INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and
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Annex XII
Windows and fenestration

Step 3

Calculation of Seasonal Heat Loss and Gain through Windows; a comparison of some simplified models

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INTERNATIONAL ENERGY AGENCY

Energy Conservation in Buildings and
Community Systems Programme

Annex XII, WINDOWS AND FENESTRATION

Report from Step 3

CALCULATION OF SEASONAL HEAT LOSS AND GAIN THROUGH WINDOWS; A COMPARISON OF SOME SIMPLIFIED MODELS

This report is part of the work of the IEA Energy Conservation in Buildings & Community Systems Programme

Annex XII - Windows and Fenestration

Participants in this task:

Belgium, FR-Germany, Italy, The Netherlands (Operating Agent), Norway, Switzerland, United Kingdom, United States of America.

The complete list of representatives who have contributed to this report is given in Appendix 1.

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PREFACE

INTERNATIONAL ENERGY AGENCY

In order to strengthen co-operation in the vital area of energy policy, an Agreement of an International Energy Programme was formulated among a number of industrialized countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organization for Economic Co-operation and Development (OECD) to administer that agreement. Twenty-one countries are currently members of the IEA, with the Commission of the European Communities participating under special agreement.

As one element of the International Energy Programme, the Participants undertake co-operative activities in energy research, development and demonstration. A number of new and improved energy technologies which have the potential of making significant contribution to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat staff, co-ordinates the energy research, development and demonstration programme.

ENERGY CONSERVATION IN BUILDINGS AND COMMUNITY SYSTEMS

As one element of the Energy Programme, the IEA encourages research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is encouraging various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programmes, building monitoring, comparison of calculation methods, as well as air quality and inhabitant behaviour studies.

THE EXECUTIVE COMMITTEE

Overall control of the R&D Programme energy conservation in buildings and community systems is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures all projects fit into a predetermined strategy without unnecessary overlap or duplication but with effective liaison and communication.

ANNEX XII

In June 1982 the Executive Committee approved Annex XII, 'Windows and Fenestration' as a new joint effort project, with the Netherlands acting as 'Operating Agent' to co-ordinate the work.
The following countries are participating in this project:

BELGIUM, FEDERAL REPUBLIC OF GERMANY, ITALY, THE NETHERLANDS, NORWAY, SWITZERLAND, UNITED KINGDOM, UNITED STATES.

The project consists of 5 steps:

Step 1: Survey the state-of-the-art in all types of existing windows and future designs (including glazing and combinations of glazing and insulating and/or sunshading systems).

Step 2: Survey the state-of-the-art in thermal and solar properties of windows and compare definitions, test methods, calculation procedures and measured, calculated or assumed data, wherever possible converted into one or several sets of standardized conditions. The aim: to try and cover all existing (and sometimes conflicting) information in this field in an extensive report for "expert groups".
A separate report contains summarized information for general use among architects, consultants and manufacturers.

Step 3: Review and analyze existing simplified steady-state calculation methods dealing with heat gains and losses through window systems. These methods can provide a preliminary and global figure for the influence of the window on energy consumption without considering the interaction with the building, occupants and climate in a detailed way.

Step 4: Adapt and compare existing dynamic calculation methods dealing with the influence of window type, size and orientation on energy consumption and thermal comfort in buildings.

Normally, a good window design will often be treated with a global approximation, with the consequence that specific features of the design cannot be revealed properly. With a study specifically focussed on windows complex systems also can be simulated, like multi- layer systems with foils, coatings and/or gas-fillings and e.g. systems in which the control of an openable window, insulation panel, or sunshading is associated with indoor temperature and/or time and/or intensity of solar radiation. A thorough consideration of the effect of windows calls for a calculation model that can handle such simulation.

Step 5: Apply unsteady state models in a series of selected, general sensitivity studies and thereby produce extensive information on optimal window design from an energy point of view for different buildings (mass, insulation), occupants' behaviour schemes (control of equipment, internal heat) and climatic zones. The results are aimed at groups like architects, manufacturers and policy makers.

1. INTRODUCTION

This report describes part of the work within Step 3.
In this report results are presented from comparative calculations of annual heat gains and losses through window systems.
The aim of this comparison was to come to a better understanding of existing simplified calculation methods.

Two main categories of methods to calculate annual energy consumption in buildings can be distinguished, namely simulation and correlation methods. Simulation methods are based on the solution of more or less detailed thermal models of the building in short time steps, e.g. hour by hour. Correlation methods, on the other hand, give the energy consumption as a simple relation between the thermal losses of the building and mean weather data over longer periods (12).
In this report only correlation methods have been compared.

Among the methods involved in the comparison different approaches can be found. The different approaches can roughly be divided into:
- steady-state heat balance;
- degree-day or corrected degree-day methods;
- other correlation methods.

Also different applications can be found, which means that one should be careful in drawing conclusions from a direct comparison.
On the other hand, the comparison of different approaches and application areas enlarges the potential of the analysis.

As compared to the large number of simplified models on the market, only a few methods have been involved in this part of the study.
The reason is mainly that it was considered of the utmost importance to analyse the different calculation approaches and the kind of results in a detailed way.

Had the goal been to include a high percentage of all existing simplified methods, then the main effort would necessarily have been to collect all the results of the calculation cases, without sufficient opportunity for detailed analysis aimed at understanding the results.

One of the important fields of application of the results is Step 5 of the project, where simplified methods are needed as a tool to systematically analyse and present the results from the sensitivity studies.

2. GENERAL CONSIDERATIONS

The energy consumption for space heating in buildings is determined on the one hand by the heat loss by transmission through the envelope and by ventilation, on the other hand by the heat gain from solar radiation and from internal heat sources (persons, lighting, equipment), see figure 1. In addition the efficiency of the heating installation plays a role (figure 2).

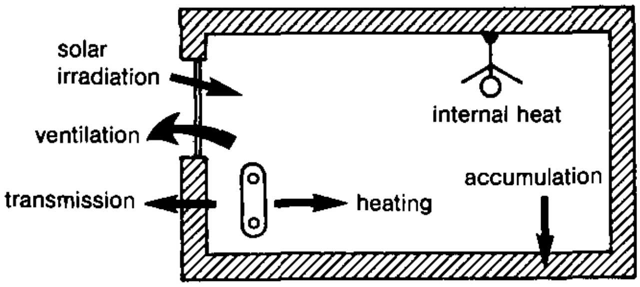

Figure 1: Apart from the efficiency of the heating installation, the heat balance of a building determines the energy consumption for space heating.

The window system accounts for the heat losses (transmission) and part of the gains (solar) (figure 3). Moreover, also the ventilation losses could partly be attributed to the window (infiltration).

