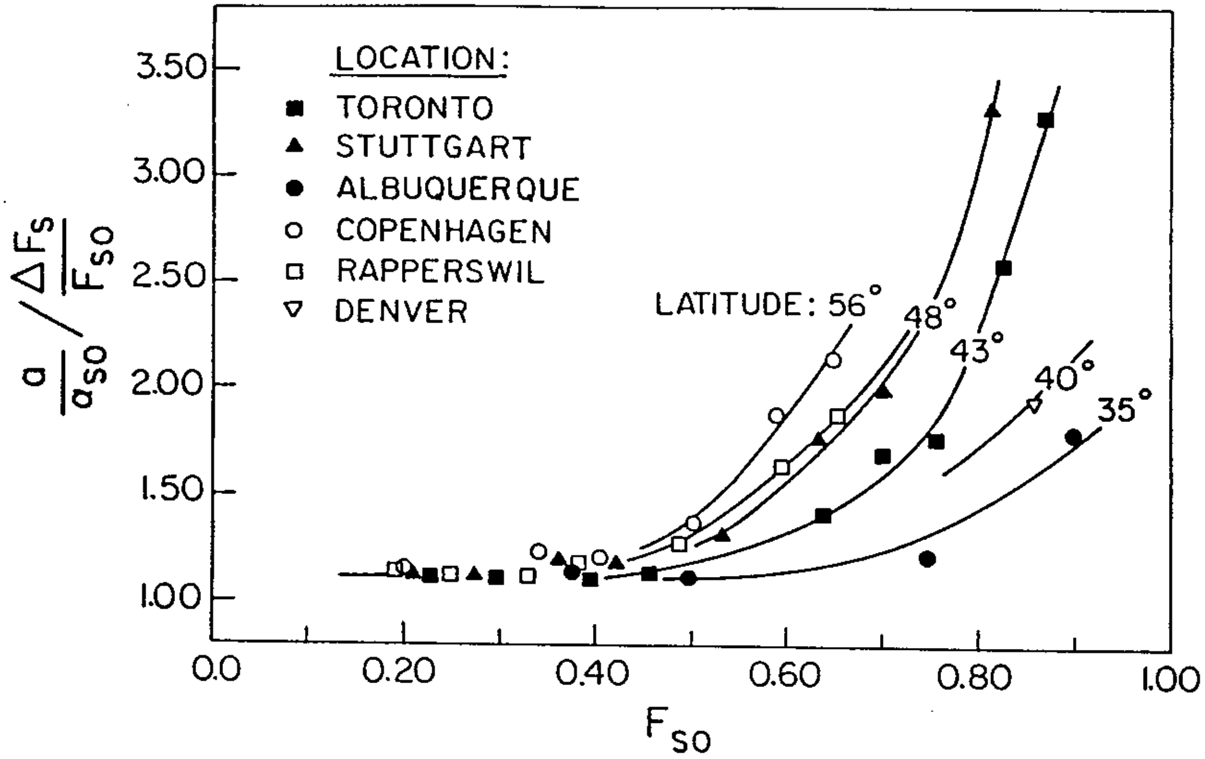


Fig. 9.8 Plots for all simulations performed in chapter 8 and 10.

At low fraction solar, a is relatively insensitive to a wide range of variables, the ratio approaches unity (or a value just above unity 1.10). However, it assymptotically approaches infinity as $F_{s,o}$ increases to high values.

The dependence on location for high values of $F_{s,0}$ as illustrated in fig. 9.3 is explained by Hollands et al as follows. For extreme northern locations, the available solar radiation in the months near the winter solstice is very small, and so these locations have an effective upper bound for F_s which is much less than unity.
Thus for a given value of $F_{s,o}$, northern locations would have higher values for the ratio $(a/\alpha_{s,o}) / (\Delta F_s/F_{s,o})$. This is indeed what is observed in the figure, in which the latitude of the individual cities has been indicated by a different symbol.

The main conclusions of this case study may be summarized as follows : for modest values of solar fraction (F_{so}< 0,5) the ratio of percentage solar fraction decrease to absorption decrease as well as to emittance increase is relatively insensitive to system and climate variables.

For larges values of the solar fraction the ratio of percentage solar fraction decrease to absorptance decrease (a) can be estimated form the plot shown in fig. 9.3, using the latitude of the location in question. The ratio to emittance increase can be estimated from the relation a/b in the figures 8.4, 9.3 and following. In chapther 11 a methodology to predict the thermal performance is described.

9.4 Performance Criterion for Degradation of Solar Absorbers

In order to formulate the criteria for the failure of an absorber coating in present case study, the relationships between deterioration of the optical properties of coating and decrease of solar system efficiency as described in ref. 1 were taken as a point of departure.

In the framework of Subtask B activities on degradation of absorbers a performance criterion function (PC) of the following linear form may seem the most preferable, as justified by the calculations made by Hollands et al in ref. 1.

$$PC = -\Delta\alpha_s + k_1 \cdot \Delta\varepsilon \leq k_2 \qquad (9.2)$$

Following the recommendations the value of $k_1 = a/b$ may be set equal to about 0.25 which value is based on some more preliminary results for most severe conditions and locations.

As failure in the case study was arbitrarily chosen as the deterioration of the optical performance of absorber, which corresponded to a 5% loss in system efficiency. This means that $\Delta F_s/F_{s,o}=0.05$ in terms of loss in the annual solar fraction.

From fig. 9.8 it is seen that at low fraction solar ≤ 0.5, the ratio $a/\alpha_{so}/\ (\Delta F_s/F_{s,o})$ is fairly constant (about 1.10) and, consequently,:

$$k_2 = a = \alpha_{s,o} \cdot 0.05 \cdot 1.10 \approx 0.05 \qquad (9.3)$$

As $\alpha_{s,o}$ varies between 0.90 - 0.95 for studied coatings in case study, see chapter 6, the definition of failure used in the case study as expressed before with values of k_1 and k_2 inserted will accordingly be

$$PC = -\Delta\alpha_s + 0.25 \cdot \Delta\varepsilon \approx\ 0.05 \qquad (9.4)$$

This definition of absorber failure seems to be rather well justified to correspond to a 5% loss in efficiency for solar systems having an initial annual fraction solar of 0.5 or less. For higher values of the initial annual fraction solar, the plots in fig. 9.8 may be used to interpret absorber failure or estimated service lives of coatings in case study in terms of decrease in solar system efficiency.

9.5 Conclusions

- Sensivity to system and climate variables of material degradation ($\Delta\alpha$ and $\Delta\varepsilon$) to relative change of solar fraction. ($\Delta F_s/F_{s,o}$):
  - for solar fraction $F_{so} < 0.5$
    - ratio $\Delta\alpha$ to $\Delta F_s/F_{s,o}$: relatively insensitive
    - ratio $\Delta\varepsilon$ to $\Delta F_s/F_{s,o}$: relatively insensitive
  - for solar fraction $F_{s,o} > 0.5$
    - ratio $\Delta\alpha$ to $\Delta F_s/F_{s,o}$: according to fig. 9.8 ($a = \Delta\alpha$)
    - ratio $\Delta\varepsilon$ to $\Delta F_s/F_{s,o}$: according to the relation a/b from the $\Delta\alpha/\Delta\varepsilon$ plots.

- The definition of failure of an absorber coating in most severe situations (the smallest changes of α and ε which cause 5% loss in efficiency) is expressed as the performance criterion PC = $-\Delta\alpha_S + 0.25 \cdot \Delta\varepsilon = 0.05$.
  For higher values of fraction solar ($F_S > 0.5$) relationships may be derived from fig. 9.8.

- For solar hot water systems, which have a low system temperature e.g. 30 °C (caused by low set point temperature, by big storage capacity or by very high amounts of hot water demand), selective surfaces have a negligible effect on the thermal performance).

9.6 Nomenclature

a	vertical intercept on a plot of $\Delta\alpha_S$, versus $\Delta\varepsilon$
b	horizontal intercept on a plot of $\Delta\alpha_S$, versus $\Delta\varepsilon$
F_S	yearly fraction solar
ΔF_S	change in fraction solar due to changes in $\Delta\alpha_S$, and $\Delta\varepsilon$
F'	collector efficiency factor
T_{sp}	DHW system set point temperature, °C

Greek letters

α_S	solar absorptivity of selective surface on collector's absorber plate
$\Delta\alpha_S$	change in α_S due to selective surface degradation: $\Delta\alpha_S = \alpha_{SO} - \alpha_S$
β	a/b
ε	thermal emittance of selective surface on collector's absorber plate
$\Delta\varepsilon$	change in ε due to selective surface degradation: $\Delta\varepsilon = \varepsilon - \varepsilon_O$

Subscripts

0	value of a quantity when solar system first goes into service

9.7 References

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2. Brouwer G. (editor). Solar System and Component Modeling Database of Calculation Programs. Working Document, Nijmegen NL, May 1991, Task X, IEA. Annex C.

3. Hollands K.G.T., Shipley D., Karagiosis A. Effects of degradation of α_S and ε on solar system performance. Phase II and III case study results. Task X, IEA 1987/1989.

10. THE ENERGY BENEFITS OF TRANSPARENT INSULATION CASE STUDY

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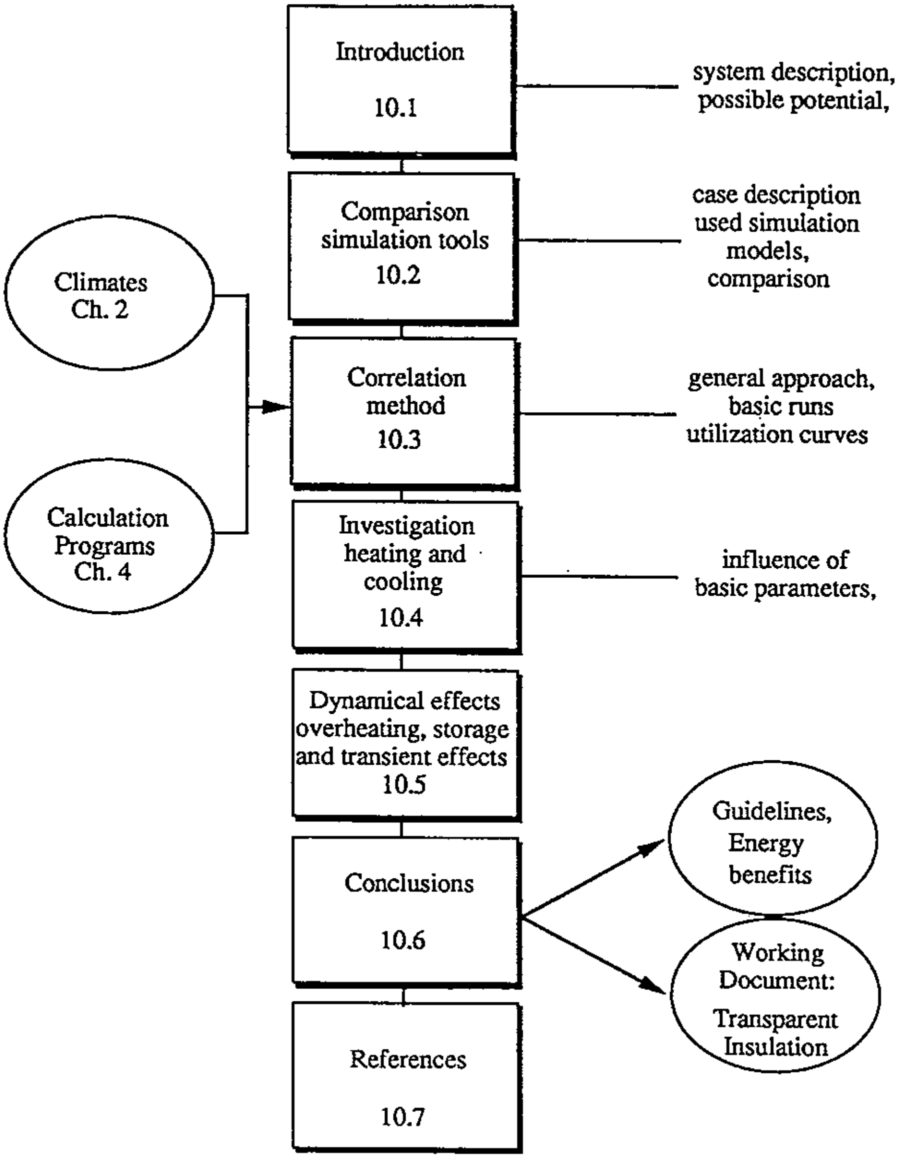
with contribution of H.A.L. van Dijk , TNO-Bouw Institute, the Netherlands



10.1 Introduction

Within Subtask A of the IEA TASK X it was decided in 1988 to start a case study on transparent insulation of massive walls (collector-storage-walls). This system is a promising new development in the field of passive solar heating. As the passive utilisation of solar energy in general has a large potential of reducing heating energy for buildings, the transparent insulation materials (TIM) could enable us to make a large step forward towards a world with less fossil and nuclear energy and therefore less environmental problems.

The content of the case study should be the investigation of the system in a rather general context. The emphasis should lie on a investigation of the main physical parameters affecting the system performance. Specific designs for complex buildings and architectural aspects should not be included.

As a means of this investigation simulation tools seemed to be appropiate, so starting from a first description of simple reference cases ('shoebox houses'), participants wanted to check their possibilities with existing simulation tools. In the end two participants (TNO-Bouw/Netherlands and FhG-ISE/Germany) remained.

FhG-ISE presented a simplified method (monthly correlation method) which will enable other persons to investigate their own specific questions at least approximately. However, dynamical effects of the heat transport and the control strategies cannot be treated with this method. It was generally felt, that even some very basic results should be explicitly included in the report.

The author acknowledges that many questions have been treated not comprehensively. Concerning the limited time and resources, however, the results should give valuable insights in the TI-wall system performance.

10.1.1 Description of System

The new concept of external insulation of massive house walls with TIM combines the advantages of conventional opaque insulations and solar collector systems. The dark coloured wall surface acts like the absorber of a collector by converting the solar radiation transmitted through a TIM, which may be both clear or diffusing, into useful heat. The transmission heat losses of the wall can be dramatically reduced and parts of the solar gains can be stored in the wall itself. The contribution of these gains for heating purposes is time-shifted, dependent on the wall's material properties (conductivity, volumetric heat capacity). The inner wall surface acts like a large low temperature wall heater. The system provides passive solar heating without any active heat distribution device.

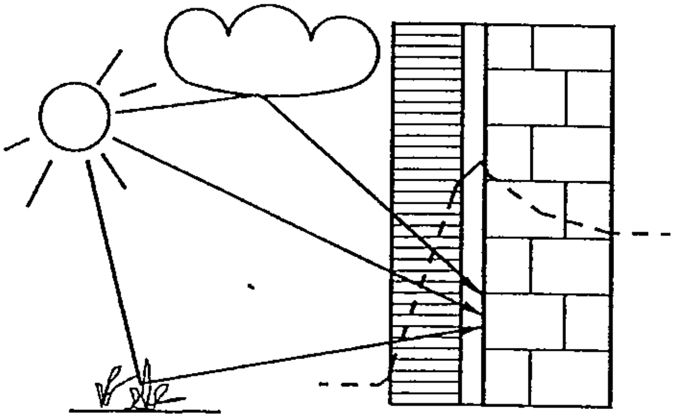


Fig. 10.1 Transparent insulation of massive house walls (principle)

10.1.2 Adaptation to Climate

Transparent insulation provides an excellent possibility to adapt a collector storage-wall design to different climatic conditions as well as to different wall orientations. The wide range of possibilities to choose between materials allows to select total energy transmittance g and heat conductance Λ according to insolation, prevailing temperatures and application needs. A balance between heat losses and solar gains may be prescribed within certain ranges in a design process. For southern climates certainly glazing units are still favorable, whereas for moderate to northern climates the high insulation value of the materials is needed.

10.1.3 Building Stock

The simple approach of an outside cladding of existing massive walls makes the system eligible for retrofitting in the building stock. As the percentage of new buildings is small - only 1-2% of the building stock will be built anew each year, this area will be most important in future reductions of primary energy use. The advantage of new buildings, on the other hand, is that the design can be optimized towards the application of transparent insulation.

10.1.4 Possible Technical Potential

The technical potential of transparent insulation is enormously large, even when it is considered that many wall areas in the building stock cannot be considered. The reasons are manifold. Although not only South walls, but also East and West oriented collector storage-walls are sensible with transparent insulation, for many facades conventional opaque insulation will be more interesting.

For Germany a study estimated that only 70% of the total wall area (not including fenestration) may be equipped with opaque insulation (antique buildings, stucco facades, small areas etc.). Excessive shading by neighbouring buildings and obstacles, the low insolation conditions for North-oriented facades lead to a further reduction of useful TIM-area. Nevertheless this would be for Germany approximately 400 Mio. m^2 collector area, ref.1. This potential has to be investigated technically and economically in much more detail.

10.2 Comparison of Reference Cases with Different Simulation Tools

10.2.1 Motivation

As transparent insulation of massive walls (TI) is a relatively new concept, most simulation programmes can handle the situation only approximately. Usually a glazed collector-wall is a possible feature, but the temperature dependence of U-values and the special angle dependence of the solar transmittance / total energy transmittance is usually not covered. TI-systems tested in reality often have shading devices incorporated which are controled by environmental parameters. The collector modules developed by the ISE/Germany use solar radiation, absorber temperature and an averaged ambient temperature, ref. 2.

The program SIMHAUS was specially developed to model the heat transfer within the collector-wall and the shading device rather detailed, but other aspects of the building were treated less detailed (heating system, zoning, film coefficients, radiation through windows etc.). Other models like the commercially available SUNCODE or ESP are much more detailed in this field, but are less suited for TI-application. In our case the comparison could only test certain plausibility limits of the results.

10.2.2 Description of Reference Cases

From an initial proposition of 18 reference cases, ref.3, after a thorough discussion a smaller subset of 4 cases was selected. The cases are closely related to the 'shoebox' houses used for the Task VIII simulation exercises. These shoebox houses had large window areas on the South oriented facade. The main modification of the present exercise is the replacement of well-insulated walls for East and West orientation with a relatively good conducting brick wall of 30 cm thickness. This walls are then either insulated opaquely or transparently to compare these systems. The construction of a TI-wall from outside to inside is: glass cover - TIM - air gap - wall. Table 10.1 shows the general idea of the reference cases: Starting from a house without any solar gains, insulation, windows and transparent insulation are added to the system to identify the single contributions. For instance the difference between case 8 and case 10 is only the non-zero transmittance of the insulation of the East and West walls, thus changing 'opaque' to 'transparent'.

Table 10.1 : Reference cases

case	building mass	South windows	East+West wall insulation
4	heavy	opaque	none
6	heavy	opaque	opaque
8	heavy	transparent	opaque
10	heavy	transparent	transparent

As reference climates the Copenhagen and the Denver Test Reference Years have been chosen to make results comparable to Task VIII exercises.

