Windows and Space Heating Requirements; Parameter studies leading to a simplified calculation method

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pages 22 and 23:

in equations (27) and (29) the expression:

\[ 1 - \frac{\Sigma_{e} A_{e} U_{e}}{A_{t} h_{ri}} \]

should be replaced by:

\[ \left\{ 1 - \frac{\Sigma_{e} A_{e} U_{e}}{A_{t} h_{ri}} \right\} \]

page 50, line 14
page 51, table 13, final three rows \( C_{NWH} = 1 \) should be replaced by
page 64, lines 9 and 13 \( C_{NWH} = 0 \).
INTERNATIONAL ENERGY AGENCY

Energy Conservation in Buildings and Community Systems Programme

Annex XII, WINDOWS AND FENESTRATION

The Netherlands' National Report from Step 5

WINDOWS AND SPACE HEATING REQUIREMENTS
Parameter studies leading to a simplified method
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 participated in the task is given in Appendix I.

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Delft, December 1987
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SUMMARY

The project "Windows and Fenestration" (1983-1986) is one of about 14 projects ("Annexes") of the International Energy Agency (IEA) R&D Programme "Energy Conservation in Buildings and Community Systems". Eight countries participated in this project. Activities were divided into 4 Steps.
Step 5, dealing with calculation series to find the influence of windows on the energy consumption, was carried out in het form of national studies by USA, Switzerland, Germany and the Netherlands. This report documents the activities and results of the Netherlands within Step 5.

The report starts with a brief introduction into the thermal and solar properties of windows and its relation with the heating requirements and energy consumption. This chapter is followed by the presentation of the main terms in the heat balance of a heated space. A method is introduced to calculate by hand monthly heat losses and gains. Simple correction factors have been developed to deal with special situations. Particular attention is given to the influence of various types of window systems.

Correlation factors are proposed to take into account unsteady state effects; the gain utilization factor $\eta_G$ as function of the gain loss ratio $GLR$ and the correction factor for thermostat set-back during night ($G_N$) or during non-office hours ($G_{NWH}$). Furthermore a parameter $dT_R$, the mean relative overheating has been introduced; the latter quantity gives some indication of the overheating due to non-utilized gains.

Novel aspects of the methods compared to other existing methods are:
- the applicability of the method for office buildings without mechanical cooling;
- the applicability of the method in a multi-zone situation with exchange of heat by transmission and/or ventilation between different spaces;
- the rough indication of thermal comfort by the introduction of the relative overheating.
The main limitation of the method in comparison with some of the other methods is that passive solar elements other than "direct gain" fenestration, like collector storage walls have not (yet) been included.

Series of parameter studies using the unsteady state computer model DYWON are reported. The results of these calculations made it possible to quantify the correlation factor mentioned above.

With the correlation factors a simplified calculation method has come available to calculate the space heating requirements for a wide range of situations.

The method received the name TCM-heat (TPD Correlation based on Multizone calculation method to calculate the monthly heating requirements).

The simplified method has been verified against a calculation with DYWON for two complicated multizone situations in a highly insulated dwelling.

Although the selected cases were quite extreme, the agreement in annual heating requirements for the whole dwelling is good.

Some deviation occurs in the distribution over the months and over the zones. The first is due to the fact that for some months the heat demand is the very small difference between the much larger heat losses and almost equal gains; the latter is due to the strong interaction between the zones in a well insulated building.

Finally, examples are presented of one of the possible applications of the method, namely to show the influence of window size, type and orientation on the energy consumption for space heating in a selected number of typical situations.
These examples illustrate that the influence of a change in window size, type or orientation may depend on the actual conditions like for instance climate, type of use of the considered zone, insulation level and also the conditions in the adjacent zones.

With TCM-heat the influence of the window on energy consumption can be calculated "tailor-made" to a particular situation.

Although TCM-heat is basically a hand calculation method, the calculation is inevitably complicated in case of a multizone situation. With the Fortran-version of TCM-heat, however, also complex multizone situations can be dealt with easily.
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 arrangement.

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 contributions 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 analyse existing simplified steady-state calculation methods dealing with 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 at 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.

This publication is the result of the activities by the Dutch participant within the framework of Step 5.
**TERMINOLOGY AND SYMBOLS**

<table>
<thead>
<tr>
<th>symbol</th>
<th>unit</th>
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<tbody>
<tr>
<td>$Q$</td>
<td>$J^*$</td>
</tr>
<tr>
<td>$\phi$</td>
<td>$W$</td>
</tr>
<tr>
<td>$q$</td>
<td>$W/m^2$</td>
</tr>
<tr>
<td>$R$</td>
<td>$(m^2.K)/W$</td>
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</tbody>
</table>

- **Heat**: quantity of heat
- **Heat flow rate**: the quantity of heat transferred to or from a system per unit time:
  \[ \phi = \frac{dQ}{dt} \]
- **Density of heat flow rate**: heat flow rate divided by area:
  \[ q = \frac{d\phi}{dA} \]
- **Thermal resistance**: temperature difference divided by the areal density of heat flow rate in the steady state condition:
  \[ R = \frac{T_1 - T_2}{q} \]

**NOTE**: For a plane layer for which the concept of thermal conductivity applies and when this property is constant or linear with temperature:

\[ R = \frac{d}{\lambda} \]

where $d$ is the thickness of the layer.

These definitions assume the definition of two reference temperatures, $T_1$ and $T_2$, and the area through which the density of heat flow rate is uniform.

* Or MJ or kWh; from MJ to kWh: divide value by 3.6.