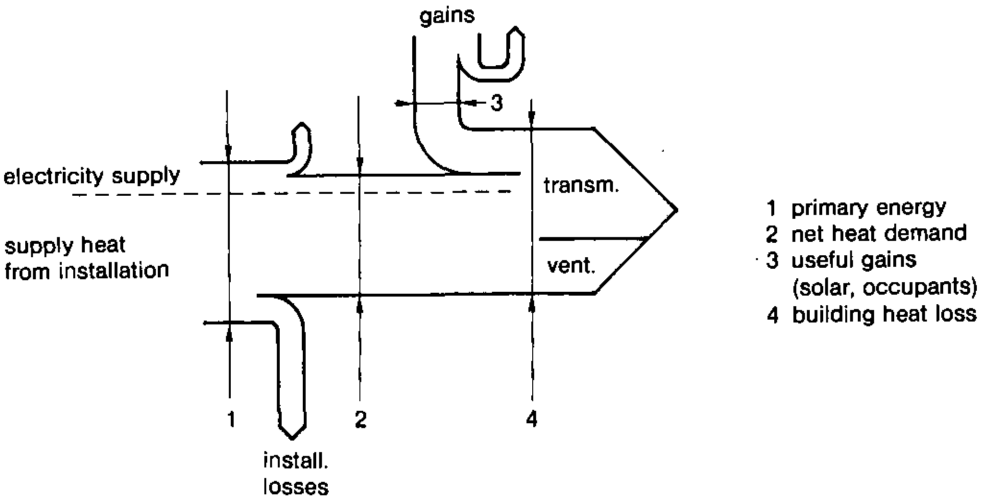

Figure 2: Thermal balance including installation.

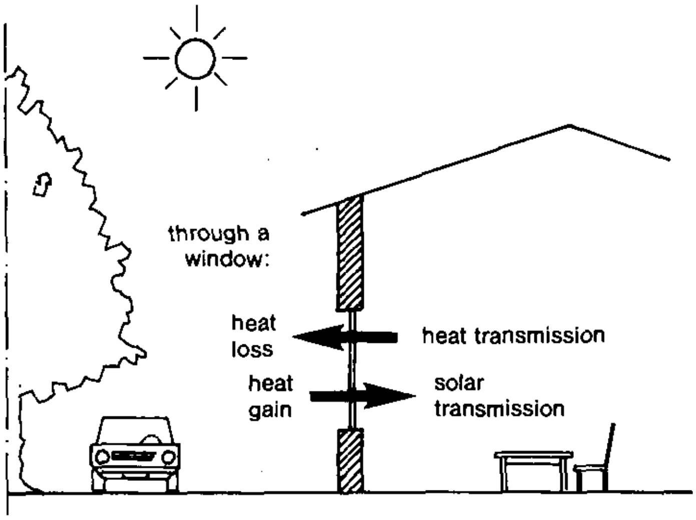

Figure 3: The window accounts for part of the losses and gains.

The heat balance of the window is integrated in the heat balance of the building or room under consideration.
Therefore, when comparing the methods to determine seasonal heat loss and gain through windows the thermal characteristics of the building involved play an important role.

The heat loss per unit of window area and per K temperature difference between indoor and outdoor environment is described by the thermal transmittance or U-value:

$$U = \frac{\text{heat flow density through window}}{\text{indoor-outdoor temperature difference}} \qquad (W/m^2K)$$

In the usual definition of U-value, the effect of solar radiation is not included. The latter effect is described by the so-called (total) solar energy transmission coefficient, here presented with the symbol g:

$$g = \frac{\text{total solar energy entering the room through the window}}{\text{solar radiation incident on the window}} \qquad (-)$$

So, the solar energy transmission coefficient includes both directly transmitted short wave solar radiation (primary part) and the indirect heat transfer by the part of the solar radiation which is absorbed in the window and transfered to the indoor space by infrared radiation and free convection (figure 4).

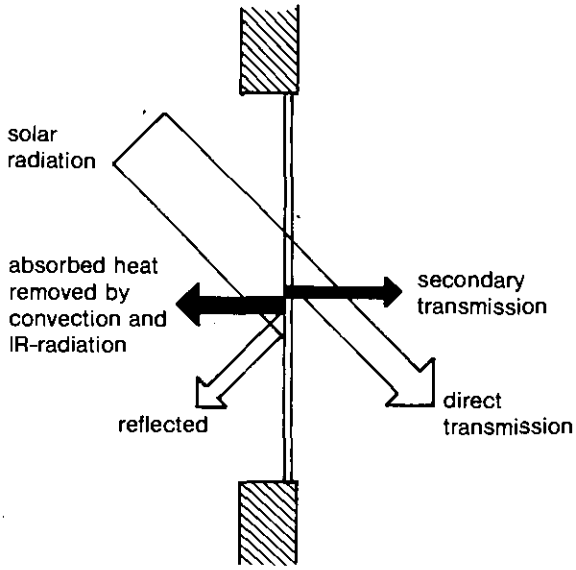

Figure 4: Illustration of the transmission of solar energy through a window.

3. METHOD

This report is based on the results of calculations with a limited number of simplified models.
Each of the models deals, in some way or another, with the seasonal heat losses and solar gains through windows. The selection of the models was left to the individual participants (see appendix 1).
Ten cases with the following characteristics were specified for the calculation:

dwelling : 1. single family house in a terrace, masonry type;
2. single family house in a terrace, wooden frame type;

heating mode: A. continuous heating;
B. night time temperature set-back;

climate : typical heating season for: Lugano (CH);
Basel (CH);
De Bilt (Nl);
Oslo (N).

The results requested consisted of the following items:

- description of the applied method;
- monthly and total (= heating season) heat flows by:
  - transmission through the envelope of the dwelling;
  - ventilation;
  - solar gains;
  - internal heat sources;
- monthly and total heat demand of the dwelling;
- monthly and total net heat gain per m^2 of the south respectively the north window.

4. APPLIED MODELS

The models used in this comparison are:

"Temperature without heating", presented by
Centre Scientifique et Technique de la Construction,
Brussels, Belgium.

"k-eff" (effective U-value), presented by
Fraunhofer - Institut für Bauphysik,
Stuttgart, FR Germany.

TPD-method, presented by
Technisch Physische Dienst TNO-TH
(TNO Institute of Applied Physics)
Delft, The Netherlands.

EFB1, presented by
Norwegian Building Research Institute,
Trondheim, Norway.

SIA 180/3,
LESO-A,
LESO-SAI, presented by
Ecole Polytechnique Féderale de Lausanne, GRES,
Lausanne, Switzerland.

Impuls Programm Handbuch, presented by
EMPA, Section Building Physics,
Dübendorf, Switzerland.

5. FIRST RESULTS

The first results showed a very wide scatter.
Many of the differences could be traced back to:

1. differences in the definition of the various quantities;
2. deviations from the specifications.

ad 1, differences in definitions

Unless precisely specified, heat flows like transmission and ventilation losses and solar and internal gains can be defined in various ways. In each calculation procedure, implicitly or explicitly, the following effects are taken into account:

- the actual duration of the heating season in a given situation compared to the chosen timestep;
- the actual indoor temperature, which e.g. in case of night set-back deviates from the thermostat settings;
- the overheating effect from internal heat sources;
- the overheating effect from solar heat entering the buildings;
- the actual heat transfer mechanisms inside a room (convection, thermal radiation) may deviate from the simplified assumptions.