Single results are available in a working document, ref. 3. Every model had its own deficiencies, but after a discussion of different problems (different solar radiation processors, input specifications, input details and simplifications), the participants gained confidence in the congruent results of either SIMHAUS, SUNCODE or the TNO-models TI-wall combined with TCM-HEAT. Small differences exist, but do not influence the general tendencies of the results.

10.3 Correlation Method on Monthly Basis

10.3.1 Motivation

Within monthly calculation methods for an estimation of solar gains generally two important quantities have to be determined. The first one is the efficiency, averaged over the period, the second one is the utilisation Φ for the gains of the system. The latter quantity states, how much solar gains actually can be used in the system. This depends on user patterns and load, of course. As loads and gains are not simultaneous, some gains cannot be used. Although storage of gains generally increases the utilisation, due to thermal losses and limited capacity the maximal utilisation is nearly never met. Only ideal storage would overcome this situation.

Utilisation factor Φ is closely related to dynamical processes and storage effects; it can be determined by dynamical simulations. However, for a certain range of parameter variations (e.g. concerning buildings: single-family house, heavy weight construction in temperate climate) a functional dependance of the utilisation factor can be given. Such a method has been developed and tested for windows within the IEA Annex 12 of the energy conservation programme, ref. 4. For this method (TCM-heat) internal gains and solar gains through windows are added to a total gain and by dividing this with the heat load the gain-load-ratio GLR is calculated. This proceeding will be modified for the transparent insulation system, where a solar-load-ratio SLR is used, which is calculated taking the additional solar gains due to TIM and dividing that by the remaining heat load of the house without TIM, but with windows.

10.3.2 General Approach

Solar load ratio SLR versus gain-load ratio GLR

When considering the design of a building there is a major distinction between direct gains and indirect solar gains by TIM-walls. Every building needs windows and only the extent, orientation and quality of fenestration may be discussed. Contrary to that TIM-walls are optional. When considering retrofitting houses, the window area already is fixed. Internal gains too are fixed within certain limits.

This is an argument for a correlation method for indirect solar gains of TIM-walls, which should start from the heating load QL' of the building, where direct solar gains and internal gains have already reduced the basic load QL. The effect of the heat insulation of the TIM is to reduce QL which affects the utilisation of the direct gains. This effect may be calculated by the TCM-heat-method.

A second argument for a correlation of utilisation $\Phi_{TIM\text{-}wall}$ versus solar-load-ratio SLR=QS_{cw}/QL' (QS_{cw}: solar gains through the TIM-collector wall), being preferred over a gain-load-correlation method, where all gains are summed up, is the very specific nature and application of the direct gain element (instantaneous) and the indirect gain element (storage and time lag). The two gains are too different in character to mix them together in one correlation, therefore the SLR-approach has been used for the method.

Calculation of monthly efficiency for a collector wall

When using steady state analysis with monthly means of U-values and total energy transmittances, an efficiency of the TIM-wall system can be calculated ref. 5,6. Given this efficiency expression, the monthly mean of the net heat flux through the wall can be calculated using mean temperature and radiation values. The formula used consists of two parts, the thermal load part and the solar gain part:

$$q_{net} = q_{load} - q_{gain} = \frac{QL_{cw} - QS_{cw}}{A_{cw} * T_{mon}}$$

$$= U_{tot} * (T_i - T_{amb}) - g_{TIM} * \frac{U_{tot}}{U_{TIM}} * S$$

$$= U_{tot} * (T_i - T_{amb}) - g_{tot} * S \qquad (10.1)$$

$$U_{tot} = (U_{wall}^{-1} + U_{TIM}^{-1})^{-1}$$

where: T_i - internal mean temperature [°C]
T_{amb} - ambient mean temperature [°C]
S - mean solar irradiation [W/m2]
U_{tot} - total U-value of TI-wall [W/m2K]
U_{wall} - U-value of wall (absorber surface to interior) [W/m2K]
U_{TIM} - U-value of TIM-cover (absorber to ambient) [W/m2K]
A_{cw} - area of the TIM-wall
T_{mon} - time period (month)
g_{TIM} - mean total energy transmittance of TIM-cover
g_{tot} - mean total energy transmittance of total wall

For a set of cases with different collector wall configurations (TI-material, wall type and orientation) monthly heat gains QS_{cw} have been determined with the help of formula 1 using monthly mean transmittances g and the iteratively determined internal temperature, and also with the simulation model SIMHAUS. Figure 10.2 shows the good correspondence.

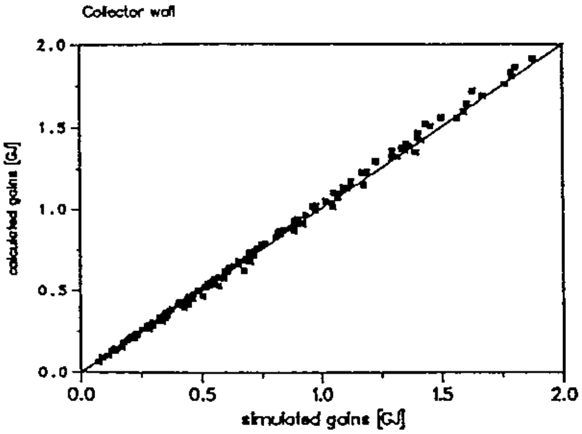


Fig. 10.2 Comparison of calculated and simulated monthly net heat gains through TIM-wall.

NB: The approach could be used the other way around as well: given the monthly net heat flux through the TI-wall calculated with a detailed model, one can try to derive the mean U-value and g-value by simple linear regresssion analysis with given monthly mean values for the incident solar radiation S and the indoor- outdoor temperature difference. In case of angle and temperature dependent properties this may however lead to best fit U and best fit g which are poorly related with the real values.

If a shading unit is used to protect the building from overheating in summer, the mean value of the total energy transmittance g has to be corrected accordingly. This, of course, is a difficult task, if the control strategy is not a fixed schedule but responding to the current state of the building. Therefore this problem definitely should be treated with a dynamical simulation.

Utilisation factor

The difference between the optional collector wall system and the window system is reflected by the sequential proceeding. By a suitable method (e.g. TCM-heat) the utilisation of solar gains through windows and internal gains and the remaining heating load QL' can be calculated:

$$QL' = QL - \Phi_{W+I} * (QS_w + QI) \qquad (10.2)$$

QS_w : gains through windows
QI : internal gains
QL : heat losses by transmission and ventilation, under the situation of no gains (no overheating, no cooling)
NB : Only months with positive values of ΔT has to be taken into account ; otherwise $QL(_{mon}) = QL'(_{mon})$
$QL=HL*(T_{i,set}-T_{amb}) *T_{mon}$
HL : overall heat loss coefficient (W/K)
The utilisation factor Φ_{w+i} for both gains is a function of the gain-load ratio GLR:

$$GLR = (QS_w + QI) / QL \qquad (10.3)$$

The collector wall utilisation factor $\Phi_{TIM\text{-}wall}$ is a function of the marginal solar-load ratio:

$$SLR = QS_{cw} / QL' \tag{10.4}$$

Heating demand and excess temperature

Using the utilisation factor $\Phi_{TIM\text{-}wall}$ for the gains of the collector wall, the heating demand can be calculated quite easily:

$$QHD = QL' - \Phi_{TIM\text{-}wall} * QS_{cw} \tag{10.5}$$

A second interesting quantity is the mean monthly excess temperature due to solar direct and internal gains = ΔT_{W+I} and the additional mean excess temperature due to the collector wall gain ΔT_{cw}, when compared to the set point temperature $T_{i,set}$. The excess temperatures are also determined by the utilisabilities.

$$\Delta T_{W+I} = \frac{(1 - \Phi_{W+I}) * (QS_W + QI)}{HL \cdot T_{mon}*} \tag{10.6}$$

$$\Delta T_{cw} = \frac{(1 - \Phi_{TIM\text{-}wall}) * QS_{cw}}{HL \cdot T_{mon}*} \tag{10.7}$$

The mean room temperature without TI-walls according to this is $T_{i,set}+\Delta T_{W+I}$, if collector walls are additionally installed, ΔT_{cw} has to be added.

10.3.3 Short Description of Basic Runs for Correlation

The cases selected for simulation in order to get utilisation result for a correlation are closely related to the case 10 of the standard shoebox house. However, to get a wide range of SLR-values for the correlation, load and gain have been changed by variing the opaque insulation standard and the parameters U and g of the TIM used. The orientation of the TIM-wall for these cases always was South. Building capacity and wall capacity have not been changed. As within this task it did not seem possible to develop the correlation method fully, only one type of building was chosen. Correlation parameters for other types have to be found in future.

10.3.4 Utilisation Curve

A correlation $\Phi_{TIM\text{-}wall}(SLR)$ has been developed from the 13 yearly simulation runs (156 monthly data) mentioned above, ref. 7. The two parameters K and D of the function

$$\Phi_{TIM\text{-}wall} = 1 - \exp(-K / (SLR - D)) \tag{10.8}$$

were determined by a Least-Square-Fit (SIMPLEX-method). The results for the type of building used in the simulations of this IEA Task were satisfactory insofar, as the scattering of the monthly utilisation factors determined from the simulation around the fit curve (K=1.31, D=-0.177) is acceptable (Fig. 10.3).

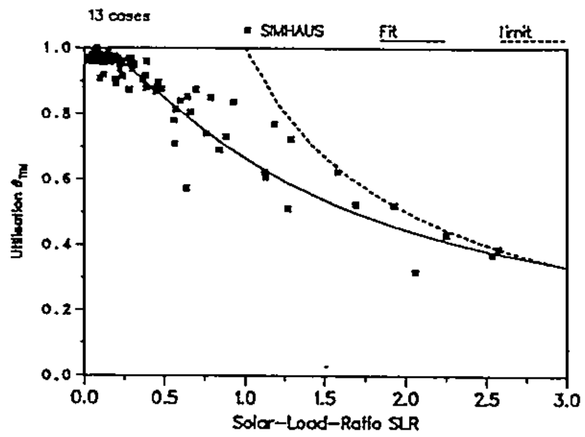


Fig. 10.3 Utilisation correlation curve determined with a least- square-fit from 13 simulated cases

The correspondence between simulated and calculated monthly gains QS_{cw} was excellent, as expected (Fig. 10.2). Moreover the difference between annual heating demands from simulations and from the correlation procedure (using QL from the simulation as input) was less than 1% even for cases where the orientation was different from South (Fig. 10.4).

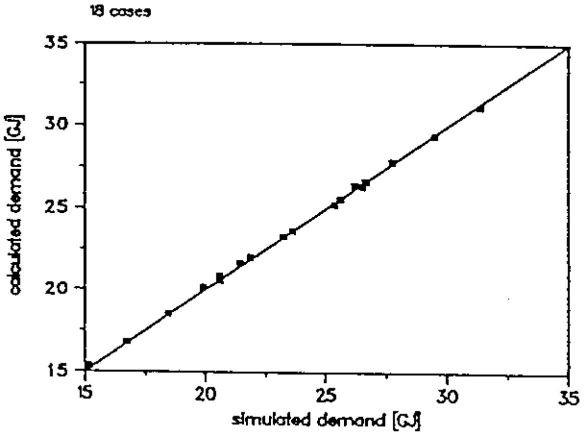


Fig. 10.4 Comparison of yearly heating demand from simulation and correlation (18 cases)

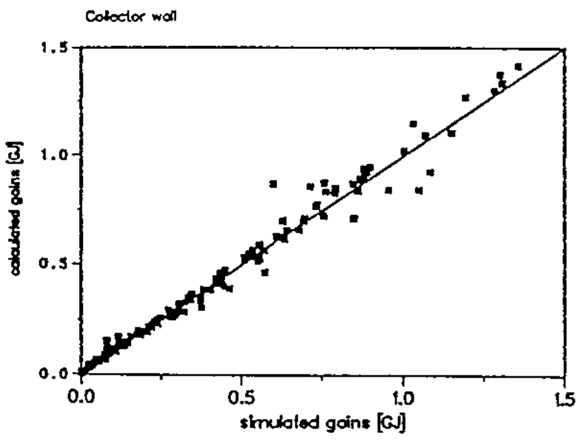


Fig. 10.5 Comparison of monthly utilised solar gains from simulation and correlation (18 cases)

In Fig. 10.6 the calculated monthly mean room temperatures are compared with simulation results. The values compare well with the simulated case with fixed ventilation rate. A second case was simulated, were an increased air change of 5 h^{-1} was chosen (open windows), whenever the room temperature exceeded 24 °C and the outdoor temperature. This leads to a much lower overheating, which is shown by the third curve.

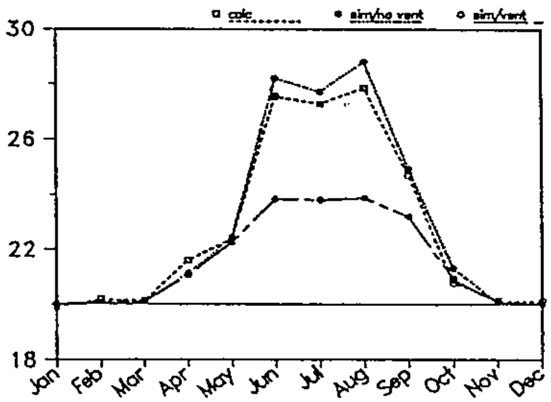


Fig. 10.6 Calculated and simulated monthly mean room temperatures

For the purpose of IEA task X the utilisation function seems satisfactory, as only a general idea of the impact of TIM on the heating demand should be demonstrated. This work could be continued to determine fit parameters for different building types, as it has been done for TCM-heat. However, this would exceed the scope of this task.

10.3.5 Utilisation Curves for Case 10

From the differences of heating load between case 10 and case 8 the actual reduction due to TI-walls can be inferred. SIMHAUS also calculates the net heat flows through the TI-walls, whereas for ESP this has been done manually. From these numbers the utilisation of the solar gains can be derived. Fig. 10.7 shows the utilisation factor versus the marginal solar-load ratio (solar TI-wall gains divided by remaining heat load of case 8). The results of ESP are worse than the other ones.
However, ESP is less suited for TI-application as motivated in 10.2.1.
The actual utilisation often is better than the predicted one by the correlation. This is probably due to the time shift effect: The correlation has been developed for South oriented facades, however case 10 has two facades oriented East and West, therefore the gains are better distributed over the day.

It is obvious that case 10 is a grossly oversized solar system (having 9 m^2 South window area and 44 m^2 TI-wall area East/West, many monthly SLR-values are larger than 3.0). With no additional shading of the systems in summer time the cooling problem becomes much more important than the heating problem. Either a reduction in collector area is appropriate or good shading devices for the solar systems are necessary. Both options will be investigated in the next chapters.

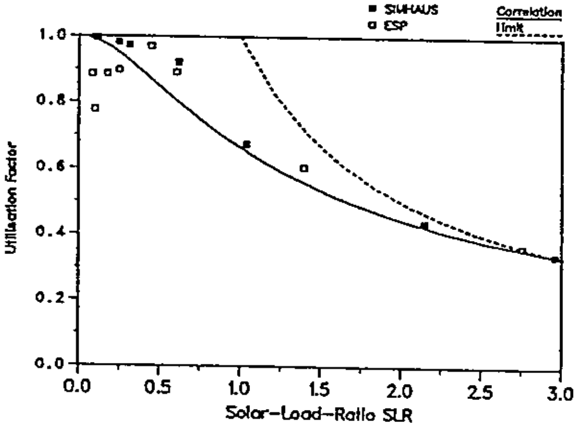


Fig. 10.7 Monthly utilisation factors for case 10

10.4 Systematic Investigation of Heating and Cooling Demand

10.4.1 Influence of Basic Parameters

The correlation model has been used to study the influence of several system parameters starting from a modified case 8 without transparent insulation. Opaque insulation of a wall has been replaced by transparent insulation with specified properties. The modified case has 6 m^2 double-glazed windows oriented South and 3 m^2 oriented North. The transparently insulated wall had a standard area of 15 m^2 and was oriented South, if not mentioned otherwise. As no specific material was chosen, the calculations were made with constant Λ_{TIM}-value (standard 1.20 W/m^{2}K) and constant monthly transmittance g_{TIM} (standard g_{TIM}=0.60). The U-value of the walls was chosen U_{wall}=1.9 W/m^{2}K, the opaque insulation had a heat conductance Λ_{opaque}=1.20W/m^{2}K.

NB: The heat conductance Λ is equivalent with the heat loss coefficient U, only the surface film coefficients are not taken into account.

Transmittance TIM

The transmittance g according to steady-state theory controls the solar gain part of the net heat flux. If gains are to large, they cannot be utilized, therefore overheating is produced. Obviously a seasonally adjusted transmittance would be most appropriate. Fig. 10.8 shows the yearly heating demand depending on climate (solar radiation sums divided by degree days) for different transmittance g. The heat conductance used was Λ_{TIM}=1.20 W/m²K.

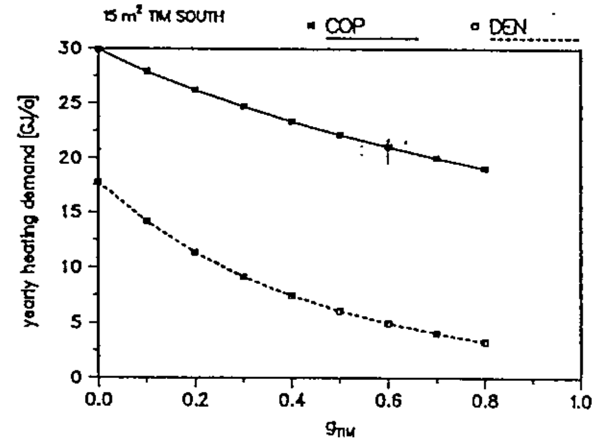


Fig. 10.8 Yearly heating demand for variable total energy transmittance λ_{TIM}
COP: Copenhagen DEN: Denver

Heat conductance TIM

The heat conductance Λ_{TIM} does influence both thermal losses and solar gains. A variation of Λ_{TIM} has been done for constant transmittance g=0.60 (Fig. 10.9).

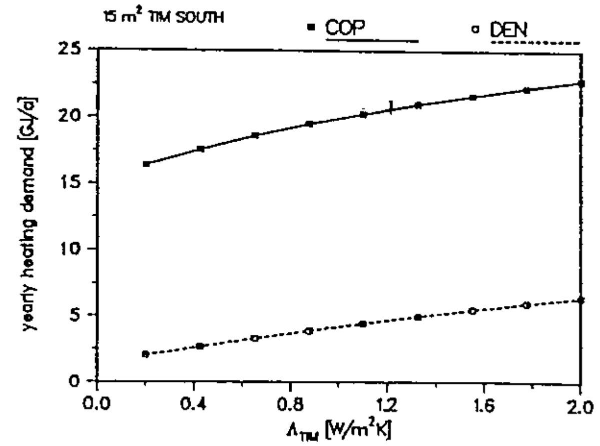


Fig. 10.9 Yearly heating demand for constant total energy transmittance g_{TIM}=0.60 and variable heat conductance Λ_{TIM} COP: Copenhagen DEN: Denver

Wall conductance

If the massive wall behind the transparent insulation has a high heat resistance, the absorbed solar energy cannot flow into the building, i.e. solar gains will be small. On the other hand replacing a high-resistance wall with a low-resistance wall does increase the night losses to some extent. An effect, which cannot be treated with the correlation model, is the variable storage capacity of the wall, which is connected with the question of wall-U-value (thickness, material choice). Fig. 10.10 shows remaining yearly heat loads for different walls.