** This list is, wherever possible, based on ISO draft standard DIS 7345/1 [1].
**Surface coefficient of heat transfer**: density of heat flow rate at a surface in the steady state divided by the temperature difference between that surface and the surroundings:

\[ h = \frac{q}{T_s - T_a} \]

**Thermal transmittance**: the heat flow rate per unit area in the steady state divided by the temperature difference between the surroundings on each side of a system:

\[ U = \frac{\phi}{(T_1 - T_2)A} \]

**Thermodynamic temperature**

\[ T \quad \text{K} \]

**Celsius temperature**

\[ \theta \quad ^\circ \text{C} \]

**Area**

\[ A \quad \text{m}^2 \]

**Volume**

\[ V \quad \text{m}^3 \]

**Overall specific heat loss coefficient**: the sum of heat flow rates by steady state transmission and ventilation divided by the temperature difference between the considered space and the surroundings:

\[ H_L = \sum_j \phi_j/(T_1 - T_j) \]

**Emissivity**: the ratio of the emitted radiant intensity to the radiant intensity emitted by a black body at the same temperature and in the same direction or with the same angular distribution:

\[ \varepsilon \quad -- \]
<table>
<thead>
<tr>
<th>Solar absorptivity: the density of absorbed solar energy in a surface divided by the intensity of incident solar radiation:</th>
</tr>
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<tr>
<td>a</td>
</tr>
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</table>

<p>| Total solar energy transmission coefficient: |
| or: total solar energy transmittance |</p>
<table>
<thead>
<tr>
<th>or: solar factor</th>
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<tbody>
<tr>
<td>g</td>
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<tr>
<td>or: SF</td>
</tr>
</tbody>
</table>

| Gain Loss Ratio: the total heat gains divided by the steady state or minimum heat loss: |
| GLR | -- |

| Utilization factor for gains: the ratio of the utilized gains to the total heat gains: |
| $\eta_G$ | -- |

| Time interval: the length of a considered period, e.g. month: |
| dt | Ms |
SPECIFIC DIMENSIONLESS PARAMETERS AND CORRECTION FACTORS

for the relation $\eta_0^{(GLR)}$ : $K, D$ (defined in chapter 5)
for thermostat setback correction: $C_N, C_{NWH}, F_{WD}$ (chapter 4)
for night insulation : $r, F_{TEN}, F_{TW}$ (chapter 4)
for solar shading : $z, F_Q(j)$ (chapter 4)

SUBSCRIPTS

interior $i$
exterior $e$
surface or sky $s$
interior surface $si$
exterior surface $se$
convection $c$
radiation $r$
ambient or air (!) $a$
setpoint $set$
window $w$
opaque $op$
transmission $T$
ventilation $V$
internal sources $I$
solar $S$
loss $L$
gain $G$
heat demand or heat supply $HD$

INDICES

month $m$
orientation $j$
other zone, space $k$
construction $l$
1. INTRODUCTION

The parameter studies within Step 5 of the IEA research project Annex XII, Windows and Fenestration, were carried out in the form of national studies, in which U.S.A., Switzerland, Germany and the Netherlands are involved. Reference calculation cases and standard variations were specified to optimize the exchange of results. Each involved laboratory further selected the calculation cases on the basis of the national situation. The evaluation of results was carried out also on a national basis. Preliminary results, however, were presented and discussed during the project's experts meetings over the years 1984-1986.

Moreover, the parameter studies were preceded by a comparison of computer programs selected for the calculations (Step 4, [2]) and by a review and analysis of existing simplified steady state calculation methods (Step 3, [3]); the activities within Step 3 resulted in a number of recommendations to be used in the evaluation of the Step 5 results.

This report describes the activities within Step 5 by the Dutch participant in the project.

The report starts with a brief introduction into the thermal and solar properties of windows and its relation with the heating requirements and energy consumption. This chapter is followed by the presentation of the main terms in the heat balance of a heated space. A method is introduced to calculate by hand monthly heat losses and gains. Simple correction factors have been developed to deal with special situations. Particular attention is given to the influence of various types of window systems. Correlation factors are proposed to take into account unsteady state effects.

Series of parameter studies using the unsteady state computer model DYWON are reported. The results of these calculations made it possible to quantify the correlation factors mentioned above.

With the correlation factors a simplified calculation method has come available to calculate the space heating requirements for a wide range of situations.

The simplified method has been verified against a calculation with DYWON for two complicated multi zone situations.
Finally, examples are presented of one of the possible applications of the method, namely to show the influence of window size, type and orientation on the energy consumption for space heating in a selected number of typical situations.

In figure 1 the main contents of the report are presented schematically.
I Development of the simplified method:

- Set-up of expressions for heat demand as function of steady state heat losses and gains and correlation coefficients (3.1-3.6, 4.1-4.3)
  
- Monthly integrated climate data (4.4)
  
- Hourly climate data
  
- Selection of calculation cases with widely varying parameter values (5.1-5.7)
  
- Unsteady state hour by hour computer calculation with DMSN (5.3)
  
- Calculated monthly heat loss and gain (5.8.3)
  
- Correlation procedure (5.8.1-5.8.2)
  
- Simplified method TCH-heat: monthly heat demand as function of heat loss, gain and correlation parameters (5.8.3, 5.9, 6.1-6.2)

II Verification of the simplified method:

- Simplified method TCH-heat
  
- Monthly integrated climate data
  
- Hourly climate data
  
- Hour by hour calculation with DMSN
  
- Selection of two complicated multi zone calculation cases (7.2)
  
- Monthly heat demand (7.4)
  
- Verification of the simplified method TCH-heat (7.5)
  
- Monthly heat demand (7.4)

III Selected sensitivity study using the simplified method:

- Simplified method TCH-heat
  
- Typical monthly climate data
  
- Selection of typical cases for calculation, focussed on windows (8.2)
  
- Annual sum of monthly heat demands (8.3)
  
- Influence of changes in window size, type and orientation for a few selected situations (8.3-8.5)

Figure 1: Schematic survey of the main contents of the report.
2. THERMAL AND SOLAR PROPERTIES OF WINDOWS

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 2. In addition the efficiency of the heating installation plays a role (figure 3).

Figure 2: Apart from the efficiency of the heating installation, the heat balance of a building determines the energy consumption for space heating.

Figure 3: Thermal balance including installation.
The window system accounts for part of the heat losses (transmission) and part of the gains (solar) (figure 4). Moreover, also the ventilation losses could partly be attributed to the window (infiltration).

Figure 4: 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 looking for a method to determine 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:

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

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

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 transferred to the indoor space by infrared radiation and free convection (figure 5).