The calculation procedures differ in where and how each of these effects are taken into account:

- the actual duration of the heating season can be taken into account, e.g.:
  . by monthly comparison of the gain/loss ratio;
  the presented total heat flows may be valid for a fixed number of months or for the actual heating season only;
  . by an explicit correction factor, e.g. on the heat demand, per month or per heating season; the heat flows may be presented before or after the correction is made;
- the actual indoor temperature can be dealt with, e.g.:
  . directly by a somehow well-adapted input value as a basis for the calculation;
  . by a correction on the transmission and ventilation heat flows; again, the heat flows may be presented before or after the correction is made;
  . implicitly via the utilization factor for the heat gains;

- the overheating effect from internal heat sources can be taken into account, e.g.:
  - . by a utilization factor on the corresponding heat flows; here again the heat flows may be presented before or after the correction is made;
  - . via the utilization factor for the solar heat gains; in this case the internal heat sources are assumed to be fully utilized;
  - . by forgetting the internal heat sources in the thermal balance and introducing instead a correction factor on the heat losses (e.g. degree day methods); these heat losses may also be presented either before or after this correction is made;
- the overheating effect from solar heat gains can be dealt with in similar ways, e.g.:
  - . by a separate utilization factor;
  - . it may contain implicitly an extra correction for the utilization of the internal heat sources;
  - . the solar heat gains could be forgotten in the heat balance and taken into account by a correction factor on the heat losses.

ad 2, deviations from the specifications

Some of the models require explicitly that specific conditions are assumed, which then may deviate from the specifications here.

Moreover, in most models a number of implicit assumptions are used which limits the validity of the method to e.g. a specific climate or building type or a specific pattern of occupants' behaviour.

Also, in some cases it appeared that the values from the specifications had been replaced by known 'real' values, e.g. for the ground temperature.

6. PRELIMINARY CONCLUSIONS

From the first results preliminary conclusions were drawn.
None of the 10 calculation cases met all the validity restrictions of all the methods. This has to be taken into account when comparing results.
It would, however, be very interesting when results could be compared which at least did not suffer from differences in definition or (unnecessary) differences in specifications. This means that the procedure of each method has to be investigated step by step to see where sources for deviation appear.
Therefore, it was decided to set up a detailed comparison of the calculation procedures.
Furthermore, only 1 calculation case was selected for a detailed analysis.
The selected case is a masonry type dwelling with continuous heating in the Lugano climate (see appendix 2).

7. COMPARISON OF CALCULATION PROCEDURES

7.1 Description of methods

From each method involved in the comparison a detailed description was requested. These descriptions have been processed to make quick comparison possible. The processing concerns mainly the symbols used to identify correction factors, heat flows, a.s. and some schematization of the calculation procedure.

This implies that the symbols and the calculation procedures presented in this report may deviate from the original description of the method. For the original symbols and the calculation procedures the reader is referred to the corresponding literature.

The following symbols are introduced for the uniform presentation of the descriptions:

HD : annual heat demand (MJ/year)
T^* : specific heat loss by transmission = Σ U.A, unless otherwise specified (W/K)
T : heat loss by transmission (MJ)
V^* : specific heat loss by ventilation (W/K)
V : heat loss by ventilation (MJ)
I : internal heat gains (MJ)
S : transmitted solar energy (MJ)
U : thermal transmittance or U-value (W/m^2K)
g : (total) solar energy transmission coefficient (-)

DD : degree days = $\sum_k (\bar{T}_i - \bar{T}_e)$,

for all days k over the considered period with $\bar{T}_e < T_b$ (K.days/period)

$\bar{T}_e$: average outdoor temperature (°C);

T_b : base temperature (°C).

c : coefficient (-)

"Temperature without heating"-method (TWH)

Timestep : Month.

Procedure :

$$\boxed{HD = (T^* + V^*)\ DD\ .\ 0.0864 - I - c_s\ (T^* + V^*)}$$

This formula has resulted from mathematical operations on the original equations.
The original method is:

$$Q = 0.024\ (\bar{U}\ .\ A + 0.34\ n\ V)\ \Sigma\ (T_{NH} - T_{WH})\quad (kWh)$$

where:

T_{WH} = temperature without heating (°C)

$$T_{WH} = T_e + \frac{\text{solar gains}}{\bar{U}\ .\ A + 0.34\ nV}$$

T_{WH} is an indiciation of the temperature to be found in an unheated house without internal gains.

T_{NH} = temperature of no heating (°C)

$$T_{HN} = T_i - \frac{\text{solar gains}}{\bar{U}\ .\ A + 0.34\ nV}$$

T_{NH} is an indication of the temperature level which the heating system must realise in case there are no internal heat gains.

Σ = monthly sommation over the heating period.

For the solar gains (W), two factors are used which we call here c_{s1} and c_{s2}:

$$\underline{c_s = c_{s1} \cdot c_{s2}}$$

with c_{s1}: factor for cloudness (montly table value);

c_{s2}: solar recuperation factor of the building = the function of the ratio of solar gains and heat losses;

Example of values : --.

Remarks : Table values adapted for the given Lugano climate.

Use of the method : In the Wallonian building regulations (recuperation factor).

References : (1).

k-eff (effective U-value)

Timestep : Season.

Procedure : $\boxed{HD = (T^* + V^*) \cdot DD \cdot 0.0864 - I}$

with T^*: specific loss with U-window corrected for solar gain: U-effective,

$$U_{eff} = U_w (1 - D) - S_F \cdot g \qquad (W/(m^2.K))$$

U_w	: U-value window	$(W/(m^2.K))$
D	: cover factor (concerning temporary insulation), depends on U_{w+t}/U	(-)
U_{w+t}	: U-value of window including temporary insulation	$(W/(m^2.K))$
S_F	: solar gain coefficient, including utilization	$(W/(m^2.K))$
g	: total solar energy transmission coefficient	(-)
V^*	: specific loss;	
DD	: $\bar{T}_i = 20\,°C$, $T_b = 15\,°C$, Sept. 1 - May 31.	

Example of values : Double glazing south U-eff = $3.2 - S_{F,S} \times 0.7$
north U-eff = $3.2 - S_{F,N} \times 0.7$,
for instance: Germany $S_{F,S} = 2.4$; $S_{F,N} = 1.2$.

Remarks : Values for cases with night set-back. Therefore, no influence of heat storage capacity on the heat demand.

The coefficient S_F has been derived from detailed calculations with climate data from Germany.

The presented coefficient values are only valid for this and similar climates.

Use of the method : Recommendation and Design tool for architects mainly.

References : (2).

TPD-method

Timestep : Season.

Procedure :

$$\boxed{\begin{array}{l} HD = (c_t.T^* + c_{vn}.V^*_n + c_{vm}.V^*_m).DD \;.\; 0.0864 - \\ \quad c_I.I - c_s.S \end{array}}$$

DD: $\bar{T}_i$ = set value, also in case of night setback;
deviations are taken care of by coefficients;
DD for all hours from Oct. 1 - Apr. 30;
shorter heating season is taken care of by coefficients:
index n: natural (24 hrs.) ventilation;
index m: mechanical or periodical ventilation;

c_t, c_{vn}, c_{vm}: for dwellings same values;
c_i, c_s : for dwellings same values;
c_t, ... c_s : function of mass and indoor temperature regulation (table values).

Example of values : For continuous heating: $c_t = c_{vn} = 0.82$;
$c_i = c_s = 0.63$, but see remarks.

Remarks : Derived from detailed calculations; specifically developed to include use of blinds, curtains, etc. by subdividing each day; coefficients only valid for De Bilt.

Use of the method : As design tool and in guidelines, both for heat demand and for net heat gain through windows.

References : (3), (4), (5).

EFB1

Timestep : Month.

Procedure :

$$\boxed{HD = HD^{-} + c_{H1}\ (HD^{+} - HD^{-})}$$

with c_{H1} : function of mass (accumulation factor; table values).

HD^{-}: heat demand for high mass building (min. HD).