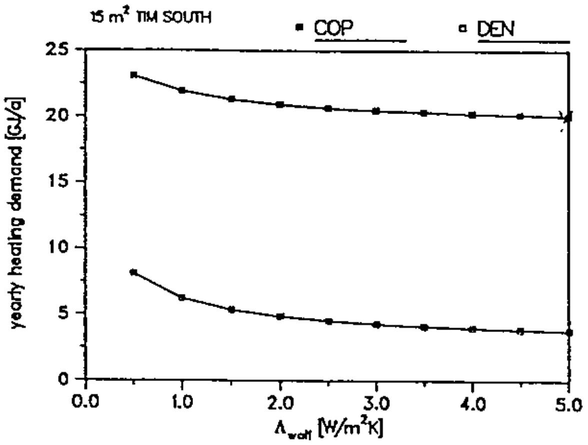


Fig. 10.10 Yearly heating demand for different collector wall conductance Λ_{wall}

Climate

For low solar intensity or for low ambient temperature the thermal losses become more and more important when compared to the solar gains. Therefore transparent insulation is the answer to adapt solar systems developed for countries with high radiation levels to countries with low to moderate insolation. From the results presented before the effect of a different climate can be inferred: for hot and sunny climates the monthly utilised gains are low, for cold climates with low solar intensities they are high.

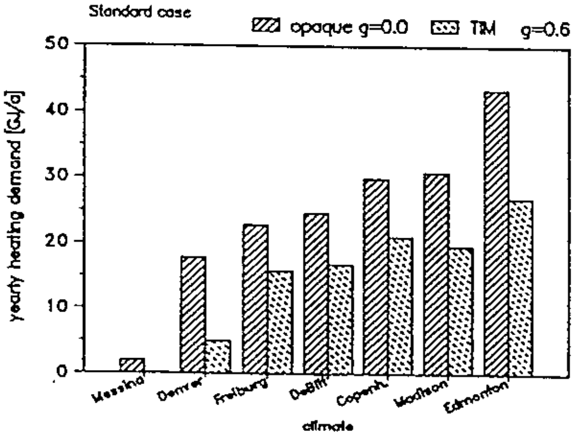


Fig. 10.11 Yearly heating demand for standard case for different climates

Fig. 10.11 Shows that the reduction of heating load due to solar gains is highest for sunny climates with moderate temperatures (Denver) as well as for less sunny, but cold climates (Edmonton), 15 m^2 opaque insulation was replaced by transparent insulation on South side.

TI-wall area

If the area of the TI-wall is increased at the expense of the opaque insulation, the solar gains are increased. This affects the solar-load-ratios, of course. If no controlled shading is provided this means large overheating in summer. With controlled shading, heating demand can be minimized without detrimental effects. Nevertheless, oversizing the collector system is an economical question: For every additional square meter added to a solar system the utilised fraction will be smaller than for the system without (Fig. 10.12).

Wall orientation

The orientation of a collector-wall affects in two ways. First there is a difference in solar radiation, and second the time of the day changes, when the gains are offered to the room behind the wall. For instance West oriented facades (having a time lag of several hours) may be less interesting for office buildings, where there is no occupancy after office hours, than for family homes, where a main part of the heating demand may be in phase with the solar gains. This latter question can be only determined for a specific project with a dynamical simulation. The influence of different irradiation is shown in Fig. 10.13.

Internal gains

Internal gains lower the heating demand of a building and therefore influence the solar-load-ratio. For the existing building stock this contribution is usually relatively small when compared to the total load during the heating season. However, for low energy buildings the load is considerably reduced. A parallel trend on the other hand is the use of better refrigerators, energy saving lamps etc., which leads to a reduction of internal gains.

10.4.2 Monthly Variation of Transmittance

The seasonal variation of transmittance is due to the variation of the sun's daily path within a year. Therefore the incidence angles are rather different between winter and summer. Especially for a South facade this is obvious: As a consequence of high solar altitude in summer the transmittance for honeycombs and glazings is low, whereas in winter time due to the near-normal incidence at noon the average transmittance is larger. Therefore the choice of the correct monthly value is important for the correlation method. The appendix gives monthly mean transmittances for different materials and climates (latitudes). The model used is rather simple, using a symmetric day, isotropic sky radiation. The values are calculated for an average mid-day of the month, which according to Klein (ref. 8) approximates the mean monthly average (using all days) very well.

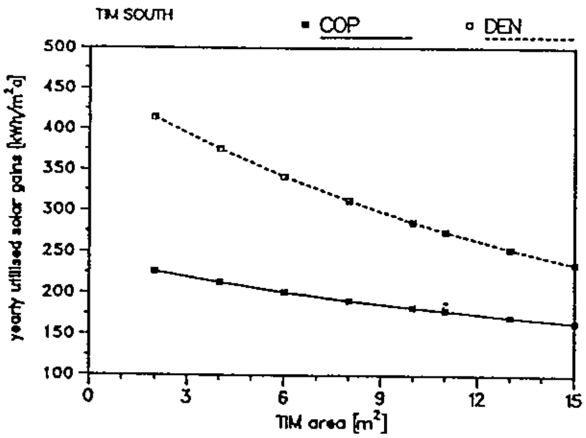


Fig. 10.12 Yearly utilised solar gains per collector area for different collector area (orientation South)

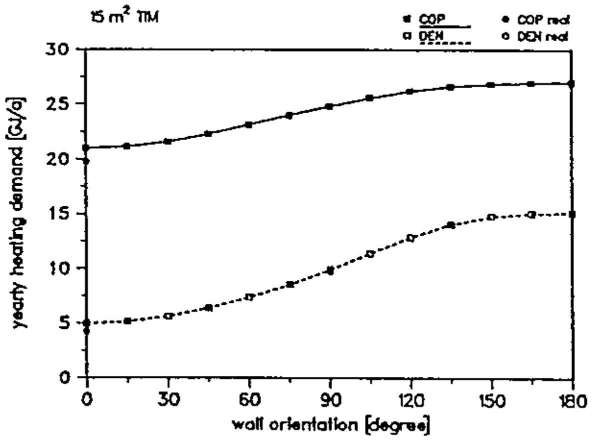


Fig. 10.13 Yearly heating load for a house with one collector wall Orientation of wall variable, properties of total house unchanged otherwise

10.4.3 Temperature Dependance of TIM-Conductance

The absorber temperatures of the collector-wall can vary between about 10 °C and 80 °C. Also the ambient temperature has some variation. This implies that the mean temperature of the TI-material also may vary between approximately 0 °C (cold, winter night) and 50 °C (hot summer day). The heat transport within the TI-materials generally is dominated by IR-radiation transport and air-conduction, which both are temperature-dependent. The resulting change in the overall TIM-U-value influences the net heat flux through the wall and hence the balance between thermal losses and solar gains. Fig. 10.14 shows the variation with temperature of a honeycomb absorber cover with air gap. Although the max. variation is quite large, the influence on the monthly results is quite small. Fig. 10.15 show SIMHAUS results for heating and cooling for U_{TIM} temperature-dependent and U_{TIM}=<U_{TIM}>year.

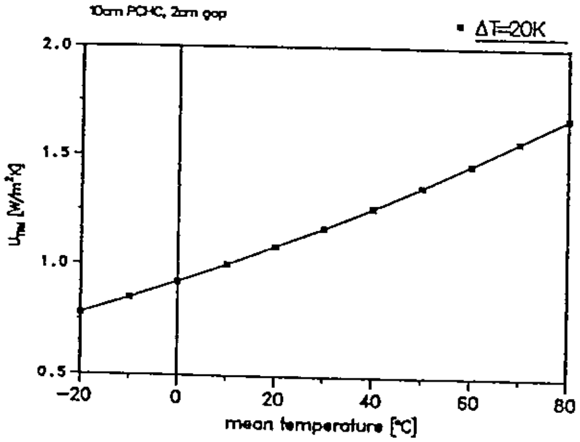


Fig. 10.14 Temperature dependent U-value U_{TIM} for 10cm PC-honeycomb including front glazing and air gap 2cm (temperature difference ΔT has little effect)

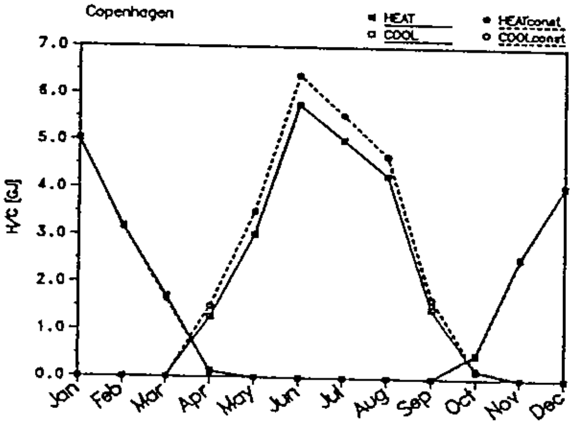


Fig. 10.15 Monthly heating and cooling demand (SIMHAUS results) for U_{TIM} temperature-dependent and for constant yearly mean value U_{TIM}

10.5 Dynamic Effects

10.5.1 Simulation Investigation of Overheating Prevention

If only a small fraction of the wall area is covered by transparent insulation, (additional) overheating will be no problem. On the other hand the reduction in heating load also will be small. Therefore large and efficient collector-walls are desirable, where overheating is prevented by complementary measures. These strategies will be treated in the next paragraphs. The strategies were investigated for the reference case 10, where overheating was a large problem due to the oversized system (43.2 m^2 collector area + 9 m^2 windows for 48 m^2 floor area).

Ventilation

Ventilation by opening the windows is a very cheap and efficient measure to reduce internal temperatures, if the ambient temperature is below some comfortable temperature. So this is difficult in summer time. Heavy weight buildings on the other hand have a large thermal storage capacity. If night temperatures are low, the building may be cooled at night to counterbalance the heating during daytime. This strategy assumes a perfect user, which opens and closes windows all the time or a automatic ventilation system. The air change for venting was increased from 1 h^{-1} to 5 h^{-1} (compare Fig. 10.6 for effect on mean temperatures).

Shading windows

As the 9 m^2 windows also contribute quite a lot to the overheating problem, the effect of closing the windows by shutters was investigated. The transmittance then is reduced to nearly zero. Of course, in reality, this measure very often is used in combination with venting, e.g. in a traditional Italian house.

TIM-shading

The shading of the largest system obviously is the most efficient measure. There exist several possibilities, which work more or less efficient. A external shading by overhangs (for a South facade) or by plants (trees, bushes, creepers) reduces somewhat the irradiation in winter time, but may be rather efficient in summer time. However, in general only a part of the solar radiation is covered. More efficient are roller blinds, venetian blinds or similar mechanical devices. Future developments may use switchable glazings, where one has to distinguish between reflecting, absorbing or scattering switchables. The important quantity is the resulting g-value, which may be larger than zero.
As an extreme case, a device with optimal shading quality, i.e. g=0, is assumed.

Results

Cooling load for different overheating prevention measures
(Copenhagen, SIMHAUS, Cooling setpoint 24°C)

Month	case 10'	venting	vent.+ rollos	vent.+ shutters	prev.case+ 1/4 TIM area
	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]
January	0.0	0.0	0.0	0.0	0.0
February	0.0	0.0	0.0	0.0	0.0
March	0.0	0.0	0.0	0.0	0.0
April	1.3	0.0	0.0	0.0	0.0
May	3.0	0.1	0.1	0.6	0.0
June	5.8	1.8	0.0	0.4	0.0
July	5.0	1.4	0.0	0.2	0.0
August	4.3	1.1	0.0	0.0	0.0
September	1.5	0.0	0.0	0.0	0.0
October	0.2	0.0	0.0	0.0	0.0
November	0.0	0.0	0.0	0.0	0.0
December	0.0	0.0	0.0	0.0	0.0
Total	21.0	4.4	0.1	1.3	0.0

Cooling load for different overheating prevention measures
(Denver, SIMHAUS, Cooling setpoint 24°C)

Month	case 10'	venting	vent.+ rollos	vent.+ shutters	prev.case+ 1/4 TIM area
	[GJ]	[GJ]	[GJ]	[GJ]	[GJ]
January	0.3	0.0	0.0	0.0	0.0
February	0.4	0.0	0.0	0.0	0.0
March	2.1	0.2	0.2	0.0	0.0
April	3.4	0.4	0.1	0.0	0.0
May	5.0	1.3	0.1	0.6	0.0
June	6.0	2.9	0.0	1.8	0.0
July	7.7	5.4	0.4	3.9	0.3
August	7.1	4.3	0.3	2.5	0.0
September	5.8	2.5	0.5	0.9	0.0
October	3.5	0.8	0.6	0.0	0.0
November	0.5	0.0	0.0	0.0	0.0
December	0.1	0.0	0.0	0.0	0.0
Total	41.9	17.9	2.4	9.7	0.3

Cavity venting

TNO carried out a calculation on a 20 cm thick wall with 10 cm of honeycomb transparent insulation in between two glass layers. A cavity between this sandwich and the wall surface was provided with openings at the bottom and top to allow natural venting (outdoor to outdoor) to investigate natural cavity venting as an option for summer venting. Figure 10.16 shows the effect on the calculated heat flux through the wall for a few days of August. Opening the cavity leads to a 65% reduction in the net heat flux. It is expected that for Copenhagen a similar result would have been found.

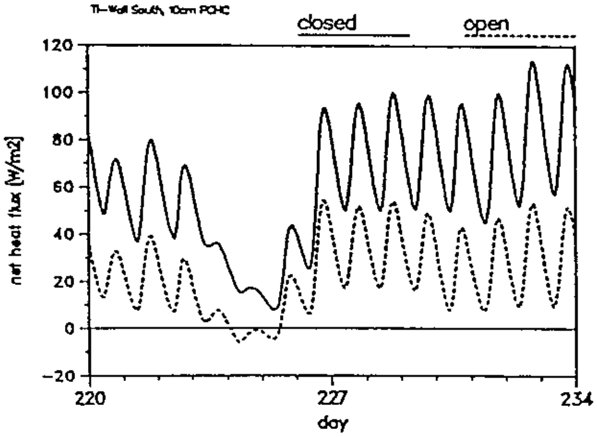


Fig. 10.16 Influence of natural cavity ventilation

Whereas for the full covering of East and West orientation with TIM a very good shading is necessary, for partial covering less efficient measures can be taken. To demonstrate this, some results for partial coverage are also included.

10.5.2 Dynamical Storage and Transient Effects

Due to thermal capacity, heat can be stored within building elements. This affects the utilisation of the gains in two ways: The storage effect itself smoothes out the hourly variations of temperatures due to solar heat gains discharged to the building. The thermal capacity of the walls additionally leads to a time lag (phase shift) of the heat flow conducted to the interior. Depending on the thickness and material typically a 2-8 hours time lag lies between the maximum solar absorption at the absorber surface and the maximum heat discharge at the inner wall surface to the room.

Wall capacity

Starting from case 10, the wall capacity was somewhat artificially varied by factors 0.5, 1.5 and 2.0 without changing wall thickness or material conductivity. Of course with real building materials changing the capacity of a wall is connected to a change of other parameters too. This path was taken only to distinguish the effects. For the integrated monthly values in the table there is very little difference. However comfort may be affected by the instantaneous heat flows and temperatures. Fig. 10.17 shows the phase lag of a West wall due to thermal capacity. High capacity walls have a large phase lag of several hours, also the heat flux is smoothed out. Only the monthly net sums are identical for the wall types.

Heating load for different wall capacity
(Copenhagen, SIMHAUS, Heating setpoint 20°C)
C=1: 1360 kJ/m^3, d=0.3m, Uwall=constant

Month	C=0.5 [GJ]	C=1.0 [GJ]	C=2.0 [GJ]	Correlation [GJ]
January	5.42	5.41	5.40	5.41
February	3.92	3.93	3.97	3.90
March	2.87	2.87	2.89	2.89
April	0.59	0.57	0.59	0.52
May	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00
July	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00
September	0.00	0.00	0.00	0.00
October	1.07	1.07	0.97	1.00
November	3.05	3.04	3.04	3.03
December	4.43	4.42	4.41	4.42
Total	21.35	21.31	21.27	21.17

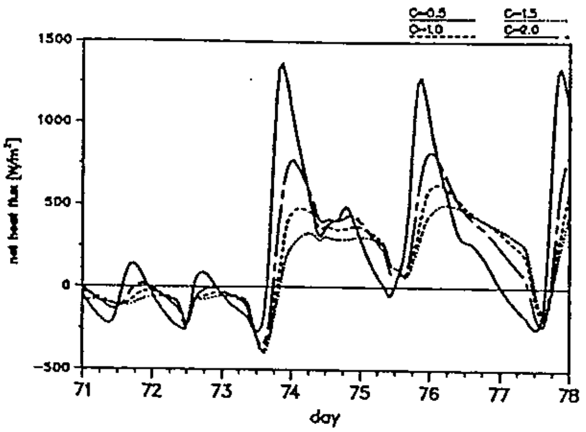


Fig. 10.17 Time-dependent net heat flows for West oriented facade with different wall capacities showing effect of phase-shift and temperature amplitude damping.

If collector storage-walls are combined withdirect gain windows the heat gains may be adjusted to complement each other. Fig. 10.18 shows the heat gains due to indirect and direct gain for a South oriented facade. The heat gains of the wall fill the night gap of the window gains.

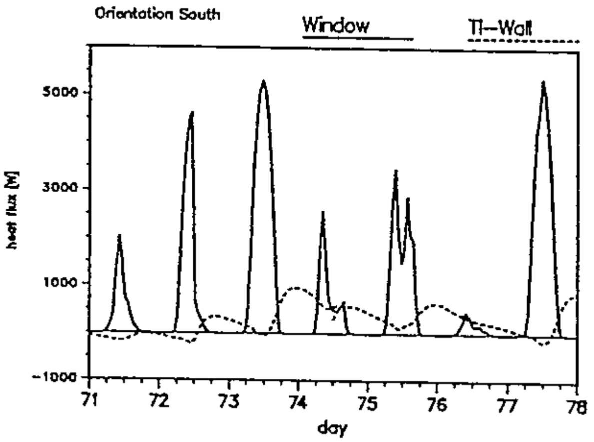


Fig. 10.18 Heat gains of South oriented facade (indirect and direct gains).