**Figure 5**: Illustration of the transmission of solar energy through a window.

Within Step 2 of the IEA research project reports have been prepared which deal specifically with the thermal and solar properties of windows ([4], [5], [6]).
3. HEAT BALANCE EQUATIONS FOR SPACE HEATING

3.1 Instantaneous balance

The instantaneous thermal balance for a heated space can be made with the following terms (see also figures 2 and 3):

\[ \phi_{HD} = \phi_L + \phi_{ACC} - \phi_G \]  \hspace{1cm} (W) (1)

where:
- \( \phi_{HD} \) = heat supplied by the heating system (W)
- \( \phi_L \) = heat losses by transmission and ventilation (W)
- \( \phi_{ACC} \) = accumulation of heat into the mass inside or surrounding the space (W)
- \( \phi_G \) = heat gains from internal sources and sun (W)

The terms \( \phi_L \) and \( \phi_{ACC} \) depend on temperature differences.

The accumulation is a complex function of the temperatures within the constructions and the indoor air and mean surface temperatures. The unsteady state effects inside heat loss giving constructions can be considered as accumulation effects; the remaining steady state heat loss can be written as:

\[ \phi_L = H_L (\theta_i - \theta_a) \]  \hspace{1cm} (W) (2)

where:
- \( H_L \) = overall specific heat loss coefficient of room \( i \) (W/K)
- \( \theta_i \) = indoor temperature of the room (°C)
- \( \theta_a \) = ambient temperature (°C)

If during a certain time interval the right hand side of equation (1) tends to become less than zero, then there is no heat demand. In that case the indoor temperature will rise: overheating. The overheating leads to increased loss and accumulation, as equation (2) for the heat loss illustrates. The increase in loss and accumulation continues until an equilibrium is reached.

In an ideal situation the potential for accumulation would be so large that the overheating remains negligible also in case of incidental high gains.
The accumulation also plays another - less beneficial - role: when the thermostat setpoint is set back for the night (dwellings) or e.g. weekend (offices), the heat accumulated during the day is given off to the room, while there is no heat demand; when the thermostat is reset to its higher value in the morning or after the weekend, the heating system must compensate the loss of accumulated heat, unless the sun is already there to take over the role.

3.2 Monthly heat balance

If the terms of equation (1) are integrated over large time intervals, say a month, then the accumulation term becomes negligible: it is a more or less diurnal fluctuation of positive and negative values.

So the monthly heat balance can be written as:

\[ Q_{HD} = Q_{L,real} - Q_G \]  \hspace{1cm} (MJ) (3)

with \( Q_{HD} \), \( Q_{L,real} \) and \( Q_G \) the integrated heat flows (MJ or kWh).

The loss term \( Q_L \) has been provided with the index "real", because the term \( Q_{L,real} \) is the integration of instantaneous losses \( \phi_L \) over all hours, including hours on which \( \phi_L \) is increased due to the overheating described above:

\[ Q_{L,real} = H_L (\bar{\theta}_i,real - \bar{\theta}_a) dt \]  \hspace{1cm} (MJ) (4)

where \( \bar{\theta}_i,real \) = real mean indoor temperature (°C)
\( \bar{\theta}_a \) = mean ambient temperature (°C)
\( dt \) = time interval; \( dt = D \times 24 \times 0.0036 \) MJ

with \( D \) = number of days of the considered period

So part of the gains, integrated in \( Q_G \) have not been used to diminish the heat supply by the system. This unutilized part has led to overheating of the space above the thermostat setpoint level.
3.3 Utilization factor for the gains $\eta_G$ and gain loss ratio GLR

If we define the utilization factor for the gains as the ratio of utilized to total gains, then equation (3) can be written in another - but fully equivalent - way:

$$Q_{HD} = Q_L - \eta_G \cdot Q_G$$ (MJ) (5)

Here, the term $Q_L$ is introduced, being the integrated heat losses in the situation without overheating (low gains or effective accumulation):

$$Q_L = H_L \cdot (\bar{\theta}_{i,\text{min}} - \bar{\theta}_a) \cdot dt$$ (MJ) (6)

with $\bar{\theta}_{i,\text{min}}$ = minimum indoor temperature based on thermostat setpoint (°C).

In case of high gains compared to the losses the monthly heat demand $Q_{HD}$ will become zero; for instance in late spring or early autumn.

If we define the gain loss ratio GLR as:

$$\text{GLR} = \frac{Q_G}{Q_L}$$ (-) (7)

then equation (5) shows that the utilization factor becomes:

for high GLR ($Q_{HD} = 0$): $\eta_G = \frac{1}{\text{GLR}}$ (-) (8a)

We already saw that the utilization factor is a function of mass, now we see it is also a function of the value of GLR in a particular situation.

In case of low gain loss ratio GLR it can be expected that the gains will never lead to overheating, so in that case:

for low GLR: $\eta_G = 1$ (-) (8b)
Thus the shape of the utilization factor as a function of GLR in an ideal situation will be:

\[
\eta_G = \begin{cases} 
1 & \text{for } \text{GLR} \leq 1 \\
\frac{1}{\text{GLR}} & \text{for } \text{GLR} \geq 1
\end{cases}
\]  

(9)

For any real situation \( \eta_G \) will have lower values in the intermediate region of GLR values.

See figure 6.

![Graph showing the utilization factor \( \eta_G \) in ideal and real situations as a function of GLR.]

**Figure 6:** The utilization factor \( \eta_G \) in the ideal and in a real situation as a function of the gain loss ratio GLR.

3.4 Unsteady state calculations and simplified method

One of the major aims of the series of unsteady state computer calculations is to quantify the \( \eta_G \)-functions for various categories of situations. With a known \( \eta_G \)-function the heating requirements can be calculated by hand for a wide range of situations using equation (5).

In the next chapter the procedure to determine \( Q_L \) and \( Q_G \) will be described.

As a time interval for the derivation of the utilization factor and thus also for the application of the simplified method one month has been selected (offices: 4 weeks).