HD^{+}: heat demand for low mass building (max. HD).

$$\underline{HD^{-} = (T^* + V^*) \ . \ DD.0.0864 - I - S}$$

with DD: $\bar{T}_i$ = set value; in case of night set-back; estimated value of real night temperature.

$$\underline{HD^{+} = HD^{L} - c_{H2} \ . \ I} \ ,$$

with c_{H2}: as function of I/HD^{L} (formula).

$$\underline{HD^{L} = (T^* + V^*).DD.0.0864 - c_{H3}.S} \ ,$$

with c_{H3}: function of $S/(T^* + V^*)$.

Example of values : Lugano case: $c_{H1} = 0.45$; March: $c_{H2} = 0.82$, $c_{H3} = 0.69$, but see remarks.

Remarks : Derived from detailed calculations; the method is developed for the Scandinavian climate with short periods of sun. The utilization factor for solar radiation is low. It is mostly used for dwellings but can be used on other building types with minor modifications. The utilization factor is too low (so HD too high) for Lugano.

Use of methods : As a design tool. In Denmark it is used for calculation of energy consumption in low energy houses. Low energy consumption is required when gas is available but other fuel is used. It is used by engineering firms and architects in Denmark.

References : (6), (7).

SIA 180/3

Timestep : Season.

Procedure : $\boxed{HD = (T^* + V^*) \cdot DD \cdot 13.10^{-3}}$

with $T^* = \bar{U} \cdot A$: specific transmission heat losses W/K

$\bar{U}$ = average U-value of the envelope (as defined in SIA 180/1).

For windows the solar gains are not calculated, however a correction factor gives a smaller penalty to favourably oriented windows:

$$U_w^c = U_w \cdot S'$$

U_w^c = corrected window U-value $[W/m^2K]$

U_w = standard U-value $[W/m^2K]$

S' = correction factor depending on the window orientation

$V^* = 0.2 \cdot V'$: specific ventilation heat losses $[W/K]$

This formula refers to an average air change of 0.75 $[h^{-1}]$. For specific cases it may be modified.

V' = heated volume $[m^3]$ (as defined in SIA 180/1).

$DD \times 13 \times 10^{-3}$: climatic factor $[K.h.10^{-3}]$

The factor 13 represents the daily average number of hours the heating system is on full power. This value was obtained by curve fitting on experimental data.

DD = degree days for $\bar{T}_i$ = 20 °C and T_b = 12 °C.

Example of values : S' = 1 for north, 0.9 for east and west, 0.7 for south.

Remarks : --.

Use of the method : recommendation.

References : (8) and (9).

LESO - A

Timestep : Month.

Procedure : $\boxed{HD \doteq (T^* + V^*) \,.\, DD \,.\, 0.0864 - c_I.I - S}$

with: T^*, V^* specific heat losses $[W/K]$.

c_I = utilization factor ($c_I = 0.70$)

$I = \bar{P} \times N \times 0.0864$

$\bar{P}$ = average power $[W]$;
N = number of days in the current month.

S: solar gains for south, east and west (north neglected).

$$S = \sum_i AF_i \times (1 - f_i) \times \bar{g}_i \times SF_i \times GR_i$$

AF_i = total window area $[m^2]$;
f_i = fraction of frame;
$\bar{g}_i$ = window solar transmission coefficient;
SF_i = shading factor;
GR_i = global solar radiation $[MJ/m^2]$ (for the considered orientation and month).

Remarks : Massive building only, derived from detailed calculations.

Use of the method : Design tool mainly for passive building design.

References : (10).

LESO - SAI

Timesteps : Month.

Procedure : $\boxed{HD = (T^* + V^*) \cdot DD \cdot 0.0864 - I - c_s \cdot S}$

with: T^*, V^*: specific heat losses [W/K]

I : internal gains in [MJ]

$$I = \bar{P} \times N \times 0.0864$$

$\bar{P}$ = average power [W];

N = number of days for the current month.

$c_s \cdot S$: useful solar gains

$$S = \sum_i . AF_i \times (1 - f_i) \times \bar{g}_i \times SF_i \times GR_i$$

(solar gains, sum over all orientations: i).

AF_i = total window area [m^2];

f_i = fraction of frame;

$\bar{g}_i$ = window solar energy transmission coefficient;

GR_i = global solar radiation [MJ/m^2] (for considered orientation and month).

c_s : utilisation factor for solar gains

$$c_s = 1 - \exp. (- 1.94 \times GLR^{-1.66})$$

where: GLR = gain load ratio with load defined as losses minus internal gains.

Example of values : Lugano 1A: mean value: $c_s = 0.92$; March: $c_s = 0.99$.

Remarks : Massive building only, derived from detailed calculations.

Use of the method : Design tool for architects (implemented on a personal computer).

References : --.

Impuls programm

Timestep : Heating season or month.

Procedure : $\boxed{HD = (T^* + V^*) \cdot DD \cdot 0.0864 - c_G \cdot (I + S)}$

with: T^*, V^*: specific heat losses (W/K);
I : internal gains (MJ);
S : solar gains (MJ);
$S = \Sigma\, AF_i \times GR_i \times (1-f_i) \times \bar{g}_i \times 0.85$

AF_i : window area
GR_i : global solar radiation
f_i : frame fraction
$\bar{g}_i$: solar energy transmission coefficient (normal incidence);
0.85 reduction due to perpendicular indicence.

c_G : utilization factor as a function of the gain/loss ratio and type of heating regulation.

Example of values : Lugano 1A: $c_G = 0.85$ (average over the heating season).

Remarks : Calculation procedure given in a handbook for planning retrofits.

Use of the method : Design tool for architects.

References : (11).

Table 1: Summary of the main characteristics of the methods involved.

Method	Country	Internal gain utilisation	Solar gain utilisation	Heat losses correction	Indoor temperatures	Period	Calculation	Origin	Type [1])
TWH	B	1	f (GLR, cloudness) [2])	1	Ti, real	variable (Nov. - April) [3])	monthly	general	DD
k-eff	D	1	Ueq	f (Sf x g)	Ti, set	fixed	season	German data (average climate)	DD
TPO	NL	f (mass, h.mode) (0.63) [3])	f (mass, h.mode) (0.63)	f (mass, h.mode) (0.82)	Ti, set	Oct. - April	season	The Netherlands, night set back, continuous heating, moveable shading and night insulation	HB
EFB1	N	f (mass) (0.55)	f (mass) (0.55)	f (mass, G_1LR, G_2LR) (0.85)	Ti, real	fixed (Oct. - April)	monthly	Scandinavia low energy houses	OC
SIA 180/3	CH	0	Ueq	0.55	20 °C	fixed (Oct. - April)	season	Swiss data	DD
LESO-A	CH	0.7	1	1	Ti, set	variable (Oct. - April)	monthly	massive buildings	HB
LESO-SAI	CH	1	f (GLR) (0.92)	1	Ti, set	variable (Oct. - May)	monthly	massive buildings	HB
IMPULS	CH	f (GLR, regulation) (0.85)	f (GLR, regulation) (0.85)	1	Ti, set	variable (Sept. - May)	monthly	general	HB

[1]) Type: HB = steady-state balance; DD = degree day or corrected degree day; OC = other correlation method.

[2]) GLR is some Gain Load Ratio.

[3]) Values between brackets are examples, valid for the Lugano-case.

7.2 Summary

In table 1 the main characteristics of each method have been summarized.