The capacity of a wall depends on building materials and wall thickness. In general U-value and capacity of the wall cannot be changed independently. Certainly the easiest and most practicable way of increasing the capacity is by increasing the wall thickness. Fig. 10.19 shows results from TNO-calculation for wall thicknesses 10 cm and 20 cm. The increased wall thickness has a positive effect by damping the fluctuations and shifting the supply of gains to a later hour in the evening. However, the increased thickness will also lead to decreased mean net heat flux because of the additional heat resistance.

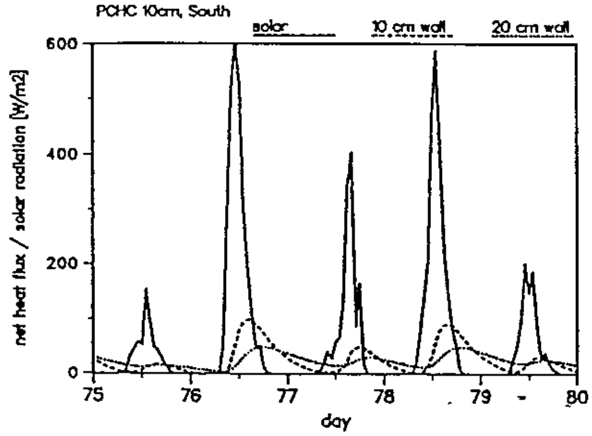


Fig. 10.19 Influence of wall thickness on amplitude and phase shift 10cm/20cm wall, 10 cm honeycomb material, South vertical climate De Bilt (March).

House capacity

The heating load for the heavy-weight construction type house changed not noticeable, when the inner node capacity was varied. This is certainly due to the dominating wall capacities. A real light-weight construction as specified for Task VIII leads to increased heating demand, because both walls and inner node have little storage capacity. This is also true for nighttime setback, as found out by SIMHAUS calculations, although then the effect is reduced.

Heating load for different house and wall capacities
(Copenhagen, SIMHAUS, Heating setpoint 20°C)

Month	light-weight	heavy-weight	correlation
	[GJ]	[GJ]	[GJ]
January	5.46	5.41	5.41
February	4.04	3.93	3.90
March	2.99	2.87	2.89
April	0.71	0.57	0.52
May	0.00	0.00	0.00
June	0.00	0.00	0.00
July	0.00	0.00	0.00
August	0.00	0.00	0.00
September	0.01	0.00	0.00
October	1.34	1.07	1.00
November	3.15	3.04	3.03
December	4.49	4.42	4.42
Total	22.22	21.31	21.17

Wall orientation

The dynamical influence of wall orientation on the heating demand is difficult to analyse. Even if the SLR may be identical for one day or on the average for one month - that may be fixed by choosing the transmittances g accordingly, because of the solar radiation values, all other months have non-identical SLR-values. This would lead also for a non-dynamical calculation with the correlation model to different results (see 10.4.2). However for one month the total energy transmittances of the TI-materials may be fixed such that identical SLR's result and the differences then may be attributed to dynamical effects.

Fig.10.20 shows the net heat flux through collector walls with different orientation for a period of three days. One can readily observe the different main heat discharge periods.

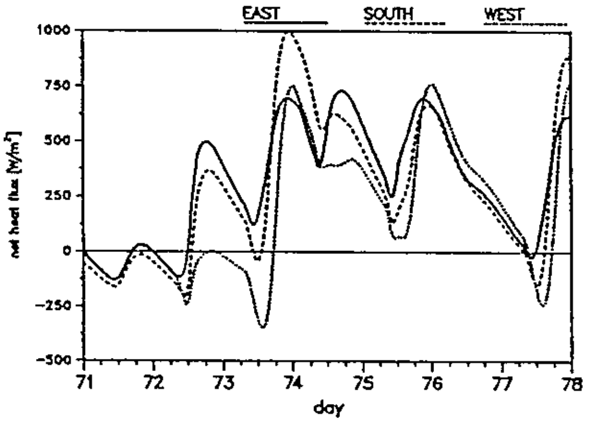


Fig. 10.20 Net heat flux for different orientated collector walls.

10.6 Conclusions

10.6.1 Comparison Direct Gain and Wall Collector

A comparison of TI-collector wall and double glazed window on the South facade was done in the following way: The whole South facade consisted of window and TIM-collector area, and the proportion of both was changed for differnt runs. Although the South orientation is very sunny and gains should be comparatively important, the TIM-wall proved to be more energy efficient. The heating demand and the cooling demand was reduced when the percentage of TIM-wall was increased.

The total benefit per unit area certainly is dependent on many parameters. As there is a benefit from the additional insulation ('conservation benefit') and a benefit from solar gains ('solar benefit') for this system, the reference case is important as well as the climate conditions. For the cases calculated the total benefit per unit area had been between 180 kWh/m^{2}a and 360 kWh/m^{2}a. For the South facades most of this benefit could be attributed to the solar part. In all cases the wall without any insulation (neither TIM nor opaque) was assumed as reference wall.

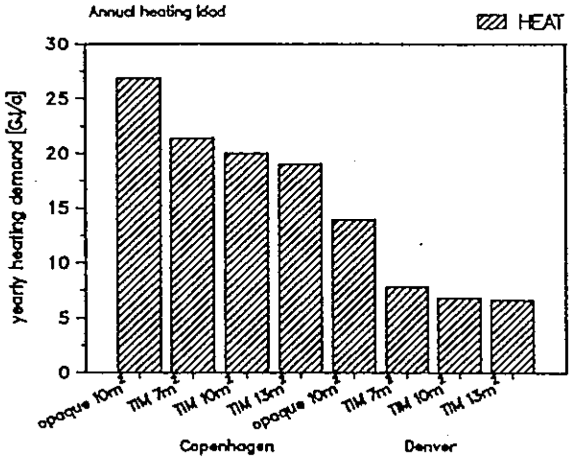


Fig. 10.21 Energy benefit for house with South oriented collector facade (Copenhagen, total area 16 m^2) variable percentage of direct/indirect gain collector.

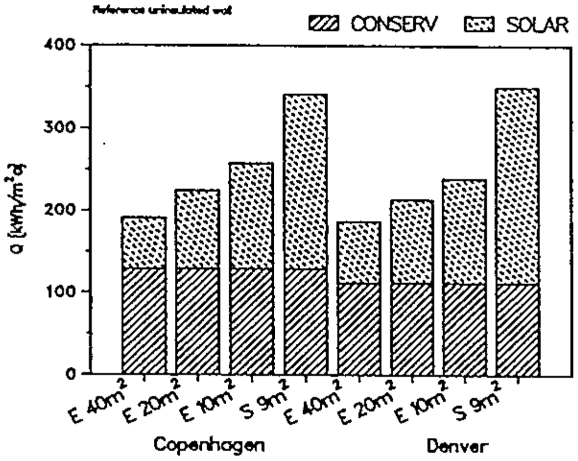


Fig. 10.22 Energy benefit per square meter for TI-wall collector E: orientation East, S: orientation South
CONSERV: reduced loss due to insulation, SOLAR: useful solar gains.

10.6.2 Climate Dependent Design

From the two climatic cases considered, namely Copenhagen and Denver, it is obvious that the same system is not appropriate for both situations. Collector area, TI-materials and shading devices may be different for each situation. Cooling and heating loads are too different for both cases. A second argument for climate dependent design is the different architecture and building stock already prevalent in different climates. Light-weight buildings are less apt for simple transparent insulation of the walls, however may be adapted by introducing the whole collector-wall unit into the building, where a suitable massive wall material (e.g. concrete) may be chosen.

10.7 References

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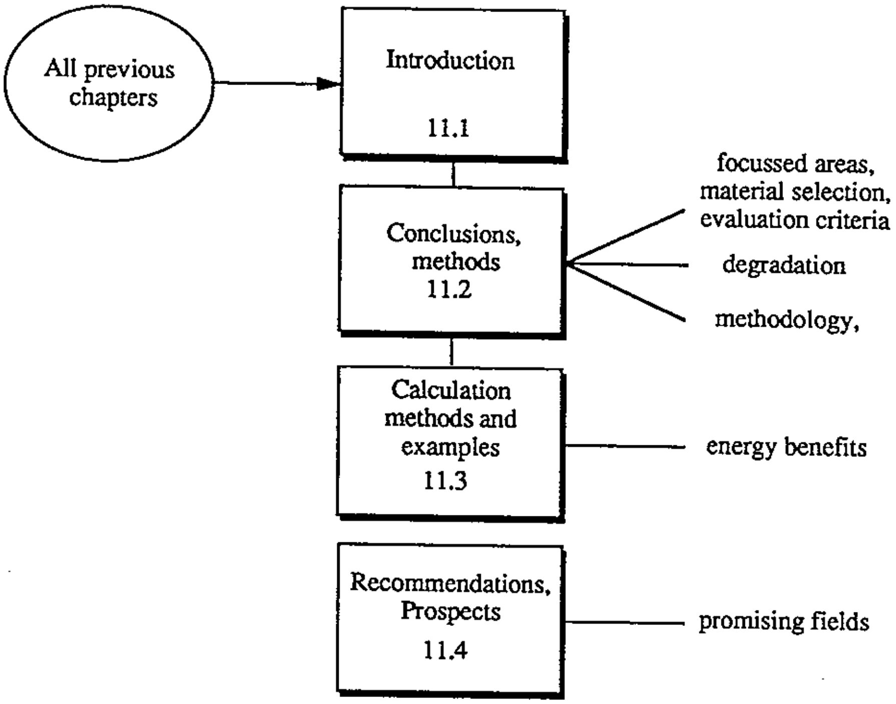
11. CONCLUSIONS, PROSPECTS



11.1 Introduction

A systematic and comprehensive methodology was developed to evaluate the energy benefits that can be obtained through the proper selection of materials and to determine the properties of new materials needed to increase system and subsystem efficiency and durability.

The material selection methods integrate ambient climates, material properties, and system performances to provide input for the required energy benefits analyses. The methods and data were used to study selective coatings for solar collectors and transparent insulation materials.

The main conclusions of the report and the case studies are summarized in the next section. Many facets of these results should have relevance to systems, applications and locations in addition to those included in the case studies.

Section 11.3 presents two numerical examples that illustrate the methods and empirical corrections developed in the studies, and Section 11.4 list the recommendations of the Subtask participants on materials and material research, solar collectors, transparent insulation materials and general collaborative research.

The report does not make pronouncements on the quality of specific materials.

11.2 Conclusions and Remarks

11.2.1 Material Selection and Evaluation Criteria

A guide for material selection for various solar applications throughout the world is provided in the sequence that follows: define climate data and criteria; select the application and system of interest; select a simulation tool for analysis; establish the operating conditions (table 5.2); consult the database of solar materials; establish the system energy performance; estimate the effects of degradation of materials.

Also see table 11.1, " Evaluation Criteria for Material Selection," which is divided in non-technical, technical, material-criteria and economics. This table refers, step by step, to the content of the chapters of this report. A database on material properties containing the most recent data (including the results of other subtasks) was also prepared (See Annex C for more information).

11.2.2 Degradation of Spectral Selective Coatings for Solar Collectors.

- The operating conditions and the limits of the selected coating are provided in Table 5.2. The operating temperatures for absorbers in different applications and solar systems are established (Table 5.1).

- The definition of failure of an absorber coating in most severe conditions is expressed as the performance criterion $PC = -\Delta\alpha_s + 0.25\Delta\varepsilon = 0.05$. This definition corresponds to a 5% loss in efficiency.

- The interior climate of solar collectors depends strongly on the ventilation rate (if ventilated). The time of wetness of solar absorbers can amount to as much as 3500 hours per annum for temperate climates.

11.2.3 Method for estimating the Effects of Spectral Selective Coating on System Performance

- The impact of the thermal properties of solar absorbers on the performance of solar hot water systems is approximately as follows: a 10% decrease in system performance is caused by an absorptance decrease of 0.1 or an emittance increase of 0.4.

- A comparison of performances between different coatings was established in Fig. 8.4 with the coating $\alpha = 0.95$ and $\varepsilon = 0.1$ as a reference.

- The change in solar fraction due to variations of absorptance and emittance is relatively insensitive to geographical locations for solar fractions < 0.5.

TABLE 11.1	Evaluation Criteria for Material Selection		RESULT:
NON TECHNICAL CRITERIA:			
Intended application (Ch. 3)			
	- local climate	- macroclimate (table 2.1)	- location (climate) - application - system - material classification
		- microclimate	
	- energy demand	- total requirement	
		- simultaneous occurrency	
		- temporal distribution	
		- temperature conditions	
		- solar system	
	- governmental rules, standards	- building codes	
		- siting	
TECHNICAL CRITERIA:			
Operational and extreme conditions (Ch. 5)			
	- thermal performance	- solar radiation	material: - thermal conditions - durability - failure
		- solar spectral distribution	
		- ambient temperature	
		- service operating temperature of material	
		- service stagnation temperature of material	
		- thermal spectral distribution	
	- degradation (Subtasks B and C)	- solar UV radiation UVB radiation	
		- air impurities, SO2, NO2	
		- high temperature exposure	
		- temperature cycling	
		- temperature shock	
		- relative humidity ambient air	
		- time of wetness of material	
		- life time	
	- failure	- structural exposure, hail, wind, snow	
MATERIAL CRITERIA:			
Material properties (Ch. 7, WD Database Solar Materials)			
	- optical and thermal	- transmission	material: - selection
		- absorption	
		- reflection	
		- temperatures	
	- mechanical	- strength	
		- expansion	
	- durability	- degradation	
		- weatherability	
	- environment	- kind of material	
ENERGY CRITERIA:			
Thermal performance (Ch. 8, 9 and 10)			material: - performance
		- selected solar systems and locations	
		- other system parameters and locations	
Light performance			
ECONOMIC CRITERIA:			
Material and device		- material cost	material: - feasibility
		- device costs	
		- others	

- A guideline to estimate the energy benefits of new spectral selective coatings was presented in Fig. 8.4 and summarized in Section 11.3 below.

11.2.4 Method for estimating the Effects of Transparent Insulation material on Building Performance.

- The impact of the thermal properties of transparent insulation materials on the thermal performance of solar radiated, south oriented, walls and glazings for heating is that, as expected, the maximum energy gain will generally be achieved at the highest amount of the net balance of solar heat gain minus heat losses as summarized in section 11.3 below.

- A correlation equation was derived relating solar gain utilization to solar load ratio that gives excellent agreement with calculated monthly gains. For the purpose of IEA Task X, this utilization function is satisfactory for calculations of the impact of TIM on the heating demand in dwellings.

- A guideline was derived to estimate the energy benefits of transparent insulation on the south wall of dwellings, the energy saving for heating, or the excess indoor temperature (presented in the next section).

11.3 Calculation Methods and Examples

11.3.1 Energy Performance Effects of Spectral Selective Coatings in Solar Collectors of Solar Hot Water Systems

CALCULATION OF ENERGY PERFORMANCE CHANGE

Inputs:

- System setting of SHW system,
- Annual solar fraction,
- Solar absorptance and thermal emittance properties of spectral selective coatings

Procedure:

- Determine the values a and b (intercepts—see Figure 11.1) from $-\Delta\alpha/\Delta\varepsilon$ ($\Delta F_s/F_s = 0.1$) plots, e.g., see Chapter 9.
- Mark these values in the following graph starting from the initial properties and draw a straight line through both these points. This line corresponds to a 10% decrease of solar fraction. The thermal performance factor amounts to 0.90.
- Draw parallel a line through the point of initial properties. This line corresponds to a thermal performance factor of 1.0.
- By interpolation or extrapolation, other supporting lines can be drawn with an equivalent solar fraction decrease or increase.
- Property data of other spectral selective coatings can be plotted in the graph and the relative thermal performance effect can be read off.
- The new solar fraction is given by the product of this thermal performance factor and the initial solar fraction.

It is evident that, due to saturation (high solar fraction) or non-linear effects, this method is acceptable for small changes only.

EXAMPLE (tentative approach for annual energy performance)

Main input data:

Location	Toronto, Canada
Collector area	4.8 m^2
Heat storage	180 l
Daily draw-off	350 l
Temperature	50 °C
Heat demand	5930 kWh/year
Absorptance coating	0.95
Emittance coating	0.10
Solar fraction	**0.58**

Calculation :
For comparison, a Solariselect coating with an emittance of 0.35 and an absorptance of 0.92 as shown by the square on the graph would yield a :
Solar Fraction = f 0.92 x 0.58 = **0.53**

equivalent to **275 kWh/year** performance decrease in Toronto.

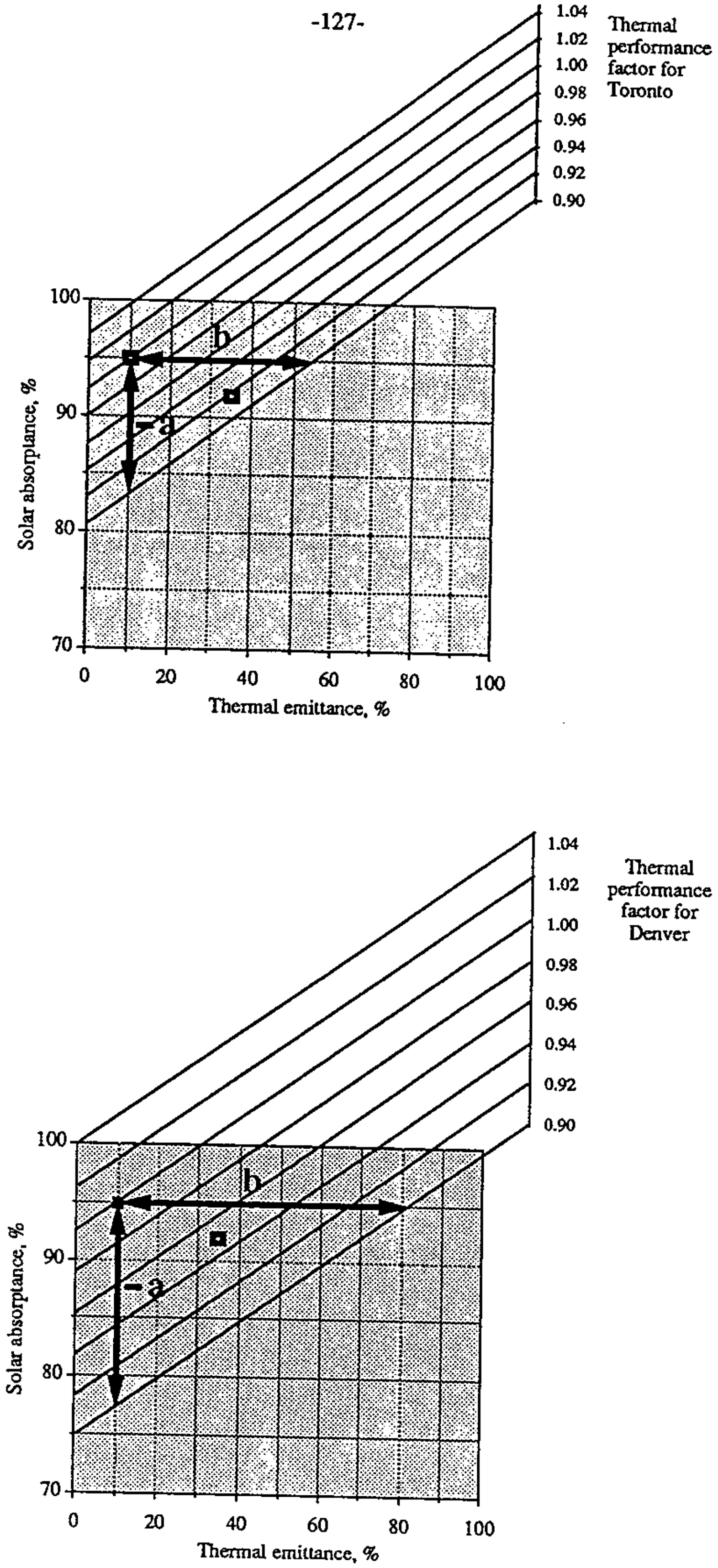


Fig. 11.1 Example of potential energy saving of SHW-systems as a function of Solar Absorptance and Thermal Emittance of solar collectors relative to Absorptance 95 % and Emittance 10 % for location Denver and location Toronto.