This period is long enough to avoid too much "carry-over" of heat from one period to the next due to the accumulation.
On the other hand, a month is short enough to provide the distribution of heating requirements or solar gains over the year and to determine the actual length of the heating season. The direct use of monthly results could, however, be subject for discussion, because the monthly results will inevitably suffer from larger inaccuracies than the integrated results over all months of the heating season, as the results of the correlations presented in chapter 5 will show.

Finally, by the monthly approach each selected case will provide about 7 monthly results, with as much different values of the gain loss ratio. This is a much better basis for curve fitting of the utilization factor versus gain loss ratio than the single result in case the whole heating season is integrated. In the latter approach the outdoor climate (weather) is no varying parameter, thus the results cannot be transferred to other climate or weather conditions. Of course, for a one climate situation the annual approach can be very useful, with a minimum of computations to be carried out: see for instance the TPD-method described in [3], [13] and [14] and used also in the publications [15] and [16].

3.5 Utilization of gains versus overheating

The equivalence of equations (3) and (5) leads to the following observation:
the real heat losses are higher than the heat losses without overheating. The ratio between both losses quantifies the increase in temperature difference between the considered room and the ambient to which the transmission and ventilation heat flows.
If we define the mean ambient temperature as experienced by the room as $\bar{\theta}_a$, then the ratio of $Q_{L,\text{real}}$ to $Q_L$ can be defined as the mean relative overheating $d_{TR}$, with:

$$\frac{\bar{\theta}_i,\text{real} - \bar{\theta}_a}{\bar{\theta}_i,\text{min} - \bar{\theta}_a}$$

$$d_{TR}$$
where: $dT_R$ = mean relative overheating of room $i$ (-)

$\tilde{\theta}_{i,\text{real}}$ = monthly mean real indoor temperature (°C)

$\tilde{\theta}_{i,\text{min}}$ = monthly mean indoor temperature in case of no overheating (°C)

$\tilde{\theta}_a$ = monthly mean ambient temperature experienced by the room (°C)

N.B. if the room has only losses to outside: $\tilde{\theta}_a = \tilde{\theta}_e$, the outdoor temperature.

The absolute overheating $dT_A$ can be defined as:

$$dT_A = (\tilde{\theta}_{i,\text{real}} - \tilde{\theta}_{i,\text{min}})$$

(°C) (11)

It can easily be shown that the relative overheating can directly be calculated when $\eta_G$ and $\eta_G$ are known:

$$dT_R = 1 + (1 - \eta_G).GLR$$

(-) (12)

or, substituting the definitions for $\eta_G$ and GLR, it can be expressed as a function of $Q_{HD}$, $Q_G$ and $Q_L$:

$$dT_R = (Q_G + Q_{HD})/Q_L$$

(-) (13)

The absolute overheating can be calculated with:

$$dT_A = \frac{(1 - \eta_G).Q_G}{H_L.dt}$$

(°C) (14)

or expressed as:

$$dT_A = (dT_R - 1). (\tilde{\theta}_{i,\text{min}} - \tilde{\theta}_a)$$

(°C) (15)

The values for $dT_R$ or $dT_A$ give some quantitative information about the discomfort due to overheating and thus of the need to take measures against it.

Of course it is only a mean monthly temperature indication without any information concerning peak temperatures.
Note, that for $\eta_G = 1$ there is no overheating ($dT_R = 1$ and $dT_A = 0^\circ C$).

The advantage of $dT_R$ over $dT_A$ is that it can be presented like the utilization factor as a function of the gain loss ratio only, for any category of situations for which an $\eta_G$ (GLR) function has been determined (equation(12)). The mean overheating in °C ($dT_A$) requires more specific information about the situation, like the overall specific heat loss coefficient or the mean ambient temperature (equations (14) and (15)).

3.6 Literature

Approaches more or less similar to the utilization factor/gain loss ratio approach described in section 3.3 can be found in other publications proposing or describing simplified calculation methods for space heating requirements. For instance proposals in ISO [7] and "Eurocode" [8], descriptions by Barakat [9], [10] and in the method 5000 [11]. See section 5.8.2 for some detailed comparison with these other methods.

Other approaches are also based on correlations between series of unsteady state calculations and steady state equations, but with different types of correlation coefficients. For instance the ASHRAE/Los Alamos method [11] uses the "solar savings fraction" (SSF) in combination with the "solar-load ratio" (SLR) instead of utilization factor and GLR. The value of SSF determines the fraction of the losses which are compensated by the solar energy. The Los Alamos approach has its origin in active solar energy systems. This led to a decoupling of the solar element from the building, which makes the method unnecessarily complicated and less transparent than the methods mentioned above.

The main novel aspects of the method presented in this report are:
- the special attention for widely varying types of window systems, with movable shading and insulation provisions;
- the possibility to assume thermostat night setback;
- the applicability of the method for office buildings without mechanical cooling;
- the applicability of the method in a multi-zone situation with exchange of heat by transmission and/or ventilation between different spaces;
- the rough indication of thermal comfort by the introduction of the relative overheating.

The main limitation of the method in comparison with some of the other methods is that passive solar elements other than "direct gain" fenestration, like collector storage walls have not (yet) been included.
4. DETERMINATION OF THE ELEMENTS OF THE THERMAL BALANCE

4.1 Heat losses

4.1.1 Main equations

For each month or 4 weeks period:
the heat loss for no gain situation:

\[ Q_L = Q_{T,W} + Q_{T,OP} + Q_V \]  \hspace{1cm} (MJ) (16)

With:
heat transmission through windows:

\[ Q_{T,W} = A_W U_W (\bar{\theta}_{i,min} - \bar{\theta}_e) dt \]  \hspace{1cm} (MJ) (17)

where \( A_W \) : window area (m²);
\( U_W \) : window U-value (W/m²K);
\( \bar{\theta}_{i,min} \) : mean minimum indoor temperature (°C);
\( \bar{\theta}_e \) : mean outdoor temperature (°C)
or temperature of adjacent space.