7.3 Comparison of calculation procedures

In the various models different principles are applied:

chosen time-step:

monthly calculation versus calculation per heating season;

chosen type of corrections:

a. solar gains replaced by some correction on the heat losses, e.g. corrected U-value ("k-eff" method, SIA 180/3) or corrected indoor and/or outdoor temperature (TWH);
b. all gains replaced by some correction on the heat losses (SIA-180/3, TWH);
c. correction coefficient on the solar gains only ("k-eff", LESO-SAI);
d. correction coefficient(-s) on the solar and internal gains (Impuls programm);
e. individual coefficients on each loss and gain term (TPD-method);
f. heat demand as a complex function of gain/loss ratios, etc. (EFB1);

correction parameters:

for some of the methods the correction factors are a function of the gain/loss ratio of the building over the specific timestep; for some models the correction factor (or functions) are only valid for a certain climate, building type and/or inhabitants' behaviour;
for other models some of these can be varied, either continuously, by chosing parameter values in a formula (e.g. mean outdoor temperature, ventilation rate, shading factor) or by selecting relevant table values, functions or curves (e.g. utilization factor).

The different principles do not necessarily lead to different results. For instance, a correction factor for the solar gains (utilization factor) that is inversely proportional with the gain/loss ratio can be transformed mathematically to a set of coefficients which includes the heat loss terms.

Example:

$$HD = T + V - I - c_S . S$$

where $c_S = 0.9 - 0.7 \cdot \left(\frac{S}{T + V}\right)$

can be easily transformed into:

$$HD = c_{TV} \cdot (T + V) - I - S$$

where $c_{TV} = 1 + 0.1 \cdot \left(\frac{S}{T + V}\right) + 0.7 \left(\frac{S}{T + V}\right)^2$

On the other hand, if e.g. the internal heat gains have an assumed utilization factor of 1.0, then the solar gains take all the blame for the "wasted" heat, the heat which is not used to compensate the auxiliary heating. In many cases this means an over-estimation of the internal heat sources at the cost of an under-estimation of the utilization of solar gains.

8. PRESENTATION OF RESULTS FROM A SELECTED CASE (LUGANO)

One case was selected for a more detailed analysis.
The main characteristics are:

dwelling	: single family house in a terrace;
construction	: masonry type;
thermal insulation	: moderately insulated walls and roof; double glazing;
heating mode	: continuous heating;
climate	: a typical heating season for Lugano (CH).

The detailed specifications are presented in appendix 2.

The results are presented in tables 1 and 2.
The main results are shown in a graphical presentation in figures 5-8.

Notes with tables 2-4 and figures 5-8:

The k-eff method could not be applied for the Lugano climate, because so far no solar gain coefficients (S_F) have been derived for this climate.

(*) See descriptions: coefficient values are not adapted to the Lugano climate;
(**) See text for definition;
(^{1}) Value for October 1 - April 30;
(^{2}) Heating season from November 1 - April 30;
(^{3}) Heating season from October 1 - May 31;
(^{4}) Heating season from September 1 - May 31.

Table 2: Net heat demand and useful solar gains. Selected Lugano case; values in MJ.

method	net heat demand			useful solar gains (whole dwelling) over the heating season	idem Oct. thru April
	heating season	January	March		
TWH	25654 (2)	7055	2967	10476 (2)	12843
TPD (*)	28270	← n.a. →		9441	9441
EFB1 (*)	34279 (1)	7485	4544	10440	10440
SIA 180/3	26800	← n.a. →		n.a.	n.a.
LESO-A	29020	7280	3690	9110	9110
LESO-SAI	30680 (3)	7122	3985	12326 (3)	10923
Impuls	27970 (4)	6643	3469	8530 (4)	7636

Notes: See page 35.

Table 3: Heat loss and useful solar gain per unit area of window.
Selected Lugano case, south orientation.

Values in [MJ/m²].

method	heat loss through window (**)				useful solar gain through window (**)			
	heating season	January	March	October	heating season	January	March	October
TWH	653 (2)	144	99	(56)	1012(2)	150	205	(235)
TPD (*)	581	--	--	--	862	--	--	--
EFB1 (*)	712	144	99	56	1047	129	144	151
SIA 180/3	--	--	--	--	--	--	--	--
LESO-A	542	110	75	43	1012	123	164	192
LESO-SAI	--	--	--	--	--	--	--	--
Impuls	748 (4) (709)(1)	144	99	56	751(4) (678)(1)	88	113	114

(*), (1) - (4): See page 35.

(**) : Definition depends on method, see text.

Table 4: Heat loss and useful solar gain per unit window area.
Selected Lugano case, north orientation.

Values in $[\mathrm{MJ/m^2}]$.

method	heat loss through window (**)				useful solar gain through window (**)			
	heating season	January	March	October	heating season	January	March	October
TWH	653 (2)	144	99	(56)	152(2)	16	39	(28)
TPD (*)	581	--	--	--	187	--	--	--
EFB1 (*)	712	144	99	56	195	26	31	24
SIA 180/3	--	--	--	--	-	--	--	--
LESO-A	542	110	75	43	190	21	36	29
LESO-SAI	--	--	--	--	--	--	--	--
Impuls	748 (4) (709)(1)	144	99	56	172(4) (146)(1)	17	28	20

(*), (1) - (4): See page 35.

(**) : Definition depends on method, see text.

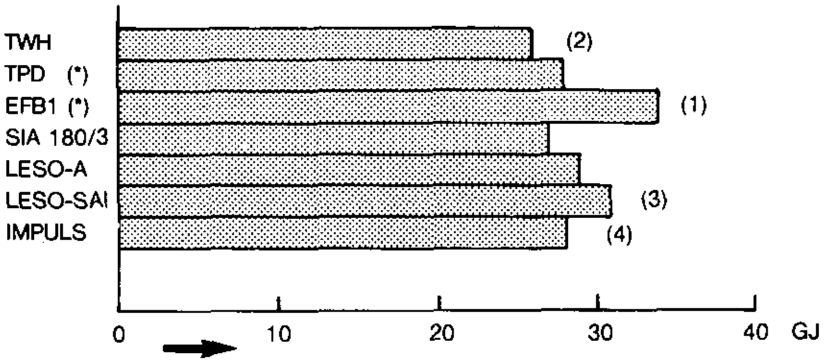

Figure 5a. Annual heat demand.

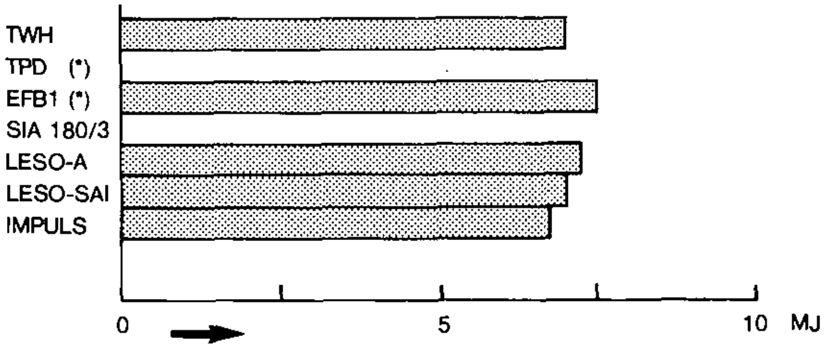

Figure 5b. Heat demand January.