11.3.2 Energy Performance of Transparent Insulation Materials in Dwellings (Monthly)

The seasonal (5 months) performance of transparent insulation materials on a south facade was calculated and presented in Fig. 11.2 The calculation is independent of the optimal dimensioning of the solar area for the building and does not take into account summer overheating. The solar gain factor was derived for different property data (from Fig. 7.4) of the transparent insulation materials and for different locations (climates).

In this graph, the gain factor is the ratio of the net (inward - outward) energy transmitted by the solar area and conducted into the building to the incident solar radiation (at the average angle of incidence). The parameter in the lower quadrant is the ratio of the seasonal average indoor - outdoor temperature difference and the seasonal average incident insolation. This graph can be used as a first approach for selecting south-oriented window and wall glazings for the many climates and materials presented on the single graph. Either seasonal or monthly performance estimates can be performed with this graphical plot. Similar graphs can be derived for other orientations.

CALCULATION OF HEAT DEMAND (Q_{HD}) AND EXCESS TEMPERATURE (ΔT)

Inputs:

- Heating load, including direct solar and internal gains and including the heat transmission through the transparent insulation, Q_L' in MWh,
- Total and mean solar radiation on TIM-wall, G in MWh, and S in W/m^2, respectively,
- Averaged ambient temperature, T_{amb} in °C,
- Averaged indoor temperature, T_i in °C,
- Properties transparent insulation material, g_{TIM}, U_{TIM} in W/m^{2}K, and wall, U_{wall} in W/m^{2}K.

See the Working Document on Data Base of Solar Materials and Annex D.

Note: g_{TIM} presents the net solar transmittance (including additional heat from the device); see Annex D. If not known, use transmission diffuse (τ_d) as a rather conservative number.

Equations:

$$Q_{HD} = Q_L' - \Phi_{TIM\text{-}wall} \times QS_{CW} \text{ (MWh)} \quad (1)$$

$$\Delta T = (1 - \Phi_{TIM\text{-}wall}) \times SLR \times (T_i - T_{amb}) \text{ (°C)} \quad (2)$$

$$U_{tot} = 1 / (1/U_{wall} + 1/U_{TIM}) \quad (3)$$

$$g_{tot} = g_{TIM} (U_{tot} / U_{TIM}) \quad (4)$$

T_i = average indoor temperature (°C)

T_{amb} = average ambient temperature (°C)

QS_{CW} = $g_{tot} \cdot G$ (MWh) (5)

SLR = QS_{CW} / Q_L', solar load ratio (6)

$\Phi_{TIM\text{-}wall}$ = gain utilization factor for TIM-wall for monthly calculations
= $1 - e^{(-K/(SLR - D))}$ (7)

Correlation equation of case study (Chapter 9), K = 1.31 and D = -0.177

The monthly solar gain factor can be used for comparison of the thermal performance of different TIM's and different locations, as illustrated in Fig. 11.2.

$$\text{Solar gain factor} = g - U\,(T_i - T_{amb})/S \tag{8}$$

where

$g = g_{TIM}$ for TIM glazing only, g_{tot} for complete wall,

$U = U_{TIM}$ for TIM glazing only, U_{tot} for complete wall.

EXAMPLE (tentative approach for seasonal energy performance using monthly correlation formula)

Main input data:

- Transparent insulation on south faced wall of a well-insulated dwelling location De Bilt, the Netherlands.

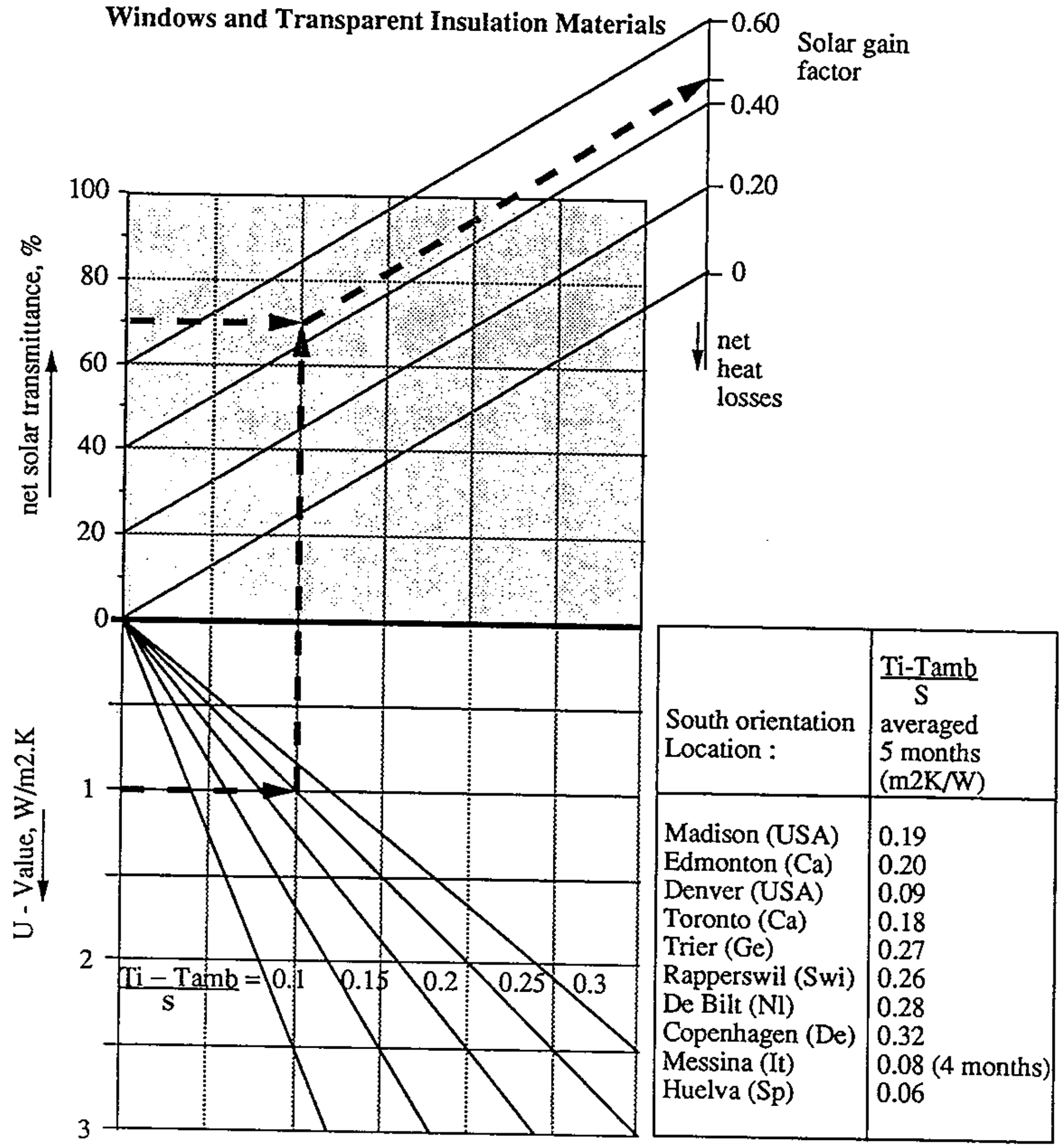
Solar wall area	10 m^2
Seasonal heating load (5 months)	6.6 MWh
Solar radiation (5 months)	2.08 MWh (= averaged 58 W/m^2)
Indoor temperature	20 °C
Average ambient temperature	3.5 °C
Insulation	16 mm Airglass + 2 x glass (low iron) evacuated
Solar transmittance TIM	0.74 (See Annex D for Copenhagen)
Heat transfer coefficient TIM	0.6 W/m^2K
Heat transfer coefficient wall behind TIM	5 W/m^2K

Calculation :

U_{tot} = 1 / (1 / 5 + 1 / 0.6) = 0.54 W/m^{2}K
g_{tot} = 0.74 x 0.54 / 0.6 = 0.67
solar gain through collector wall = 0.67 x 2.08 = 1.40
solar load ratio = 1.40/ 6.6 = 0.21
gain utilization factor = 1 - $e^{(-1.31 / (0.21 + 0.177))}$ = 0.97
heat demand = 6.6 - 0.97 x 1.40 = 5.2 MWh
mean temperature increase = (1 - 0.97) x 0.21 x (20 - 3.5) = **0.10 °C**
utilized heat gain solar wall = (6.6 - 5.2)/10 = 0.14 MWh/m^2 = **140 kWh/m^2**

For comparison to 50 mm AREL with single glass (low iron)
Solar transmittance TIM 0.81 (See Annex D)
Heat transfer coefficient TIM 1.3 W/m^{2}K
U_{tot} = 1 / (1 / 5 + 1 / 1.3) = 1.03 W/m^{2}K
g_{tot} = 0.81 x 1.03 / 1.3 = 0.64

$(T_i - T_{amb}) / S$ = (20 - 3.5) / 58 = 0.28 m^{2}K/W
Airglass: seasonal solar gain factor = 0.67 - 0.54 x 0.28 = **0.52**
AREL: seasonal solar gain factor = 0.64 - 1.03 x 0.28 = **0.35**
utilised heat gain solar wall (AREL) = 0.35/0.52 x 140 = **94 kWh/m^2**



South orientation Location :	Ti-Tamb / S averaged 5 months (m2K/W)
Madison (USA)	0.19
Edmonton (Ca)	0.20
Denver (USA)	0.09
Toronto (Ca)	0.18
Trier (Ge)	0.27
Rapperswil (Swi)	0.26
De Bilt (Nl)	0.28
Copenhagen (De)	0.32
Messina (It)	0.08 (4 months)
Huelva (Sp)	0.06

In formula: Solar Gain Factor = g - U x $\frac{\text{Ti - Tamb}}{\text{S}}$

Fig. 11.2 Example of potential energy saving of windows and transparent insulation for solar heating as a function of net solar transmittance, U-value and climate, overheating is not taken into account (only for comparison purposes).

11.4 Recommendations

Material properties and degradation

- Degradation and the occurrence of failures increase rapidly when the material or the device has to withstand severe conditions or more than one degradation stress. In fact, this is the normal situation in practice. In Subtask B, combinations of stresses were used to predict the lifetime of solar absorbers. It should be noted that the device itself strongly influences the environment of the material. In view of this, research should be carried out for the complete device (including edge seal and framing) in which the material is incorporated.

- Material properties and application requirements should be better specified with respect to spectral energy distribution, especially for polymer applications. The spectral dependence of some properties are needed to optimize material applications in particular systems.

- Research on the application possibilities and the energy benefits of polymers should be continued.

- The data bases of material properties should be supplemented; data on the influence of environmental quality on life expectancies, raw material content, energy required for refining, processing, and fabricating materials, etc. should be added.

- Tentative guidelines for applying materials in solar technology with respect to optimum energy and minimum environmental damage are needed.

Solar Collectors

- The study of spectral selective coatings included only traditional flat plate solar collectors for domestic hot water systems. A study with an equivalent methodology should be carried out for other promising collector types, solar systems, and applications.

- The study on the micro-climate of solar collectors is very tentative. The method seems to work, but the calculation program is very difficult to validate. Fluctuating ambient conditions and the absence of any controlled air ventilation need closer examination.

- Another important new field is the design and construction of complete collector elements with transparent insulation. Light-weight durable and mechanically stable collectors that are easy to handle would increase the acceptance of the technology.

Transparent Insulation

- Transparent insulation materials open up new possibilities for glazings in general, which could become a large area of research for material scientists. The work done on aerogel, geometric structured media, and coatings is far from complete. Future research and development certainly should concentrate not only on material development, but also on reliable methods to assess the performance and the long-time stability of the materials.

- Perhaps the most important research and development is on cheap and reliable shading concepts. Many options exist which have not yet been investigated thoroughly. They range from passive shading to natural shading to mechanical shading to chromogenic glazings (electro- or thermochromic). The alternative to shading may be some heat transport from the point of absorption to the building or to another heat sink. Certainly the overheating problem is a dominant obstacle to an economical use of transparent insulation.

- It is important to develop reliable, functional and aesthetic frame and facade concepts for architecturally-acceptable applications of transparent insulation materials.

- Reliable design methods should be developed to assess the different material options. A much-needed further development of the design method is a user-friendly analysis tool that can handle different applications and building types. This would be helpful for designers, architects, or engineers.

- On a similar level, methods that take into account the dynamic response of components could be included in the correlation tool. For example, a weighting of time-dependent solar gains should be investigated. The effect of gains from different orientations or through walls with different time constants could be treated.

General

- Based on the experiences in Task X, much more attention should be paid to the usefulness of research results in practice (product manufacturing and project design).

ANNEX A
CLIMATE DATABASE

G. Brouwer

1. Introduction

The Database of particular Climates provides climate data on a monthly and yearly basis for designers and researchers in solar energy. This database was performed within the framework of selecting materials for a higher energy benefit in different climates. It enables to make rough estimations of energy performances using new materials in buildings and solar systems. Only those climates were considered of the countries to which the IEA X participants belong. They represent the designated climates considered in the research of IEA Task X Subtask A.

The values in the database mostly represent an average of measurements of material weather-forcasting institutes during a number of years. (So called : Reference climate years). More accurate data on behalf of the simulation calculations in the case studies can be obtained from the particular weather institutes.

The Database Climates consists of A4 lists of data in tabular and in graphic form of each particular climate type. A survey of yearly average data is given in table 1.

2. Explanation of Climate Specifications

In this Annex are tabulated and graphically presented monthly and annual average temperature, solar radiation, sunshine duration and heating degree-days.

The quantities used are the following, respectively :

- Temperature :
  normals of daily ambient temperatures (°C)
- Solar radiation :
  normal daily values of total hemispheric radiation incident on a horizontal surface (Wh/m^2)
- Sunshine hours :
  normal daily values of the duration of bright sunshine (hours)
- Heating Degree-Days :
  monthly or annual normals of values below the base temperature ....
  (°C.days)

Combined Occurrence of Solar Radiation and Temperature

The potential total exposure of materials in devices to high temperatures can be estimated by considering the combined occurrence of high insolation and high ambient temperature.

Accordingly, the tables present for each designated climate type the total number of hours in a typical year or an averaged year that the insolation and temperature occur within particular intervals.

Climate Description

For each city in the database, the latitude, the elevation and a brief description of the climate is presented.

TABLE I Climate locations		Yearly, averaged climate data			
		average temperature °C	total horizontal solar radiation Wh/m2.day	daily sunshine hours	total degree-days (below 18-19 °C) Kd
Canada	Toronto	8.9	3617	5.7	3646
	Edmonton	2.4	3451	6.3	5713
Denmark	Copenhagen	7.6	2782	4.3	2918
F. R. Germany	Freiburg	10.4	3033	4.5	3123
Italy	Messina	18.4	4753	6.8	327
the Netherlands	de Bilt	9.3	2591	4.0	3131
Switzerland	Rapperswil	10.1	3325 *	6.5	3848
U. S. A.	Denver	10.1	5316		3343
	Madison	7.3	3749	7.3	4294
Spain	Huelva	17.0	4884	9.3	1202

Remarks: * south faced, tilt 45 °

CLIMATE DATA IN VARIOUS CLIMATES

Location: Canada, Toronto

Latitude: 43.6 °N Heating degree-days (18 °C): 3646
Elevation: 200 m

Short description: Canada has a continental humid climate with severe winters, moist in all seasons and short warm summers. For this temperate, nearly boreal climate about 3-5 months are over 10 °C. During winter frequently clouded but in summer maximum precipitation. However, it is rather sunny and thereby provides an ideal climate for solar heating.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

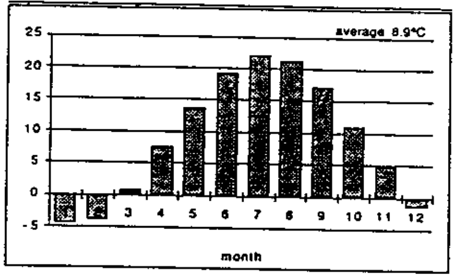
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0	1925	190	154	123	69	51	36	14	7			
0 - 5	1129	110	74	49	25	24	23	15	9			
5 - 10	856	88	60	57	35	22	19	21	16	4		
10 - 15	727	83	69	51	61	32	36	27	23	5		
15 - 20	667	86	69	67	65	52	61	44	28	16		
20 - 25	379	77	70	70	73	70	59	64	52	19		
25 - 30	59	27	34	26	25	36	25	41	31	11		
30 - 35	4	2	4	6	2	7	6	4	4			
sum	5746	663	534	449	355	294	265	230	170	55	0	0

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE, INSOLATION AND HEATING DEGREE-DAYS

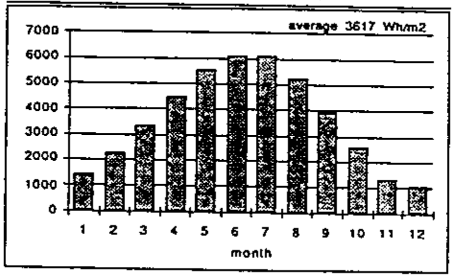
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature, monthly average daily (°C)	-4.6	-3.9	0.7	7.6	13.6	19.1	22	21.2	17.1	11	4.9	-1.6	8.9
solar radiation on a horizontal surface, monthly average daily (Wh/m2)	1442	2278	3347	4464	5508	6103	6094	5189	3900	2567	1339	1083	3617
daily hours of sunshine	3	4.4	4.6	6.5	7.4	9.1	9.5	8	6.1	4.6	2.6	2.5	5.7
monthly normals of heating degree-days below 18°C	701	618	536	314	150	30.7	3.3	6.9	66.5	220	393	608	3646