The values for \( A_W, U_W \) are to be found in the building specifications; in case of night insulation: see section 4.1.3.
The value for \( \bar{\theta}_{i,min} \) is the thermostat setpoint; in case of a thermostat setback a downward correction is needed, see section 4.1.2.
The values for \( \bar{\theta}_e \) and dt can be derived from climate data, see for De Bilt and other Dutch locations section 4.4.

Heat transmission through opaque constructions:

\[ Q_{T,OP} = A_{OP} U_{OP} (\bar{\theta}_{i,min} - \bar{\theta}_e) dt \]  \hspace{1cm} (MJ) (18)

where \( A_{OP} \) : area of the opaque construction (m²);
\( U_{OP} \) : construction U-value (W/m²K).
The values for $A_{OP}$, $U_{OP}$ are to be found in the building specifications.

N.B.: Sometimes an individual heat loss component is negative; for instance the positive heat flow to (thus negative heat loss from) a North room through the partition wall separating the room from a South zone. These negative heat losses then lead to a lower sum of heat losses according to equation (16). Negative losses should not be regarded as part of the gains, because they respond to changes in temperatures like the positive losses and unlike the solar or internal gains.

Ventilation heat loss:

$$Q_v = 0.336 \cdot V \cdot (\bar{\theta}_{i,\text{min}} - \bar{\theta}_e) \cdot dt$$

(MJ) (19)

Where: $\bar{V}$: mean ventilation rate ($\text{m}^3/$h).

The value for $\bar{V}$ is the assumed sum of infiltration and ventilation. The factor 0.336 is the thermal capacity of air ($\text{J/m}^3$) divided by 3600 (s/h).

N.B.1: Only air flow from outside or from another indoor space have to be taken into account.

N.B.2: In case the ventilation pattern shows a significantly uneven distribution over the day, equation (19) should be calculated for each part of the day separately, on the basis of $\theta_{i,\text{min}}$, $dt$ and $\theta_e$ (if available) for that part of the day. This is for instance the case in office buildings where mechanical ventilation is used only during the office hours when $\theta_{i,\text{min}}$ is high (and the outdoor temperature somewhat higher than the average value).
4.1.2 Correction for thermostat setback

a. Dwellings

For dwellings a parameter, $C_N$, has been defined which makes it possible to correct the mean minimum indoor temperature in case of a night set back of the thermostat. For offices a similar parameter, $C_{NWH}$, has been defined to take into account the thermostat setback during the non working hours and the weekends. The value of $C_N$ and $C_{NWH}$ respectively is to be derived in the correlation process together with the $n_G$ (GLR) function (see chapter 5).

For the night setback in dwellings the following correction is introduced:

$$\bar{\theta}_{i,\text{min}} = C_N \cdot \theta_{i,\text{set, day}} + (1 - C_N) \cdot \bar{\theta}_e$$  \hfill (°C) (20)

where: $\theta_{i,\text{set, day}}$: the daytime (mean daytime and evening) thermostat setpoint (°C).

N.B.: the temperature $\theta_e$ is the real mean outdoor temperature, also in multi-zone situations in which one could be tempted to replacing $\theta_e$ by the mean ambient temperature $\theta_a$ as experienced by the room. See for a more extensively discussion on the night setback correction the last part of this section.

b. Offices

For the setback before and after the working hours and during the weekends in offices another correction formula is introduced:

$$\bar{\theta}_{i,\text{min}} = (F_{\text{WH}} + (1 - F_{\text{WH}}) \cdot C_{\text{NWH}}) \cdot \theta_{i,\text{set, WH}} + (1 - F_{\text{WH}}) \cdot (1 - C_{\text{NWH}}) \cdot \theta_{i,\text{set, NWH}}$$  \hfill (°C) (21)
where: $F_{\text{WH}}^T$: ratio of "degree hours" over the working hours to the "degree hours" over all hours of the considered period. See equation (22);

$\theta_{i,\text{set,WH}}$: thermostat setpoint during working hours (°C);

$\theta_{i,\text{set,NWH}}$: idem, non working hours (°C).

The term $F_{\text{WH}}^T$ can be derived from hourly climate data, from:

$$F_{\text{WH}}^T = \frac{\sum_{\text{WH}} (\theta_{i,\text{set,WH}} - \theta_e)}{\sum_{\text{all hrs}} (\theta_{i,\text{set,WH}} - \theta_e)} (-) (22)$$

The value for $F_{\text{WH}}^T$ can be found in the tables of section 4.4 for the Dutch climate.

For both $C_N$ and $C_{\text{NWH}}$ goes, that the value ranges between 1 and 0.

A value 1 means that $\theta_{i,\text{min}}$ is equal to the high thermostat setpoint;

A value 0 means the strongest possible drop in temperature.

The difference in approach between dwellings and offices originates from the fact that for typical situations in dwellings the nightly (low) setpoint is hardly ever reached, so the temperature drop during the night can not be considered as a function of this non-active setpoint.

For offices, the setback periods are longer: evenings and weekends are within the set back regime. The lower setpoint will be reached often, particularly for the no gain situation. Remember that overheating by gains is treated separately via de term $dT_A$ (e.g. equation (15)). The lower setpoint is therefore a decisive parameter for offices.
c. Discussion on adequacy of the correction factor: dwellings

If the thermostat in a dwelling is set back for eight hours from 20°C to 15°C then it can easily be calculated that the minimum value of the correction factor $C_N$ in case of monthly mean outdoor temperatures between 0 and 10°C ranges from 0.92 to 0.83. The real value will be significantly higher because in many situations the lower setpoint will not be reached, and certainly not during the first hours after the setback.

The $C_N$-value to be derived by correlation (chapter 5) is supposed to be a constant value for a whole category of situations. The category is mainly defined by type of building (dwelling), thermal mass category (heavy versus light weight) and type of heating system and control. It is expected that a more refined approach could lead only to a marginal improvement of the accuracy, with the risk that the parameter values then found by correlation are too much disturbed by other second order effects.