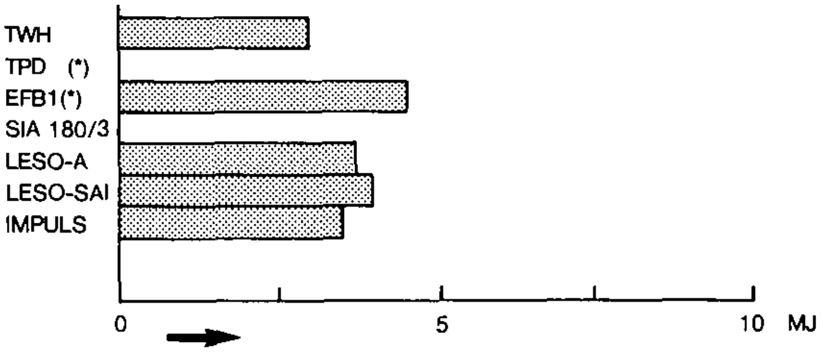

Figure 5c. Heat demand March.

Notes: See page 35.

Figure 5: Comparison of heat demand, selected Lugano case.

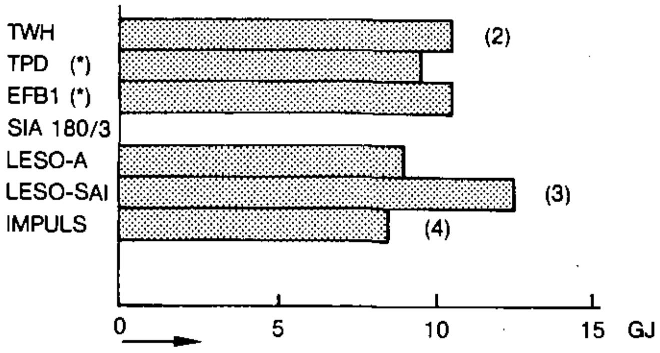

Figure 6a. Useful solar gains over the heating season.

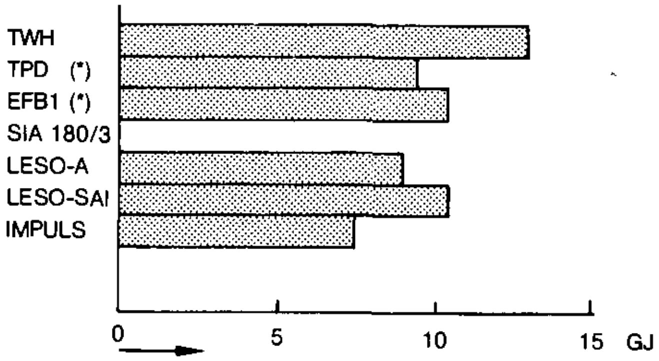

Figure 6b. Idem, for fixed period October 1–April 30.

Notes: See page 35.

Figure 6: Useful solar gains for the dwelling, selected Lugano case.

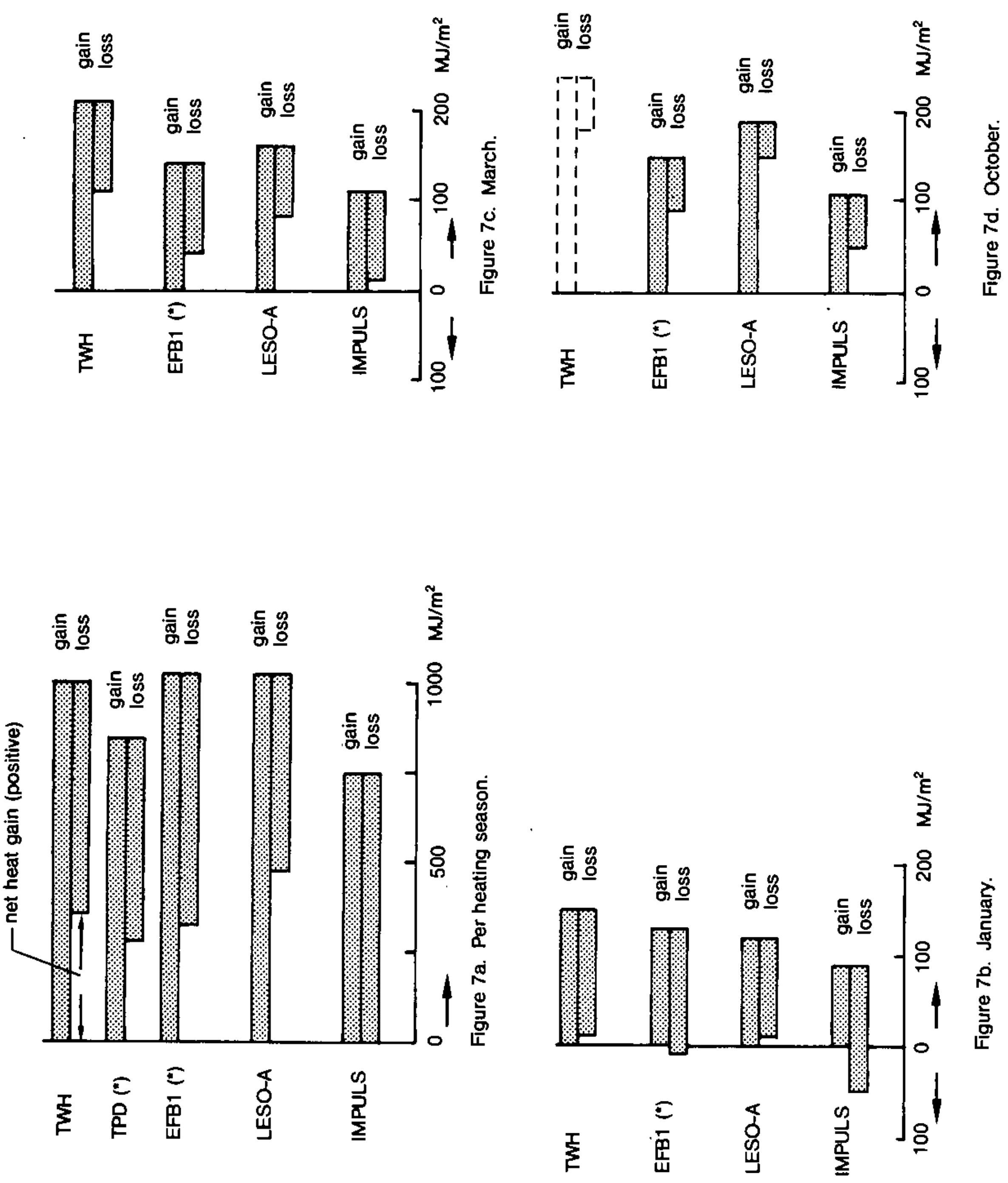

Figure 7a. Per heating season.

Figure 7b. January.

Figure 7c. March.

Figure 7d. October.

Notes: See page 35.

Figure 7: South window, heat loss and useful solar gain per unit of window area; Selected Lugano case.