Remarks: Weather data from University of Waterloo and from Canadian Climate Normals (1951-1980), AES Canada

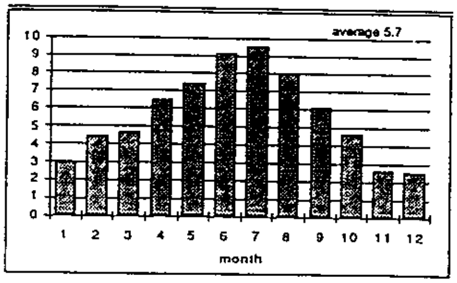
Ambient Temperature (°C)



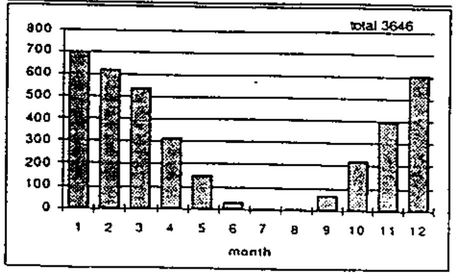
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 18°C)



CLIMATE DATA IN VARIOUS CLIMATES

Location: Canada, Edmonton

Latitude: 53.5 °N
Elevation: 700 m

Heating degree-days (18 °C): 5713

Short description: Canada has a continental humid climate with severe winters, moist in all seasons and short warm summers. For this real boreal climate about 1-3 months are over 10 °C. During winter frequently clouded but in summer maximum precipitation. However, it is rather sunny and thereby provides an ideal climate for solar heating.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

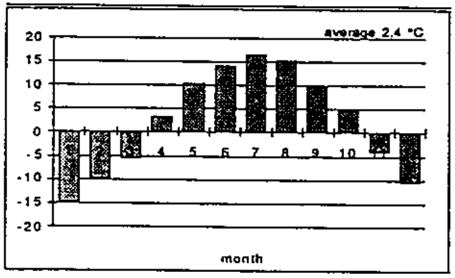
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< -5	2059	228	152	69	47	51	18	6	3			
-5 - 0	900	126	96	51	31	23	13	6				
0 - 5	776	127	100	74	36	19	11	4				
5 - 10	656	99	101	100	55	45	29	7	1			
10 - 15	615	117	117	110	105	74	67	30	11			
15 - 20	297	58	68	73	102	97	95	59	38			
20 - 25	78	37	36	39	38	44	53	31	29	4		
25 - 30	8	14	9	16	19	14	16	12	9			
sum	5389	806	679	532	433	367	302	155	91	4	0	0

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE, INSOLATION AND HEATING DEGREE-DAYS

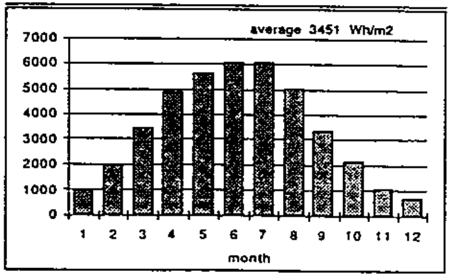
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature, monthly average daily (°C)	-15.1	-10	-5.6	3.4	10.4	14	16.3	15.1	10.1	5.2	-4.2	-10.7	2.4
solar radiation on a horizontal surface, monthly average daily (Wh/m2)	1014	1969	3453	4869	5614	6075	6081	5025	3364	2136	1097	719	3451
daily hours of sunshine	3.2	4.2	5.6	7.8	9.1	9.6	10.1	9.2	6.1	5.3	3.4	2.5	6.34
monthly normals of heating degree-days below 18°C	1026	790	732	438	238	127	69,8	101	238	397	666	890	5713

Remarks: Weather data from University of Waterloo and from Canadian Climate Normals (1951-1980), AES Canada

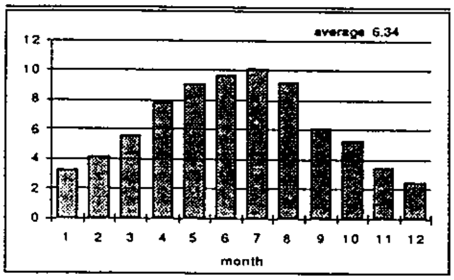
Ambient Temperature (°C)



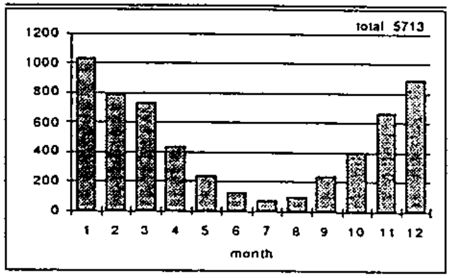
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 18°C)



CLIMATE DATA IN VARIOUS CLIMATES

Location: Denmark, Copenhagen

Latitude: 55.6 °N
Elevation: 30 m

Heating degree-days (17 °C): 2918

Short description: Denmark, lying along the coast is largely influenced by the sea and the Gulf stream. The climate is atlantic with relatively mild temperatures and abundant, well distributed rainfall. About 5 months are over 10 °C.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

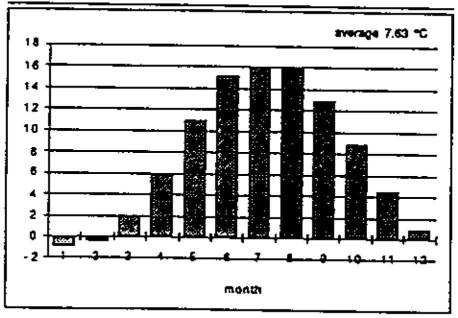
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0	911	94	43	18	8	2						
0 - 5	1642	131	60	32	22	13	3					
5 - 10	1353	160	94	58	38	26	22	9	1			
10 - 15	1266	210	155	121	87	56	39	28	11	1		
15 - 20	804	155	137	122	115	101	78	59	29	1		
20 - 25	118	27	31	33	38	44	48	44	18			
25 - 30	1	2	3	4	5	7	9	11	2			
30 - 35												
sum	6095	779	523	388	313	249	199	151	61	2		

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE, INSOLATION AND HEATING DEGREE-DAYS

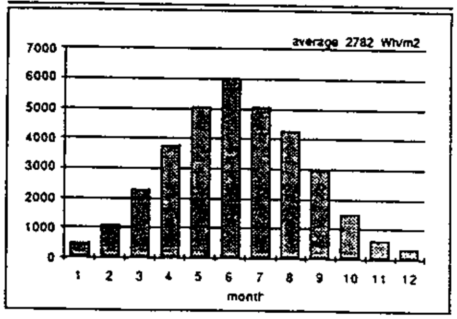
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature, monthly average daily (°C)	-1	-0.5	1.9	5.9	10.9	15.2	16.1	15.9	12.9	8.9	4.5	0.8	7.63
solar radiation on a horizontal surface, monthly average daily (Wh/m2)	472	1086	2277	3739	5054	6027	5071	4245	2981	1480	602	349	2782
daily hours of sunshine	1.1	1.9	3.5	5.2	7	8.5	6.7	6.8	5.2	3.1	1.4	0.9	4.3
monthly normals of heating degree-days below 18.3 °C	550	478	434	275	78	2	2	0	31	205	365	498	2918

Remarks: Weather data from Copenhagen, 1959-1973.

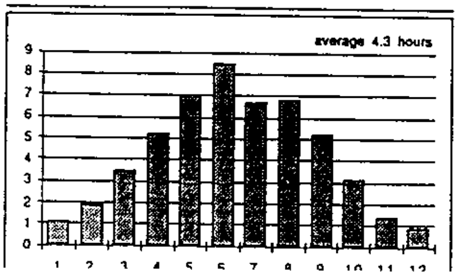
Ambient Temperature (°C)



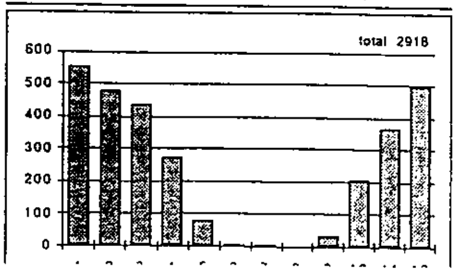
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 17°C)



Location: Federal Republic of Germany, Freiburg

Latitude: 48°N, Heating degree-days (18.3 °C): 3123
Elevation: 269 m

Short description: The Federal Republic of Germany can be divided into three climatic areas. The northern part is typically maritime with frequent rainfall. In the midland, more mountainous, solar radiation is higher. The southern part is influenced mainly by the Alps. Rainfall is more important, especially in summer, than in the rest of the country.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

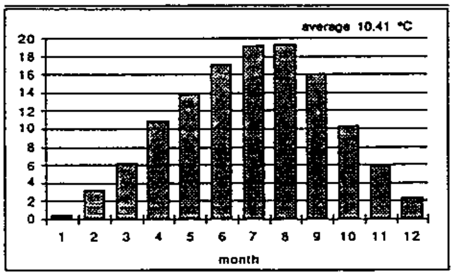
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0	691	82	35	17	5							
0 - 5	1315	164	57	20	12	20						
5 - 10	1488	289	57	33	33	14	9	3				
10 - 15	1114	279	104	54	52	40	31	20	4	2	2	
15 - 20	857	206	137	101	63	59	54	53	23	13	3	
20 - 25	295	118	80	81	49	62	68	71	61	19	2	
25 - 30	32	21	19	14	19	25	36	30	17	9		
30 - 35			2	4	2	5	2	2	2			
sum	5792	1159	491	324	235	225	200	179	107	43	7	0

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE, INSOLATION AND HEATING DEGREE-DAYS

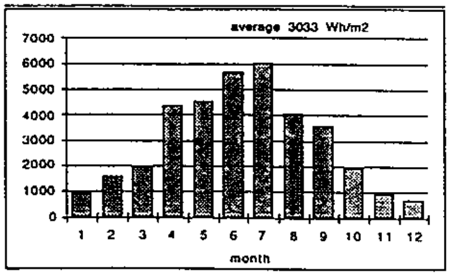
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature, monthly average daily (°C)	0.4	3.2	6.2	10.9	13.8	17.1	19.2	19.3	16	10.3	5.8	2.3	10.4
solar radiation on a horizontal surface, monthly average daily (Wh/m2)	952	1579	1974	4386	4555	5653	6041	4073	3582	1945	939	715	3033
daily hours of sunshine	1.3	2.1	4.6	6.4	7.6	7.1	7.1	6.4	5.4	3.2	1.3	1.3	4.48
monthly normals of heating degree-days below 18.3 °C, resp. 20 °C	555 607	422 469	375 428	225 273	160 203	70 106	40 66	39 67	118 153	250 301	374 425	495 547	3123 3645

Remarks: Weather data from Fraunhofer Institut, Freiburg

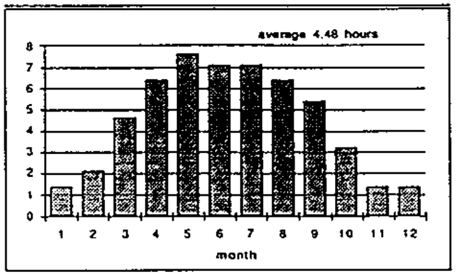
Ambient Temperature (°C)



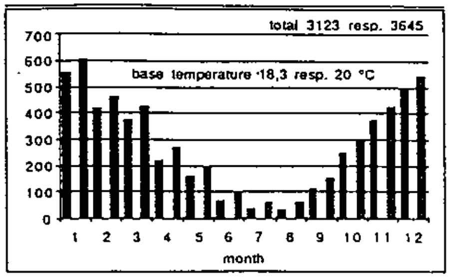
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 18.3 / 20°C)



CLIMATE DATA IN VARIOUS CLIMATES

Location: Italy, Messina

Latitude:	38.2 °N	Heating degree-days (19°C):	327
Elevation:	50 m		

Short description: Italy characterizes different climates from low temperatures and heavy precipitation in the Alps to rather hot summers and mild winters in the Mediterranean region. The northern region has a more continental climate with abundant rainfall.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

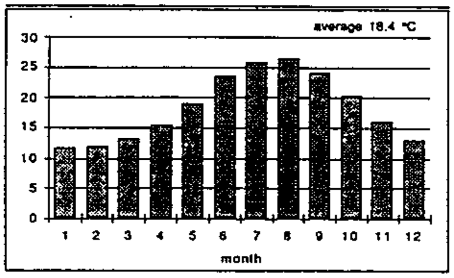
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0												
0 - 5												
5 - 10												
10 - 15												
15 - 20												
20 - 25												
25 - 30												
30 - 35												
sum												

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE, INSOLATION AND HEATING DEGREE-DAYS

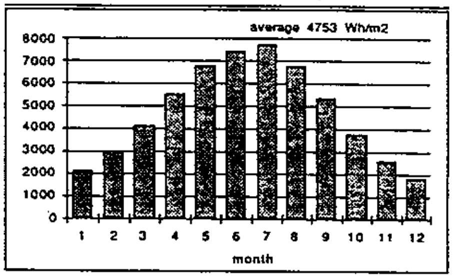
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature, monthly average daily (°C)	11.6	11.9	13.3	15.5	18.9	23.7	25.8	26.5	24.1	20.3	16.1	13.1	18.4
solar radiation on a horizontal surface, monthly average daily (Wh/m2)	2111	3011	4112	5534	6771	7425	7735	6787	5366	3766	2584	1830	4753
daily hours of sunshine													6.8
monthly normals of heating degree-days below 19 °C,	88	75	64	33	0	0	0	0	0	0	0	67	327

Remarks: Weather data from Conphoebus, Catania

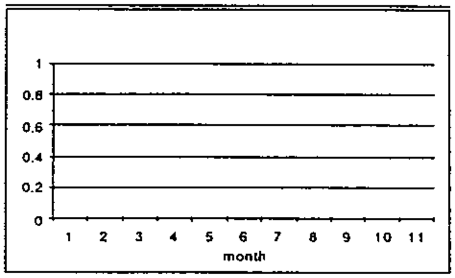
Ambient Temperature (°C)



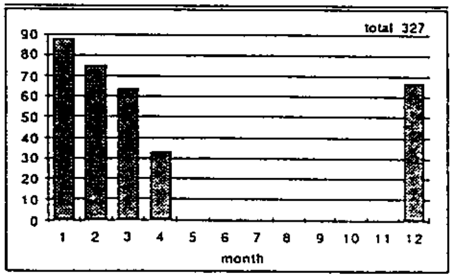
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 19°C)



CLIMATE DATA IN VARIOUS CLIMATES

Location:	the Netherlands, de Bilt			
Latitude:	52.1 °N		Heating degree-days (18°C):	3131
Elevation:	40 m			

Short description: The Netherlands is perfectly flat and in fact a considerable amount of its surface, near the North Sea is one or two meters below sea level. The climate is Atlantic with relatively mild temperatures and abundant, well distributed precipitation. However winter temperature does become more severe inland.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

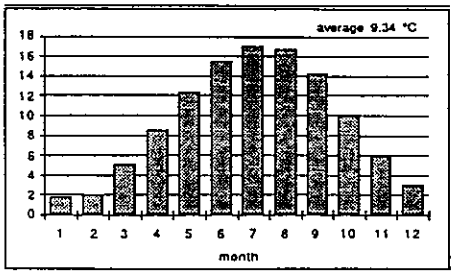
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0	532	26	3	3								
0 - 5	1662	112	44	10	2							
5 - 10	1772	213	117	74	28	16	6	2				
10 - 15	1511	226	131	103	61	39	27	15	6			
15 - 20	585	217	187	170	141	112	85	33	7			
20 - 25	41	38	34	47	65	57	61	43	29			
25 - 30	4	1	2	5	5	11	13	15	1			
30 - 35				1	2		2	4	1			
sum	6107	833	518	413	304	235	194	112	44			

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE. INSOLATION AND HEATING DEGREE-DAYS

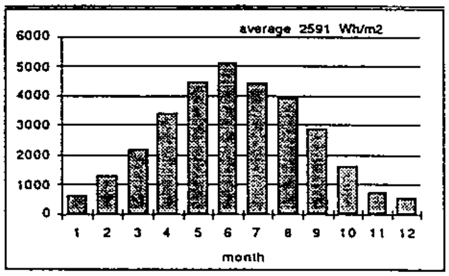
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature. monthly average daily (°C)	1.7	2	5	8.5	12.4	15.5	17	16.8	14.3	10	5.9	3	9.34
solar radiation on a horizontal surface. monthly average daily (Wh/m2)	655	1306	2168	3377	4461	5080	4403	3877	2850	1639	750	528	2591
daily hours of sunshine	1.7	2.4	3.3	4.7	5.9	6.6	5.7	5.9	4.5	3.3	1.7	1.64	3.95
monthly normals of heating degree-days below 18°C	514	441	422	292	96	98	47	36	73	225	376	511	3131

Remarks: Weather data from KNMI, de Bilt, 1961-1970.