In theory, however, the temperature drop after the setback of the thermostat is a function of the thermal losses and the thermal capacity of the considered building zone. The thermal capacity is taken into account by allowing different $C_N$-values for the different categories of situations. The losses are not taken into account in $C_N$.

N.B. The gains play no role, because possible overheating by gains is superposed separately (see e.g. equation (12)).

The following equation can be derived:

$$C^*_N = 1 - \sigma \frac{H_L}{C}$$

(-) (23)

where: $C$: is the overall thermal capacity of the room (J/K);
N.B. in fact only the effective capacity: that part of the mass in which a diurnal temperature swing can penetrate;
\( \alpha \): is a proportionality constant (s); its value depends mainly on the length of the setback interval and on the shape of the temperature decrease (e.g. whether the nightly setpoint is reached or the temperature usually remains significantly above the setpoint); a typical value for \( \alpha \) is e.g. \( \alpha = 5000 \) s.

The symbol \( C^*_N \) is used instead of \( C_N \) because \( C_N \) is a correction based on \( (\theta_{i, \text{set}, \text{day}} - \theta_e) \) with \( \theta_e \) the monthly mean outdoor temperature, while \( C^*_N \) is a correction based on \( (\theta_{i, \text{set}, \text{day}} - \theta_a) \) with \( \theta_a \) the weighted mean ambient temperature which in a multi-zone situation may be different from \( \theta_e \).

So, for special cases it could be considered in the future to try to find the best fitting \( \alpha \)-value (equation (23)) by correlation and to use instead of \( C_N \) the correction factor \( C^*_N \). One should however not forget that the values for \( C_N \) or \( C^*_N \) will be within the range of 0.90-1.00, so any refinement in the correction would only have a very limited effect on the result.

### 4.1.3 Correction for night insulation

In case of movable night insulation applied on windows between sunset and sunrise the thermal transmission coefficient \( U_w \) in equation (17) is not a constant value for the whole period. A good approximation of the effect on the transmission is found by defining:

the \( U \)-value reduction factor:

\[
r = \frac{U_w \text{ (with night insulation)}}{U_w \text{ (without night insulation)}}
\]

and:

\[
\frac{\sum_{\text{ev.+night}} (\theta_{i, \text{set}, \text{day}} - \bar{\theta}_e)}{\sum_{\text{all hrs}} (\theta_{i, \text{set}, \text{day}} - \bar{\theta}_e)}
\]
The ratio $FT_{EN}$ can simply be found by once going through all hourly climate values for each month.

The value for $r$ depends of course on the type of window.

The value for $FT_{EN}$ can be found for dwellings for De Bilt and other Dutch locations in the tables of section 4.4 for $\theta_{i,\text{set,day}} = 20\pm 2^\circ\text{C}$; equation (25) is very insensitive for a few degrees different $\theta_{i,\text{set,day}}$.

With these two quantities the heat loss through the window can be corrected for night insulation applied on the window between sunset and sunrise:

$$Q_{T,W}(\text{corrected}) = (1 - (1 - r)FT_{EN})Q_{T,W}(\text{uncorrected}) \text{ (MJ)} \quad (26)$$

### 4.1.4 Correction for cold surfaces

In general the temperatures of the internal surfaces in a room will deviate from the air temperature:

- by absorption of solar heat and radiative heat from internal sources; this is to be taken into account by the gain utilization factor $\eta_G$;
- by cooling off due to transmission: particularly the window will have an internal surface which is in a no gain situation much colder than the indoor air; this, in turn, leads to a radiation exchange with other surfaces in the room which will therefore cool down too.

A heating system with heat supplied partly as radiative heat (radiator panels, floorheating, a.s.) will compensate for these cold surfaces.

A purely convective heating system with a thermostat which senses some mean value of air and surface temperatures will automatically compensate the cold surfaces by supplying extra heat to the air (increased air temperature).

In both cases the setpoints are more or less representative for the temperature that is to be used in the calculation of the heat losses.
However, in case of a convective heating system with a thermostat controlling the indoor air temperature there is no compensation for cold surfaces. With the surfaces significantly colder than the air temperature a calculation of the heat loss based on the air temperature setpoint would overestimate the heat losses. Therefore a correction is introduced.

N.B. In the latter situation the thermal comfort requirements may not have been fulfilled although the heating system is switched off by the thermostat action.

The correction for cold surfaces in case of convective heating and thermostatic control of air temperature amounts:

\[
Q_L(\text{corrected}) = \frac{1 - \sum A_e \cdot U_e}{A_t \cdot h_{ri}} \cdot Q_L(\text{uncorrected}) \quad (\text{MJ}) \quad (27)
\]

where: 
- \( A_e \): area of heat loss giving surface (m²)
- \( U_e \): U-value of heat loss giving surface (W/m²K)
- \( A_t \): total surrounding area of the room (loss giving and not loss giving)
- \( h_{ri} \): radiative heat transfer coefficient at the internal surfaces; \( h_{ri} = 5 \) W/m²K.

Values for \( A_e, U_e, A_t \) are to be found from the building specifications.

4.1.5 Determination of overall specific heat loss coefficient \( H_L \) and mean ambient temperature \( \theta_a \)

For the determination of the mean absolute overheating, \( dT_A \), the value for the overall specific heat loss coefficient, \( H_L \), or the mean ambient temperature, \( \theta_a \), is needed (see equations (14) and (15)).

Later on a procedure will be introduced to use the simplified method in a multi-zone situation (chapter 6).
It will then appear to be useful firstly to calculate $H_L$ and $\theta_a$ and via those to determine $Q_L$, according to equation (6).

$H_L$ can easily be calculated by taking equations (17)-(27) and ignoring the temperature differences and time interval there, so:

$$H_L = \sum_{lw} \{(1 - (1 - r)FT_{EN})A_wU_w\}_{lw} \quad \text{for each window } lw$$

$$+ \sum_{lo} \{A_{OP}U_{OP}\}_{lo} \quad \text{for each opaque construction } lo$$

$$+ \sum_{lv} \{0.336.\theta\}_{lv} \quad \text{for each ventilation opening } lv$$

$$(W/K) \quad (28)$$

In case the special correction for cold surfaces is required (see previous section):

$$H_L \text{ corrected} = \frac{1 - \sum A_{e}U_{e}}{A_{l}h_{ri}} \cdot H_L \text{ uncorrected} \quad (W/K) \quad (29)$$

The mean ambient temperature for the considered zone is equal to the outdoor temperature $\theta_e$ in case all heat exchange takes place to the outside.