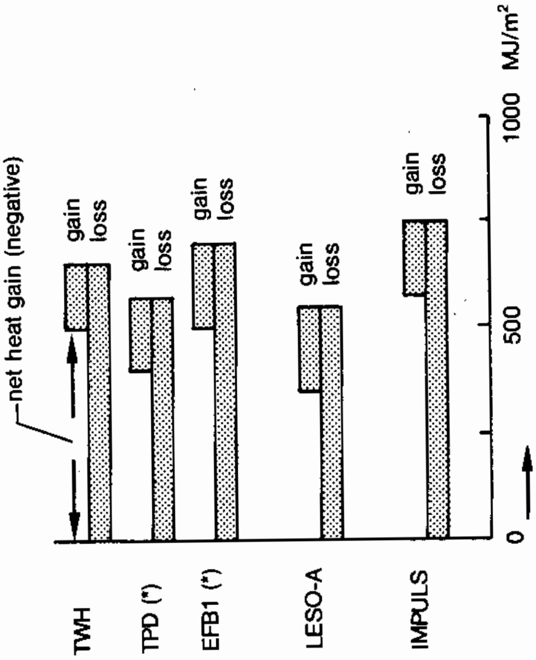

Figure 8a. Per heating season.

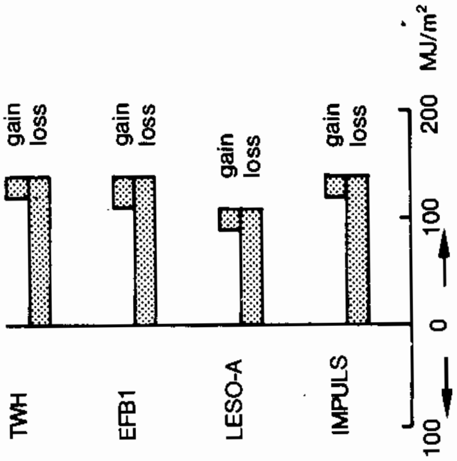

Figure 8b. January.

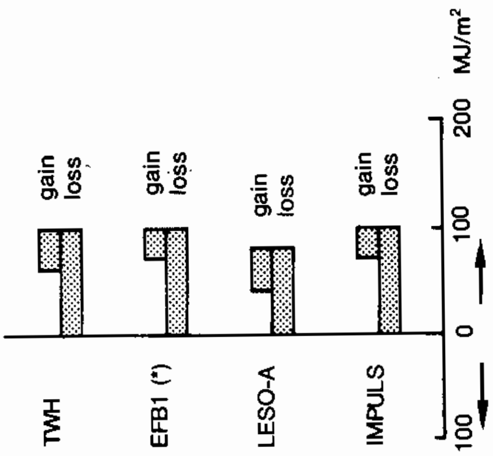

Figure 8c. March.

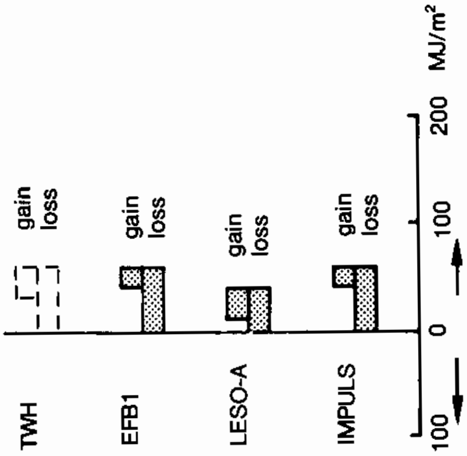

Figure 8d. October.

Notes: See page 35.

Figure 8: North window, heat loss and useful solar gain per unit of window area. Selected Lugano case.

9. DISCUSSION OF THE RESULTS

9.1 Relative importance of relative errors

When discussing the results it should be noted that both heat demand and the net heat flow through a window are in fact differences of two opposing sums of heat flows, the sum of heat losses (e.g. by ventilation and/or transmission) and the sum of heat gains (e.g. by internal sources and/or solar radiation).

In a number of methods presented in this report the subtraction of the opposing heat flows can be recognized explicitly.

This implies that a small relative error in one of the latter heat flows may result in a large relative error in the net result.

For instance for the heat demand the relative error can be derived from:

$$\frac{\Delta QHD}{QHD} = \frac{\sqrt{(\Delta X_L)^2 + (\Delta X_G)^2}}{X_L - X_G}$$

when $QHD = X_L - X_G$, the difference of losses X_L and gains X_G.

When e.g. the losses and gains differ by 30%, a relative error in X_L or X_G turns up roughly three times as high in the net result.

However, in practice, this phenomenon is well-known too:

the actual heat demand in well-insulated houses often shows extreme fluctuations in relative terms, due to e.g. variations in occupants' behaviour.

9.2 Heat demand and useful solar gains

Figure 5 shows that the annual heat demand varies with ± 20 percent around the mean value of the presented results.

As mentioned in the previous paragraph this error is a result of smaller relative errors in the opposing heat loss and gain flows.

In the selected case the ratio of losses and gains over the heating season is roughly 5/2.

For autumn and spring months this ratio is closer to one, in which case the relative error in heat demand - or net heat flow through a window - is even more magnified. In mid-winter the situation is reverse. The results in figure 5 for January and March show this effect: for January the ratio of maximum over minimum available value is 1.1, for March this value is already 1.5.

However, a more precise look at the figure reveals that even in absolute terms the differences in heat demand for March are larger than for January; January contributes about ± 1.5 percent to the uncertainty in annual heat demand, March almost 3 percent.

This is a clear indication that the uncertainty in solar gains plays an important role. In January the useful solar gains compensate for only 10 to 15 percent of the heat losses, in March this figure has increased to roughly 30 percent.

Once again: in the selected case the solar gains are not the predominant factor in the heat balance over the heating season. Therefore, the differences in calculated heat demand are not so large as could be expected in case of a building type with higher thermal insulation level and e.g. larger window areas.

This means on the one hand that the calculation models for the windows (loss and gain components) are not teased to their limits, on the other hand this also means that the calculated heat gains and losses for the windows are better comparable, because they are less sensitive now to the calculated heat demand.

Figure 6 shows for the whole dwelling (with o.a. a South and a North oriented window) the useful solar gains over the heating season. The length of the heating season differs from one method to another (figure 6a).

The "SIA-180/3" method is not suited for the derivation of the useful solar gains.

The useful solar gains vary ± 20 percent around the mean value.

The differences are somewhat larger when the useful solar gains are considered over the fixed period October 1 - April 30 (figure 6b). This implies that the differences in length of heating season in fact slightly compensate for other deviations.

One principal difficulty in comparing seasonal useful solar gains is the following: in spring or autumn months the heat demand may be low or zero. Some methods delete such months. Other methods do not, and in that case the useful solar gains from these months contribute significantly to the seasonal value, despite the low utilization factor. The increased value for the seasonal useful solar gains does not show that for that particular month about the same amount of heat losses have to be added when calculating the heat demand.

This problem is solved when the net heat gain is used instead.

9.3 Net heat gain of a window

One could expect to derive the net heat gain of the window by subtracting its heat loss from its solar gains, because the thermal conduct of the windows is an inseparable part of the integral thermal balance of the building, as shown in figure 1.

However, this is not the case.

Two extremes that are relevant options to define the "net heat gain" can be identified .

1. the mean value for a given window area under specific conditions. This value is equal to the difference in heat demand with and heat demand without the specific window, divided by the window area. For many models this value can be found by actually calculating the heat demand with and without the window. For other models, however, with the calculation of heat demand with "no window" violates the validity restrictions.

2. the marginal value for a given window area under specific conditions. This value is equal to the difference in heat demand with the specific window with increased area A_w + dA_w (dA_w small) and heat demand with the window with given area A_w, divided by dA_w.
   For all calculation methods it should be possible to derive this value by comparing two heat demands calculated as described.