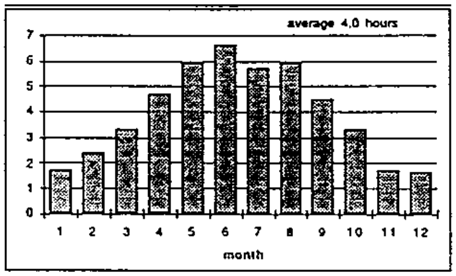
Ambient Temperature (°C)



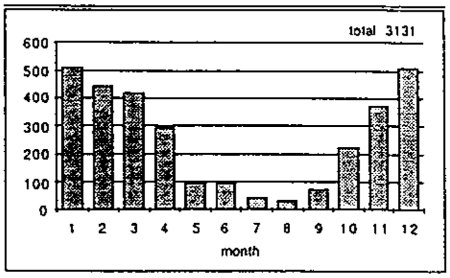
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 18°C)



CLIMATE DATA IN VARIOUS CLIMATES

Location: Switzerland, Rapperswil

Latitude: 47.3 °N
Elevation: 400 m

Heating degree-days (19 °C): 3848

Short description: The climate in Switzerland is dominated by the influence of mountains. Relatively mild temperatures, in the western part abundant, well distributed rainfall. In higher regions temperatures are lower.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

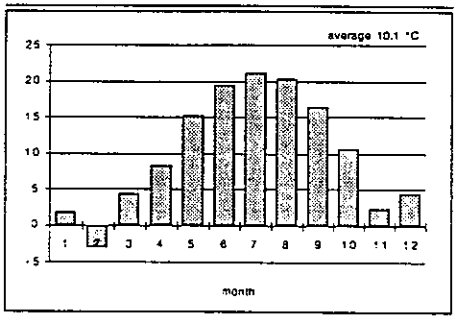
ambient temperature (°C)	insolation on tilted surface (45° south) (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0	1125	66	34	14	30	10	13	6	6			
0 - 5	1374	87	52	34	27	31	31	17	5	5	1	
5 - 10	1193	123	47	49	29	35	26	27	12	3		
10 - 15	1076	121	48	55	16	33	24	33	16	13		
15 - 20	917	110	74	51	41	56	44	48	55	21		
20 - 25	393	77	44	67	33	50	51	60	75	16		
25 - 30	105	30	23	20	25	23	35	43	63	2		
30 - 35	25	11	21	2	20	3	26	21	32			
sum	6208	625	343	292	221	241	250	255	264	60	1	

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE. INSOLATION AND HEATING DEGREE-DAYS

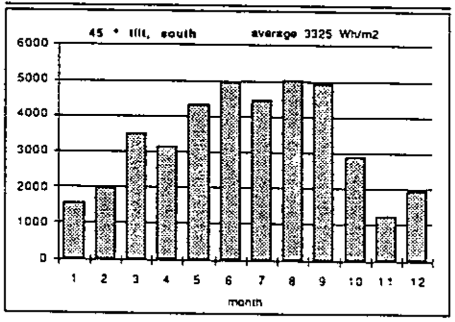
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature. monthly average daily (°C)	1.8	-3.2	4.4	8.2	15.2	19.4	21.1	20.3	16.4	10.7	2.4	4.4	10.1
solar radiation on a 45°. south surface. monthly average daily (Wh/m2)	1558	1964	3496	3151	4307	4939	4468	5041	4910	2883	1226	1953	3325
daily hours of sunshine (>120 W/m2. 45° south faced)	3.4	4.6	6.8	6.3	8.5	8.9	8.8	8.9	8.9	5.8	2.5	4.6	6.5
monthly normals of heating degree-days below 19 °C	563	650	483	356	162	98	54	61	119	291	527	484	3848

Remarks: Weather data from I.T. Rapperswil, Switzerland. 15 Aug. 1985 -14 Aug. 1986.

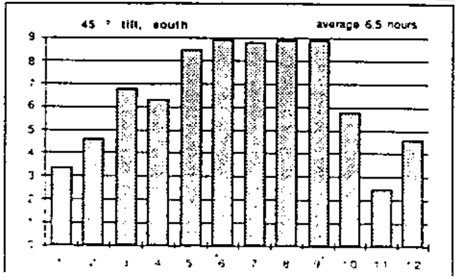
Ambient Temperature (°C)



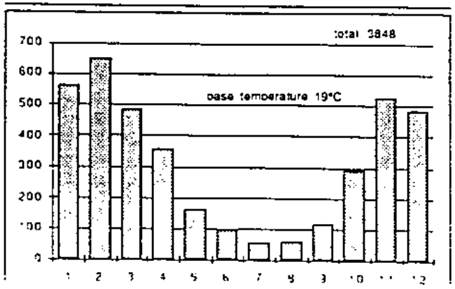
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 19°C)



CLIMATE DATA IN VARIOUS CLIMATES

Location:	United States, Denver, Colorado		
Latitude:	39.75 °N	Heating degree-days (19.3 °C):	3343
Elevation:	1609 m		

Short description: Denver is at high altitude, on the plains but near the mountains. It is cold during the winter, with night temperatures often below -20 °C. Snow of 1/2 m depth may remain on the ground all winter. However it is very sunny and thereby provides an ideal climate for solar heating. Undifferentiated highland climate to mid-latitude steppe, semi-arid, cool.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

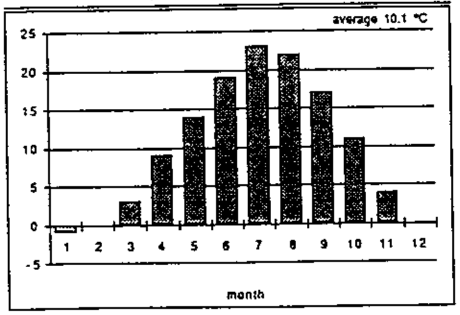
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0												
0 - 5												
5 - 10												
10 - 15												
15 - 20								61	41	36	1	
20 - 25								76	80	57	9	
25 - 30								58	78	73	8	
30 - 35								29	50	66	7	
sum								224	249	232	25	

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE, INSOLATION AND HEATING DEGREE-DAYS

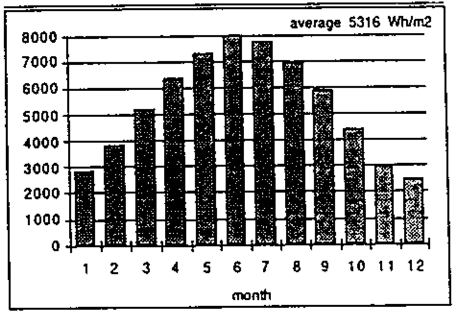
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature, monthly average daily (°C)	-1	0	3	9	14	19	23	22	17	11	4	0	10.1
solar radiation on a horizontal surface, monthly average daily (Wh/m2)	2823	3809	5205	6382	7284	7952	7698	6908	5847	4391	2968	2451	5316
daily hours of sunshine													
monthly normals of heating degree-days below 19.3 °C	604	501	482	292	141	44	0	0	67	227	427	558	3343

Remarks: Weather data from Solar Energy Thermal Processes, J.A.Duffie & W.A.Beckman, 1980

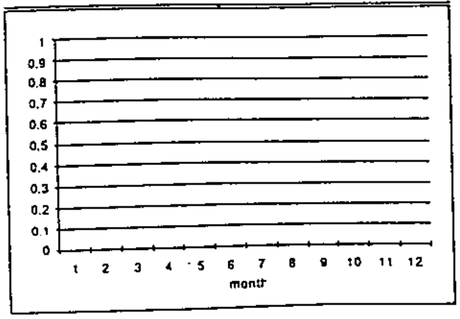
Ambient Temperature (°C)



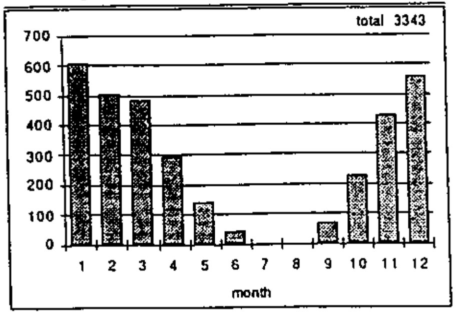
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 19.3°C)



Location:	United States, Madison, Wisconsin		
Latitude:	43.13 ° N	Heating degree-days (19.3 °C):	4294
Elevation:	262 m		

Short description: Madison is a northern city with frequent cloudy days during the winter. Snow may accumulate to more than 1 m depth and remain on the ground from December through April. Occasionally, the maximum temperature during the daytime does not exceed -20 °C. Summer is warm to hot.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

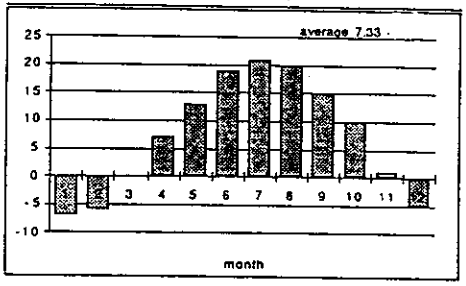
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0												
0 - 5												
5 - 10												
10 - 15												
15 - 20								32	22	12	0	
20 - 25								71	26	11	0	
25 - 30								87	74	29	2	
30 - 35								19	11	5		
sum								209	133	57	2	

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE. INSOLATION AND HEATING DEGREE-DAYS

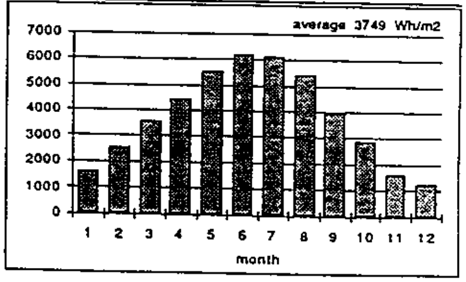
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature. monthly average daily (°C)	-7	-6	0	7	13	19	21	20	15	10	1	-5	7.33
solar radiation on a horizontal surface. monthly average daily (Wh/m2)	1623	2535	3581	4408	5496	6141	6089	5385	3958	2871	1589	1226	3749
daily hours of sunshine	4.5	5.7	6.9	7.5	9.1	10.1	9.8	10	8.6	7.2	4.2	3.9	7.29
monthly normals of heating degree-days below 19.3 °C	830	696	599	328	165	40	8	22	96	263	505	742	4294

Remarks: Weather data from Solar Energy Thermal Processes, J.A.Duffie & W.A.Beckman, 1980

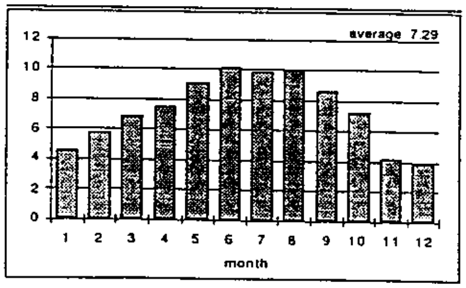
Ambient Temperature (°C)



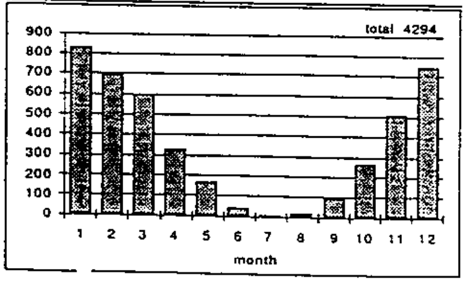
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 19.3 °C)



CLIMATE DATA IN VARIOUS CLIMATES

Location: Spain, -El Arenosillo- (Huelva)

Latitude: 37°.1 N Heating degree-days (15°/19°C): 440/1202
Elevation: 40 m

Short description: Huelva is at sea level, located at the far southwest of the Iberian Peninsula. The climate is subtropical, with a extremely sunny and hot weather during almost the whole year (max. temperatures 45°C). The winter is very short, with min. temperatures above 0°C, rainy or cloudy days are not usual. The big amount of daily sunshine hours justities this area as an excellent place for solar energy systems.

TABLE A. ANNUAL HOURS OF EXPOSURE TO TEMPERATURE AND INSOLATION.

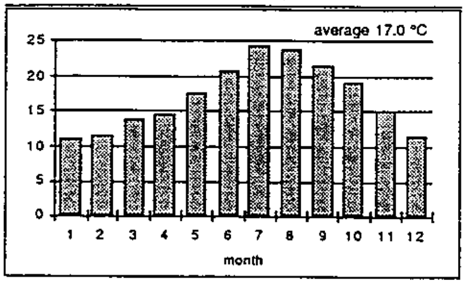
ambient temperature (°C)	insolation on horizontal surface (W/m2)											
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200
< 0												
0 - 5	74											
5 - 10	1133	44	21	3								
10 - 15	1729	123	94	70	73	26	13	2	2			
15 - 20	1456	209	171	200	194	146	86	59	42	22	2	
20 - 25	726	104	121	116	103	156	107	115	106	114	18	
25 - 30	81	39	48	52	70	76	110	109	125	102	8	
30 - 35	1	3	3	4	6	12	20	25	43	36	2	
> 40								1	2	2		
sum	5200	522	458	445	446	416	336	311	320	276	30	0

TABLE B. MONTHLY AVERAGE DATA TEMPERATURE, INSOLATION AND HEATING DEGREE-DAYS

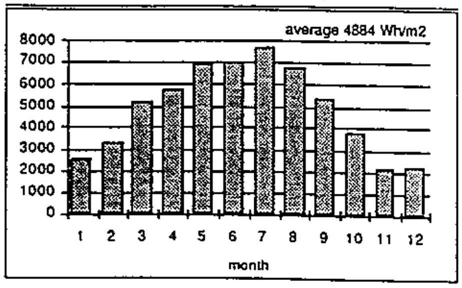
	Jan.	Febr.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
ambient temperature, monthly average daily (°C)	11.1	11.45	13.65	14.5	17.55	20.65	24.25	23.75	21.65	19.05	14.95	11.4	16.99
solar radiation on a horizontal surface, monthly average daily (Wh/m2)	2624	3253	5173	5733	6932	7011	7621	6733	5388	3796	2119	2229	4884
daily hours of sunshine	7.2	7.5	9.3	9.9	11.5	12	11.8	10.9	10.2	7.6	6.2	7.2	9.3
monthly normals of heating degree-days below 15°C resp. 19°C	122.6 245	94.9 208.8	48.3 166.2	30.6 135.6	3.5 51.9	0 8.8	0 0.8	0 0	0 0.4	0.3 26.6	27.7 121.3	112.5 235.9	440.3 1202

Remarks: Weather data from INTA-Solar Energy Lab.(March 1988-February,1990) Spain Madrid

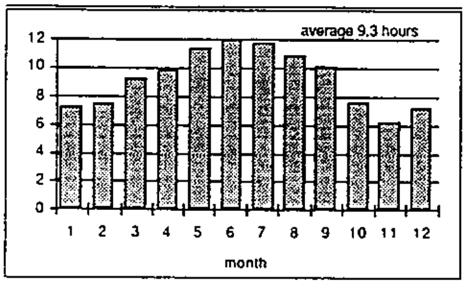
Ambient Temperature (°C)



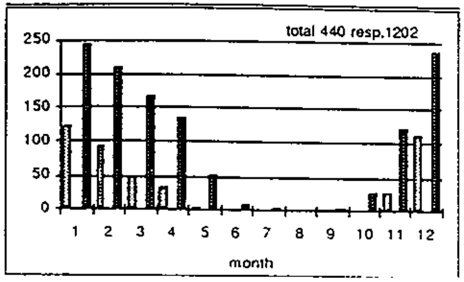
Daily Solar Radiation (Wh/m2)



Daily sunshine hours



Heating Degree-days (below 19°C)



ANNEX B
LIST OF PARTICIPATING EXPERTS

IEA Solar Heating and Cooling Programme
TASK X: Solar Materials R & D
SUBTASK A: Performance Criteria for New Solar Materials

Canada	Prof. K.G.T. Hollands	University of Waterloo
Denmark	S.A. Svendsen	Technical Univerity of Denmark
Germany	W.J. Platzer V. Wittwer	Fraunhofer Institute
Italy	F.Aleo	Conphoebus
The Netherlands	H.A.L. van Dijk A.C. de Geus J. Havinga	TNO-Bouw
	G. Brouwer (Subtask leader)	Van Heugten Consulting Engineers
United States (upto 1988)	D.A. Neeper	Los Alamos National Laboratory

ANNEX C

BIBLIOGRAPHIC DATA SHEETS OF THE TASK 10, SUBTASK A WORKING DOCUMENTS

1. Database Solar Materials. G. Brouwer. 1991.

2. Solar system and Component Modeling, Database of Calculation Programs. G. Brouwer. May 1991.

3. Effect of Selective Surface Degradation on the Performance of Solar Water Heating Systems. K.G.T. Hollands, A. Karagiozios, A.P. Brunger, G. Brouwer. (Case study). September 1990.

4. Microclimate in Solar Collectors. J. v.d. Linden, A.C. de Geus, W. Kowalczyk (Case study). May 1991.

5. Transparent Insulation, Description of Cases. W.J. Platzer (Case study). May 1991.

BIBLIOGRAPHIC DATA SHEET

Number: 01N1244-2

Publication date: 1992

Title and subtitle: Database Solar Materials, Performance Criteria for New Solar Materials, IEA, Task X. Solar Heating and Cooling Programme. Working Document.

Editor:
G. Brouwer
Van Heugten Consulting Engineers
Solar Energy Department
6500 AH Nijmegen, the Netherlands

Abstract:

The Database of Solar Materials provides basic material data to assist designers, manufacturers and researchers in solar energy in selecting the best materials for solar energy applications. This handbook provides optical and thermal performance data as well as mechanical and outdoor exposure data based on information from manufacturers and researchers. Three material categories are included:

1. Window, collector and wall glazing
2. Collector absorber coatings
3. Collector absorber substrates

Each group in this database is preceeded by a classfication of the materials. Easy readable graphs and tables of the main properties also precede each group to facilitate quick selection. Floppy discs with this information are included in both Mac and IBM formats. This study was performed within the framework of Subtask A of the IEA Task X.

Key words: Classification, database, glazing, material properties, material selection, performance data, solar collectors, solar energy materials, spectral selective coating, test standards, transparent insulation.

No. of printed pages: 110

Cost: (including 2 floppy discs) Dfl. 70,-, including postage and packing

Availability: May 1992, see order form.

BIBLIOGRAPHIC DATA SHEET

Number: 01N1244-3

Publication date: 1991

Title and subtitle: Solar Systems and Components Modeling (database of calculation programs), Performance Criteria for New Solar Materials, IEA, Task X. Solar Heating and Cooling Programme. Working Document.

Editor:
G. Brouwer
Van Heugten Consulting Engineers
Solar Energy Department
P.O.Box 305
6500 AH Nijmegen, the Netherlands.

Abstract: A group of solar energy system simulation programs were reviewed for their ability to facilitate the prediction of the benefit that could be achieved through selection of improved materials. Thirteen passive and eight active system simulation programs are included in the study. These programs, separately or in combination, can be used to calculate the impact of material property changes on the instantaneous, monthly, or annual system efficiency. The study was performed within the framework of Subtask A of IEA Task X.

Key words: Simulation models, database, energy performance, material properties, active solar systems, passive solar.

No. of printed pages: 25

Cost: Dfl. 15,-

Availability: May 1991, see order form.

BIBLIOGRAPHIC DATA SHEET

Number:

Publication date: 1991

Title and subtitle: Effect of Selective Surface Degradation on the Performance of Solar Water Heating Systems. Performance Criteria for New Solar Materials, IEA, Task X. Solar Heating and Cooling Programme. Working Document.

Editor:
K. G. T. Hollands
University of Waterloo
Solar Thermal Engineering Centre
Waterloo, Ontario, N2L 3G1
Canada

Abstract: Spectral selective surfaces of solar absorbers often degrade in the field. Their solar absorptivity and thermal emittance change with time in service by some amount from their initial values. It is important to quantify the effect this degradation has on the annual energy performance (or fraction solar). In this working document, that refers to the Subtask A report of IEA Task X, computer simulations of solar domestic hot water systems were used to graph combinations of absorptance and emittance for relative changes in solar fraction, of 5 % and 10 %. For solar fractions higher than 0.5 changes of solar fraction to changes of absorptance and emittance are dependent on the geographical latitude of location. These results have direct application to projecting the useful service life of a selective surface.

Key words: Spectral selective coatings, absorptance, emittance, solar collectors, degradation, energy benefits, fraction solar, simulation model, locations.

No. of printed pages: 35

Cost: $15, including postage and packing

Availability: February 1991, see order form.

BIBLIOGRAPHIC DATA SHEET

Number: 914.012

Publication date: 1991

Title and subtitle: Micro-climate in Solar Collectors, Performance Criteria for New Solar Materials, IEA, Task X. Solar Heating and Cooling Programme. Working Document.