Often, this will not be the case, due to heat loss to the ground floor, heat exchange with other rooms, etc. In that case the mean ambient temperature has to be calculated with an equation very similar to equation (28) for $H_L$, but with the addition of the mean temperature in the adjacent space and with the division by the value $H_L$:

$$\theta_a = \frac{1}{H_L} \sum_{lw} \{(1 - (1 - r)FT_{EN})A_wU_w\}_{lw} \quad \text{for each window } lw$$
4.2 Heat gains

4.2.1 Main equations

For each month or 4 weeks period:

the heat gains are:

$$Q_G = Q_I + Q_S$$  \hspace{1cm} (MJ) (30)

with:

internal gains:

$$Q_I = \bar{\phi}_{int} \cdot dt$$  \hspace{1cm} (MJ) (31)

where: $\bar{\phi}_{int}$ = mean heat flow from internal sources (W)

The value for $\bar{\phi}_{int}$ is the assumed internal heat production.

For offices with $\bar{\phi}_{int}$ only during 10 office hours:

$$Q_I = FWD \cdot (10/24) \cdot \bar{\phi}_{int} \cdot dt$$  \hspace{1cm} (MJ) (31a)

with $FWD$ the ratio of working days over total number of days.

Solar heat gains through windows:

$$Q_S = A_w \cdot g \cdot q_s (j) \cdot dt$$  \hspace{1cm} (MJ) (32)
where: $g$ : total solar transmission factor of the window (-)  
$q_s(j)$ : the mean solar radiation incident on the plane of the window (W/m²)

In case of different windows in one room the solar heat gains should be summated. In case of a large opaque area exposed to solar radiation, for instance a roof, see section 4.2.3 for a correction on $Q_s$.

The values for $A_w$ and $g$ are to be found in the building specifications; in case of movable shading: see section 4.2.2.

The values for $q_s(j)$ and $dt$ can be derived from hourly climate data, see for De Bilt and other Dutch locations the tables of section 4.4.

4.2.2 Correction for movable solar shading

In case of movable solar shading on windows the value $g$ is not constant. If we neglect the effect of shading on the U-value of the window a good approximation of the effect on the solar gains is found by defining:

the shading factor:

$$ z = \frac{g \text{ (with shading)}}{g \text{ (without shading)}} \quad (-) \quad (33) $$

and:

$$ F_{q \text{qtrh}}(j) = \frac{\sum \text{ hrs with shading active} q_s(j)}{\sum \text{ all hrs} q_s(j)} \quad (-) \quad (34) $$

where the superscript qtrh stands for the level of hourly incident solar radiation which is chosen as the threshold above which the shading is assumed to become active.
The ratio $F_q^{\text{qtrh}}(j)$ can simply be found by once going through all hourly climate values for each month and the required orientation.

The value for $z$ depends of course on the type of window.

The value for $F_q^{\text{qtrh}}(j)$ can be found for De Bilt and other Dutch locations in section 4.4 for threshold levels of $q_{\text{trh}} = 500 \text{ W/m}^2$ and $300 \text{ W/m}^2$ incident solar radiation intensities.

With these two quantities the heat gain through the window can be corrected for movable shading applied at hours with incident solar radiation exceeding $q_{\text{trh}} (\text{W/m}^2)$:

$$Q_g(\text{corrected}) = (1 - (1 - z) \cdot F_q^{\text{qtrh}}(j)) \cdot Q_g(\text{uncorrected})$$

(MJ) (35)

4.2.3 Correction for solar radiation absorbed by opaque surfaces

In cases of a large opaque area exposed to the sun, like a roof, a correction might be needed for solar heat entering the room via opaque constructions.

The correction amounts:

$$Q_s(\text{corrected}) = \left\{ \sum_{A_{op}} a_{op} \cdot A_{op} \cdot q_s(j) \cdot dt \right\} + Q_s(\text{uncorrected})$$

(MJ) (36)

where for each opaque construction:

- $A_{op}$: area of opaque construction exposed to solar radiation ($\text{m}^2$) at orientation $j$;
- $a_{op}$: solar absorption coefficient of the exposed outdoor surface ($-$);
- $U_{op}$: $U$-value of the construction ($\text{W/m}^2\text{K}$);
- $h_e$: exterior surface heat transfer coefficient ($\text{W/m}^2\text{K}$);

Values for $A_{op}$, $a_{op}$, $U_{op}$ are to be found from the building specifications.
4.3 Heating requirements and simplified method

The monthly heating requirements $Q_{HD}$ can be determined with equation (5) presented before:

$$Q_{HD} = Q_L - \eta_G \cdot Q_G$$

$Q_L$, $\eta_G$ and $Q_G$ can be determined with the use of the equations from the previous sections. The information needed to be able to fill in these equations can be subdivided into three types:

- a- specifications of building, occupants' behaviour and heating installation
- b- monthly integrated climate data
- c- correlation parameters
  - the utilization factor curve $\eta_G$ (GLR)
  - the thermostat setback correction $C_N$ or $C_{NWH}$

For the development of the simplified method series of calculations using the unsteady state computer model DYWON were run for various types of building, occupants' behaviour and heating installation, for a heating season (7 months) representative for the Netherlands. These series were subdivided into different categories and for each category the parameters $\eta_G$ (GLR) and $C_N$ (or $C_{NWH}$) were determined by correlating the calculation results with the known specifications as mentioned under -a- and the known integrated climate data (-b-).

The monthly climate data are presented in the next section (section 4.4), the specifications of the calculation cases are presented in 5.4 - 5.7 and the results of the correlation process are given in section 5.8.