Usually - and also in this report - the net heat gain according to the first definition is used, although too often the absence of a clear definition gives room for confusion.

Figures 7 and 8 present the net heat gain for the south respectively north facing window for the selected Lugano case, as a net result of two opposing heat flows.
Figure 7 clearly shows that the net heat gain for the south oriented window is extremely sensitive to the chosen method.
The north window, figure 8, shows significantly less variation, although the ratio between minimum and maximum value is still 1.60.
One evident reason for the differences in net heat gain for the south window being so large is, that the values are a relatively small difference of two relatively large flows. Nevertheless, the differences are too large for even a global impression of the effect of windows on the energy consumption for space heating.

10. CONCLUSIONS AND RECOMMENDATIONS

A limited number of simplified models have been compared in the way they deal with the effect of the heat losses and solar gains through windows on the energy consumption for space heating.

From first results out of 10 calculation cases it appeared that:
- there was no case which fulfilled all validity restrictions of all the methods. This had to be taken into account when comparing results;
- the results showed a very wide scatter. It appeared that the definitions for the various types of heat flows differed from one method to another and that the specifications for the calculation cases were not always met;
- for these reasons two measures were taken:
  1. a detailed comparison of the calculation procedures was started;
  2. only one calculation case was selected for further, detailed, analysis.

The results from the selected case showed:

- Variations in the heat demand are in the order of ± 20 percent around the mean value of the presented results.
  Differences are due to the following factors:
  - for some methods the coefficient values are not available for the Lugano climate in which case values valid for other climates have been used;
  - for some methods specific conditions are assumed or required which deviate from the given specifications for the selected calculation case;
    the validity of most methods is also restricted by implicit assumptions concerning climate (see above), building type or occupants' behaviour;
  - the influence of corrections for unsteady state effects, e.g. the actual length of the heating season and the amount of overheating by the solar radiation, differs from one method to another;

  - because in the selected calculation case the solar gains are not dominant in the thermal balance it is expected, that the differences in heat demand will be much larger in cases with higher insulation levels and e.g. larger window areas;

- The seasonal useful solar gain is very sensitive to the assumed or calculated duration of the heating period. Although an extra month late in spring or early in autumn has a low utilization factor for the solar gains, the total seasonal gains may still be increased significantly. The useful solar gains do not show that at the same time extra heat losses are introduced in the calculation of the heat demand which are compensated by these extra gains.

- The net heat gain of a window is - if properly defined - an effective way to quantify the effect of a window on the energy consumption for space heating in a certain situation.
  Only some methods provide this quantity explicitly.
  Discrepancies in the net heat gain are very large for the south oriented window and still large for the north facing window, though less dramatic.
  Obviously, the discrepancies are blown up to high values for south orientation due to the fact that the net gain then is the subtraction of two opposing relatively large heat flows.
  The sources for deviation are the same as described above for the heat demand.
  In particular, however, the influence is felt from the way in which corrections for phenomena like the actual length of the heating season and the amount of overheating by solar radiation are taken into account (unsteady state effects).
  The various models are based on different principles in this respect. This, however, does not automatically mean that the results are of a different kind, because sometimes a mathematical transformation is possible.
  In other cases, however, the kind of results are incomparable; e.g. the internal heat gains have an assumed correction (= utilization) factor of 1.0; this means that the solar gains take all the blame for the "wasted" heat. In many conditions this means an over-estimation of the utilization of the internal heat sources at the cost of an under-estimation of the utilization ("efficiency") of solar gains.

- With selected sensitivity studies with an unsteady state model the various effects can be quantified. Most of the models described have indeed been derived by correlation techniques using results from parameter calculations with a complex computer model.

- A monthly heat balance is preferred over a balance per heating season;
  the validation of the model or fitting of the coefficients can be carried out with higher accuracy, because a multitude of data is available, with strongly varying conditions;
  this also implies that the model is less strictly bound to a specific climate: some climate variations, namely variations over the heating season, are available to create or validate the model.
  A much shorter period is advised against, at least for heavy weight buildings, because heat accumulated in one period might be released in the following period, the so-called "carry-over" effect.

- The coefficients (utilization factors) are likely to depend on dwelling type (e.g. mass) and heating installation (type of control!). The coefficients are also some kind of function of the (monthly) gain/loss ratio of the dwelling under consideration. Already some of the methods described use this ratio as parameter.

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APPENDIX 1

PARTICIPANTS

The following participants were involved in this part of the research project:

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APPENDIX 2

DETAILED SPECIFICATIONS OF THE SELECTED LUGANO CASE

GENERAL CHARACTERISTICS:

Single family house in a row,
masonry type, 24 hours heating

- width : 6.0 m
- depth : 8.0 m
- net volume : 280 m^3
- gross volume : 326 m^3
- heat loss area : 171.4 m^2
- weighted mean U-value: 0.97 W/m^2K
- specific mass : 385 kg/m^3 gross volume.

THERMAL PROPERTIES:

CONSTRUCTION	MATERIAL	AREA (m^2)	U-VALUE (W/m^2K)	THERMAL CAPACITY (MJ/m^2K)	REMARKS
HEAT LOSS AREAS:					
ground floor	concrete	48.0	1.50	0.320	insulation under floor slab; ground temp. under insulation layer = 10 °C
south façade (opaque parts)	masonry cavity wall	23.4	0.68	0.360	insulation in wall cavity
north façade (opaque parts)	masonry cavity wall	23.4	0.68	0.360	insulation in wall cavity
south windows	double pane*	9.0	3.20	--	no shading
north windows	double pane*	9.0	3.20	--	no shading
sloping roof	wood + tiles	58.6	0.68	0.033	--
CONSTRUCTIONS WITHOUT HEAT LOSS:					
separation walls (betw.dwellings)	concrete	105.6	1.67	0.360	
intermediate floors	concrete	92.0	1.67	0.320	
internal walls	light concrete	53.0	2.17	0.084	

- Window specification:
  ratio of total solar heat through window
  (short wave + long wave + convective)
  to incident solar radiation = 0.70.

Note: Absorption of solar heat by opaque constructions may be omitted:
if not: use an absorption factor = 0.70 for all surfaces.

CONDITIONS:

Indoor temperature : 19 °C (24 hours, thermostat set point for the whole dwelling).
Infiltration : 230 kg/h (24 hours, no other natural or mechanical ventilation).
Internal heat sources: 625 W (24 hours).

CLIMATE DATA FOR LUGANO:

Monthly average air temperature (°C) and
monthly total solar radiation (MJ/m^2.month).

Latitude 46.00 N	Longitude 8.57 E	Altitude 274 m.											
No. days	total 365	Jan. 31	Feb. 28	Mar. 31	Apr. 30	May 31	June 30	July 31	Aug. 31	Sep. 30	Oct. 31	Nov. 30	Dec. 31
Temperature	11.9	2.2	3.9	7.5	11.5	15.7	19.0	21.4	20.6	17.7	12.5	7.1	3.6
Radiation													
- horizontal	4681	148	216	324	486	605	655	684	580	418	302	148	115
- south	3662	238	274	317	331	317	306	342	367	374	371	223	202
- east/west	2436	83	112	176	248	299	320	324	302	230	184	90	68
- north	1032	47	59	79	104	126	148	140	122	79	65	32	36