Editor:
J. van der Linden
TNO Building and Construction Research
P.O. Box 29
2600 AA Delft
the Netherlands

Abstract: In order to predict the service life of flat plate collectors the operating conditions of the components with the collector must be known. The temperature and humidity are the most important factors. A computer model was developed that is able to simulate the micro climate inside the collector. A heat and mass transfer model, including ventilation, calculates micro climate conditions for each time step.

Validation of the model was performed with data from long term collector tests carried out in Rapperswil, Switzerland. Annual simulations were carried out to obtain the collector operating conditions based on the test reference year of De Bilt, the Netherlands, . The results of this study were used in the Subtask A report of IEA Task X.

Key words: Micro-climate, solar collectors, degradation, simulation model, absolute humidity, validation.

No. of printed pages: 30

Cost: Dfl. 35, including postage and packing

Availability: July 1991, see order form.

BIBLIOGRAPHIC DATA SHEET

Number:

Publication date: 1991

Title and subtitle: Transparent Insulation (Description and Results of Cases), Performance Criteria for New Solar Materials, IEA, Task X. Solar Heating and Cooling Programme. Working Document.

Editor: W.J. Platzer
Fraunhofer-Institute for Solar Energy Systems
Oltmannstrasse 22
D-7800 Freiburg
Germany

Abstract: A case study on the energy benefits of transparent insulation materials (TIM) on massive walls was performed within Subtask A of IEA Task X. The study describes a methodology to calculate the performance gains of using TIM for dwellings. This working document presents the description of the reference cases ('shoebox' houses) for which calculations were performed. In addition the results, e.g. the monthly mean transmittance values for the reference cases, for several locations, orientations and materials are given.

Key words: Transparent insulation, energy benefits, reference cases, results, transmittance values.

No. of printed pages: 100

Cost: DM 40, including postage and packing

Availability: May 1991, see order form.

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Keycontact :
Van Heugten Consulting Engineers
Contactperson : G. Bert Brouwer
P.O. Box 305, 6500 AH Nijmegen, the Netherlands
Telephone : 31 80 228317
Telefax : 31 80 235016

ANNEX D

MONTHLY MEAN TRANSMITTANCE VALUES FOR SEVERAL LOCATIONS AND MATERIALS

W.J. Platzer, Fraunhofer Institute, Germany

In the following paragraphs monthly mean transmittance values for several locations, orientations and materials are given. These numbers can be used in the monthly calculations using the correlation method described in Chapter 9.3. The 12 monthly transmittance values are given in one line for the orientations South (S), South-East/West (SE/SW), East/West (E/W) and North (N). East and West are equivalent here, as a symmetrical hourly distribution of the radiation was used in the radiation model. This model used only the global monthly mean radiation on a horizontal plane. The isotropic diffuse background, the isotropic diffuse albedo (ground reflectivity 0.2) and the effective beam radiation (beam plus circumsolar) were the components of the radiation model. The diffuse background component was determined by a correlation of the equivalent diffuse fraction with clearness index.

Edmonton

AREL honeycomb 100mm + 1 low-iron cover glass

S	.778	.731	.666	.605	.564	.552	.548	.585	.640	.708	.764	.784
SO/SW	.717	.716	.694	.651	.616	.601	.607	.635	.675	.708	.720	.714
O/W	.552	.616	.660	.672	.662	.654	.661	.667	.665	.637	.578	.541
N	.638	.638	.638	.610	.596	.600	.590	.601	.636	.638	.638	.638

AREL honeycomb 50mm + 1 low-iron cover glass

S	.833	.801	.752	.702	.665	.653	.650	.685	.731	.783	.823	.835
SO/SW	.781	.781	.768	.737	.710	.697	.702	.725	.754	.776	.783	.779
O/W	.654	.706	.738	.746	.740	.735	.740	.743	.741	.722	.676	.644
N	.721	.721	.721	.694	.684	.688	.679	.687	.719	.721	.721	.721

BASF aerogel granules 16mm + 2 low-iron cover glasses

S	.569	.542	.500	.458	.428	.420	.417	.443	.483	.527	.561	.571
SO/SW	.524	.526	.517	.490	.465	.454	.459	.479	.505	.522	.526	.522
O/W	.423	.465	.491	.498	.494	.489	.494	.496	.493	.479	.441	.415
N	.478	.478	.478	.460	.450	.453	.446	.454	.477	.478	.478	.478

AIRGLASS monolithic aerogel 16mm + 2 low-iron cover glasses

S	.763	.740	.698	.651	.613	.600	.598	.633	.679	.725	.756	.765
SO/SW	.713	.715	.708	.683	.657	.644	.649	.672	.698	.712	.714	.712
O/W	.606	.653	.679	.685	.682	.678	.682	.684	.680	.666	.626	.596
N	.665	.665	.665	.640	.630	.634	.626	.633	.662	.665	.665	.665

Acrylic foam 32mm + 1 low-iron cover glass

S	.477	.451	.414	.378	.354	.348	.345	.366	.399	.438	.469	.479
SO/SW	.438	.440	.430	.406	.384	.375	.379	.396	.420	.436	.440	.436
O/W	.349	.385	.409	.415	.411	.407	.411	.413	.411	.398	.364	.343
N	.397	.397	.397	.382	.374	.376	.371	.377	.396	.397	.397	.397

Copenhagen

AREL honeycomb 100mm + 1 low-iron cover glass

S	.775	.736	.678	.621	.582	.562	.582	.602	.653	.714	.764	.790
SO/SW	.700	.699	.683	.652	.624	.610	.618	.639	.674	.694	.700	.696
O/W	.558	.606	.639	.655	.653	.652	.647	.654	.652	.621	.575	.541
N	.638	.638	.638	.628	.614	.606	.617	.621	.637	.638	.638	.638

AREL honeycomb 50mm + 1 low-iron cover glass

S	.828	.802	.760	.715	.680	.662	.679	.699	.740	.787	.820	.837
SO/SW	.769	.769	.758	.737	.715	.703	.710	.727	.753	.766	.769	.768
O/W	.656	.696	.722	.734	.734	.734	.729	.734	.731	.708	.671	.641
N	.721	.721	.721	.711	.699	.693	.702	.705	.720	.721	.721	.721

BASF aerogel granules 16mm + 2 low-iron cover glasses

S	.565	.543	.508	.468	.440	.427	.440	.455	.491	.531	.559	.572
SO/SW	.515	.515	.509	.490	.470	.460	.466	.481	.504	.514	.515	.514
O/W	.426	.458	.479	.489	.488	.488	.485	.488	.486	.468	.438	.414
N	.478	.478	.478	.471	.462	.457	.464	.467	.478	.478	.478	.478

AIRGLASS monolithic aerogel 16mm + 2 low-iron cover glasses

S	.757	.739	.704	.662	.627	.609	.625	.646	.687	.727	.752	.762
SO/SW	.705	.704	.699	.682	.662	.650	.656	.673	.695	.703	.704	.704
O/W	.606	.643	.665	.675	.676	.677	.672	.676	.673	.654	.620	.591
N	.665	.665	.665	.656	.644	.639	.647	.650	.664	.665	.665	.665

Acrylic foam 32mm + 1 low-iron cover glass

S	.474	.454	.421	.387	.364	.353	.364	.376	.406	.442	.468	.481
SO/SW	.430	.430	.424	.406	.389	.381	.386	.398	.419	.429	.430	.428
O/W	.353	.379	.398	.407	.406	.406	.403	.406	.404	.388	.362	.343
N	.397	.397	.397	.392	.384	.379	.386	.388	.397	.397	.397	.397

Madison

AREL honeycomb 100mm + 1 low-iron cover glass

S	.733	.688	.624	.563	.529	.521	.518	.535	.593	.663	.717	.741
SO/SW	.698	.686	.661	.629	.599	.585	.587	.614	.648	.681	.693	.699
O/W	.595	.628	.649	.655	.651	.648	.650	.658	.658	.639	.605	.590
N	.638	.638	.638	.626	.605	.596	.598	.609	.637	.638	.638	.638

AREL honeycomb 50mm + 1 low-iron cover glass

S	.802	.770	.719	.665	.629	.617	.616	.638	.693	.751	.792	.807
SO/SW	.767	.760	.743	.718	.694	.681	.684	.707	.734	.756	.764	.768
O/W	.688	.714	.729	.734	.732	.730	.731	.737	.736	.723	.696	.684
N	.721	.721	.721	.709	.691	.683	.684	.694	.720	.721	.721	.721

BASF aerogel granules 16mm + 2 low-iron cover glasses

S	.544	.515	.471	.428	.405	.401	.399	.408	.448	.498	.534	.549
SO/SW	.514	.510	.496	.474	.453	.442	.444	.463	.488	.507	.512	.515
O/W	.451	.472	.484	.488	.487	.485	.486	.491	.489	.480	.458	.448
N	.478	.478	.478	.470	.457	.450	.452	.460	.477	.478	.478	.478

AIRGLASS monolithic aerogel 16mm + 2 low-iron cover glasses

S	.742	.715	.667	.612	.577	.567	.566	.586	.641	.698	.733	.746
SO/SW	.703	.699	.687	.665	.641	.628	.631	.655	.680	.697	.701	.703
O/W	.636	.660	.671	.675	.674	.673	.674	.679	.676	.667	.643	.633
N	.665	.665	.665	.654	.637	.630	.631	.640	.663	.665	.665	.665

Acrylic foam 32mm + 1 low-iron cover glass

S	.453	.426	.388	.353	.336	.334	.332	.338	.370	.412	.444	.457
SO/SW	.429	.425	.412	.392	.374	.366	.367	.383	.404	.422	.428	.430
O/W	.374	.392	.403	.407	.405	.403	.404	.409	.408	.398	.379	.371
N	.397	.397	.397	.391	.380	.374	.375	.382	.396	.397	.397	.397

Messina

AREL honeycomb 100mm + 1 low-iron cover glass

S	.712	.665	.595	.522	.484	.482	.454	.481	.554	.638	.698	.721
SO/SW	.690	.680	.654	.617	.577	.558	.563	.596	.642	.674	.693	.691
O/W	.606	.633	.652	.663	.658	.655	.660	.667	.667	.646	.616	.599
N	.638	.638	.638	.616	.574	.557	.552	.583	.635	.638	.638	.638

AREL honeycomb 50mm + 1 low-iron cover glass

S	.788	.753	.695	.627	.585	.576	.551	.588	.660	.732	.779	.795
SO/SW	.762	.755	.738	.709	.677	.659	.665	.694	.730	.752	.764	.762
O/W	.697	.718	.732	.740	.738	.736	.739	.744	.743	.728	.705	.691
N	.721	.721	.721	.699	.662	.648	.642	.668	.718	.721	.721	.721

BASF aerogel granules 16mm + 2 low-iron cover glasses

S	.531	.499	.450	.400	.377	.378	.360	.373	.421	.480	.522	.537
SO/SW	.510	.506	.491	.466	.437	.424	.428	.451	.484	.504	.513	.510
O/W	.459	.476	.486	.493	.492	.490	.493	.496	.495	.484	.465	.454
N	.478	.478	.478	.464	.437	.425	.421	.443	.476	.478	.478	.478

AIRGLASS monolithic aerogel 16mm + 2 low-iron cover glasses

S	.731	.700	.643	.576	.537	.532	.509	.538	.608	.680	.724	.736
SO/SW	.699	.696	.683	.658	.624	.607	.613	.642	.677	.695	.702	.699
O/W	.644	.663	.673	.680	.680	.679	.681	.684	.682	.671	.652	.639
N	.665	.665	.665	.645	.610	.598	.592	.617	.662	.665	.665	.665

Acrylic foam 32mm + 1 low-iron cover glass

S	.441	.412	.371	.331	.314	.315	.299	.310	.347	.396	.432	.447
SO/SW	.426	.422	.408	.385	.361	.351	.353	.372	.401	.419	.428	.426
O/W	.380	.395	.405	.411	.409	.408	.410	.413	.412	.402	.386	.376
N	.397	.397	.397	.386	.363	.353	.350	.368	.396	.397	.397	.397

Freiburg

AREL honeycomb 100mm + 1 low-iron cover glass

S	.746	.706	.657	.586	.566	.544	.531	.580	.622	.686	.730	.752
SO/SW	.693	.684	.652	.637	.614	.598	.599	.626	.657	.677	.681	.688
O/W	.587	.616	.624	.657	.642	.646	.653	.644	.653	.626	.596	.581
N	.638	.638	.638	.626	.624	.607	.597	.630	.637	.638	.638	.638

AREL honeycomb 50mm + 1 low-iron cover glass

S	.809	.782	.744	.685	.664	.642	.632	.678	.716	.767	.797	.812
SO/SW	.764	.758	.734	.725	.706	.693	.694	.716	.740	.753	.755	.761
O/W	.681	.704	.710	.735	.725	.729	.734	.726	.732	.712	.688	.675
N	.721	.721	.721	.709	.708	.694	.684	.713	.720	.721	.721	.721

BASF aerogel granules 16mm + 2 low-iron cover glasses

S	.550	.526	.493	.444	.430	.415	.406	.439	.469	.513	.541	.553
SO/SW	.511	.508	.488	.480	.463	.452	.452	.472	.493	.504	.504	.508
O/W	.446	.464	.470	.489	.481	.484	.489	.482	.486	.471	.451	.441
N	.478	.478	.478	.470	.469	.458	.451	.473	.477	.478	.478	.478

AIRGLASS monolithic aerogel 16mm + 2 low-iron cover glasses

S	.745	.724	.689	.633	.610	.589	.580	.625	.664	.711	.736	.746
SO/SW	.700	.697	.677	.672	.652	.639	.641	.662	.685	.694	.694	.698
O/W	.629	.650	.655	.676	.668	.672	.677	.669	.673	.658	.635	.623
N	.665	.665	.665	.654	.653	.639	.631	.658	.664	.665	.665	.665

Acrylic foam 32mm + 1 low-iron cover glass

S	.460	.437	.408	.366	.356	.345	.337	.363	.387	.426	.451	.463
SO/SW	.426	.423	.406	.397	.383	.374	.374	.390	.409	.420	.420	.424
O/W	.369	.385	.390	.407	.400	.403	.407	.401	.405	.391	.374	.366
N	.397	.397	.397	.391	.390	.380	.375	.393	.397	.397	.397	.397

ANNEX E

REPORTS OF THE IEA-SHC TASK X, SUBTASK B AND SUBTASK C

- Subtask B :
  Accelerated Life Testing of Solar Energy Materials.
  Bo Carlsson (Ed.) Draft April 1992.

- Subtask C : (Title is tentative)
  Carl Lampert (Ed.)

INTERNATIONAL ENERGY AGENCY

The International Energy Agency was formed in November 1974 to establish cooperation among a number of industrialized countries in the vital area of energy policy. It is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). Twenty-one countries are presently members, with the Commission of the European Communities (CEC) also participating in the work of the IEA under a special arrangement.

Collaboration among member countries in the research and development of alternative energy resources in order to reduce excessive dependence on oil is an important element of the IEA program. A number of new and improved technologies, which have the potential for making significant contributions to global energy needs, were indentified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), supported by a small Secretariat staff, is the focus of IEA R&D activities. Four Working Parties (in Conservation, Fossil Fuels, Renewable Energy, and Fusion) are charged with identifying new areas for cooperation and advising the CRD on policy matters in their respective technology areas.

Solar Heating and Cooling Program

Solar Heating and Cooling was one of the technologies selected for joint R&D activities. During 1976-77, specific projects were identified in key areas of this field and a formal implementing Agreement drawn up. The Agreement covers the obligations and rights of the Participants and outlines the scope of each project or "task" in annexes to the document.

There are now eighteen signatories to the Agreement:

Australia
Austria
Belgium
Canada
Commission of the European Communities
Denmark
Germany
Finland
France (observer)

Italy
Japan
Netherlands
New Zealand
Norway
Spain
Sweden
Switzerland
United Kingdom
United States

The overall program is managed by an Executive Committee, while the management of the individual tasks is the responsibility of Operating Agents. The tasks of the IEA Solar Heating and Cooling Program, their respective Operating Agents, and current status (ongoing or completed) are as follows :

I Investigation of the Performance of Solar Heating and Cooling Systems - Denmark (completed)
II Coordination of Research and Development of Solar Heating and Cooling - Japan (completed)
III Performance Testing of Solar Collectors - Germany & U.K. (completed)
IV Development of an Insolation Handbook and Instrument Package - U.S. (completed)
V Use of Existing Meteorological Information for Solar Energy Application - Sweden (completed)
VI Performance of Solar Heating, Cooling, and Hot Water Systems Using Evacuated Collectors - U.S. (completed)
VII Central Solar Heating Plants with Seasonal Storage - Sweden (completed)
VIII Passive and Hybrid Solar Low Energy Buildings - U.S. Department of Energy (completed)
IX Solar Radiation and Pyranometry Studies - Canada & Germany (completed)
X Solar Materials R&D - Japan (completed)

XI Passive Hybrid Solar Commercial Buildings - Switzerland (completed)
XII Solar Building Energy Analysis and Design Tools - U.S. (ongoing).
XIII Advanced Solar Low Energy Buildings - Norway (ongoing).
XIV Advanced Active Solar Systems - Canada (ongoing)
XV Advanced Central Solar Heating Plants with Seasonal Storage - Netherlands (proposed)
XVI Photovoltaics in Buildings - Germany (ongoing)
XVII Measuring and Modeling Spectral Radiation - Germany (ongoing)
XVIII Advanced Glazing Materials - United Kingdom (ongoing).

Task X - Solar Materials Research R&D

Task X was initiated to address the materials problems associated with improvements in cost, performance and reliability of solar heated domestic hot water, and space heating and cooling systems. Task X activities began in 1985 and will be completed in 1990.

Originally, task activities were organized in the following four subtasks :

Subtask A Performance Levels and Evaluation Criteria for Selecting Materials
Subtask B Test Procedures and Measurement Techniques
Subtask C Service Life Prediction Methods
Subtask D Failure and Degradation Modes.

A survey was carried out to present the state-of-the art in the respective fields. In 1987 the task was re-organized according to material categories and the participants focused their efforts on the following areas :

Subtask A Performance Criteria for New Solar Materials
Subtask B Selective Absorber Materials
Subtask C Collector and Window Glazings

Subtask A, involved modeling and (sub)system performance studies of new or proposed solar materials with respect to energy benefits. Failure and degradation conditions were studied. Subtask B, addressed issues of optical measurements, failure, degradation and accelerated life testing of absorbers. Subtask C, involved the study of electrochromic optical switching devices, and testing and analysis of low emittance coatings and transparent insulation.

The following countries participated in this task:

Canada
Denmark
Germany
Italy
Japan (Operating Agent)
The Netherlands

Spain
Sweden
Switzerlnad
United Kingdom
United States