If a specific situation fits into one of the categories for which the correlation parameters have been determined, then the simplified method can be used directly (see chapter 6). If not, a new category can be created for which the correlation parameters could be determined in the same way as presented in chapter 5.
4.4 Climate data for the Netherlands

The series of unsteady state computer calculations have been carried out with the use of the hourly climate data from the Royal Dutch Meteorological Institute (KNMI) for location De Bilt over the period October 1, 1964 - April 30, 1965. This period has been used in most studies and design calculations throughout the years as the period with the most representative outdoor climate for the Netherlands.

The monthly values which are needed for the simplified calculation have been derived from the hourly data. The results are presented in table 1.

Table 2 presents the values integrated over 4 week periods from October 5, 1964 - April 26, 1965 needed for offices.

Recently, "Test Reference Years" (TRY's) have been generated for a number of countries within the CEC ([17]). These years have been composed by selecting for each month the statistically most representative one out of a number of years with known hourly climate data.

For the Netherlands TRY's have been generated for the locations De Bilt (central part), Vlissingen (South West) and Eelde (North East).

Because in recent studies the TRY is used as reference outdoor climate the monthly integrated values have been determined for these Test Reference Years too: table 3 for De Bilt and tables 4 and 5 for Vlissingen and Eelde respectively. Tables 6 - 8 present the values in 4 week periods for the situation in offices.
Table 1: Climate data for De Bilt, the Netherlands.
October 1, 1964 - April 30, 1965;
monthly integrated (for dwellings).

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<tbody>
<tr>
<td>$T_e$ [$^\circ$C]</td>
<td>7.9</td>
<td>6.3</td>
<td>2.4</td>
<td>2.7</td>
<td>2.1</td>
<td>4.3</td>
<td>7.7</td>
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<tr>
<td>$\overline{q}$ [$W/m^2$]</td>
<td></td>
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<tr>
<td>$j = south$</td>
<td>90.7</td>
<td>35.2</td>
<td>29.4</td>
<td>34.1</td>
<td>69.9</td>
<td>105.2</td>
<td>99.6</td>
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<tr>
<td>$j = north$</td>
<td>27.4</td>
<td>12.0</td>
<td>9.3</td>
<td>12.4</td>
<td>26.1</td>
<td>36.0</td>
<td>51.7</td>
</tr>
<tr>
<td>$j = east$</td>
<td>50.5</td>
<td>15.1</td>
<td>14.1</td>
<td>17.0</td>
<td>37.8</td>
<td>64.6</td>
<td>76.6</td>
</tr>
<tr>
<td>$j = west$</td>
<td>46.3</td>
<td>18.1</td>
<td>12.0</td>
<td>16.5</td>
<td>36.5</td>
<td>66.3</td>
<td>83.5</td>
</tr>
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Table 2: Idem, integrated over periods of 4 weeks (for offices).

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<tbody>
<tr>
<td>$T_e$ [$^\circ$C]</td>
<td>7.4</td>
<td>5.6</td>
<td>2.4</td>
<td>2.9</td>
<td>1.5</td>
<td>5.7</td>
<td>7.5</td>
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<tr>
<td>$\overline{q}$ [$W/m^2$]</td>
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<td></td>
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<tr>
<td>$j = south$</td>
<td>68.6</td>
<td>36.0</td>
<td>37.7</td>
<td>25.3</td>
<td>74.3</td>
<td>115.1</td>
<td>87.4</td>
</tr>
<tr>
<td>$j = north$</td>
<td>24.5</td>
<td>11.8</td>
<td>9.9</td>
<td>12.3</td>
<td>27.4</td>
<td>39.5</td>
<td>50.5</td>
</tr>
<tr>
<td>$j = east$</td>
<td>39.6</td>
<td>15.6</td>
<td>15.2</td>
<td>15.2</td>
<td>40.9</td>
<td>70.3</td>
<td>68.8</td>
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<tr>
<td>$j = west$</td>
<td>37.5</td>
<td>17.4</td>
<td>14.2</td>
<td>14.9</td>
<td>39.4</td>
<td>73.4</td>
<td>77.9</td>
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$F_{300}$ [-] |      |      |      |      |       |      |      |
| $j = south$ | 0.47 | 0.47 | 0.37 | 0.14 | 0.47  | 0.57 | 0.38 |
| $j = north$  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0   | 0.0  | 0.0  |
| $j = east$   | 0.33 | 0.12 | 0.12 | 0.22 | 0.45  | 0.42 | 0.37 |
| $j = west$   | 0.23 | 0.15 | 0.03 | 0.16 | 0.42  | 0.45 | 0.42 |

$D$ [D] | 31   | 30   | 31   | 31   | 28    | 31   | 30   |

$dt$ [Ms] | 2.7  | 2.6  | 2.7  | 2.7  | 2.4   | 2.7  | 2.6  |

$F_{eW}$ [-] | 0.27 | 0.30 | 0.27 | 0.29 | 0.29  | 0.24 | 0.24 |

$F_{MD}$ [-] | 0.73 | 0.74 | 0.68 | 0.71 | 0.74  | 0.70 | 0.68 |
Tables 3 - 5 Climate data Test Reference Years for three locations in The Netherlands; monthly integrated (for dwellings).

### Table 3: TRY location De Bilt

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Tables 6 - 8 Climate data Test Reference Years for three locations in The Netherlands; integrated over periods of 4 weeks (for offices).

Table 6: TRY location De Bilt.

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5. SERIES OF UNSTEADY STATE CALCULATIONS TO DERIVE THE CORRELATION PARAMETERS

5.1 Introduction

Series of parameter studies using the unsteady state computer model DYWON were carried out to find for different categories of situations the correlation parameters $C_N$ (offices: $C_{NWH}$) for the thermostat setback correction and the relation between the gain utilization factor $\eta_G$ and the gain loss ratio GLR. If the $C_N$ (or $C_{NWH}$) factor and the $\eta_G$ function are known for a certain category then for any situation which fits into that category the monthly heating requirements can be easily calculated using equation (5): $Q_{HD} = Q_L - \eta_G Q_G$, with the equations of sections 4.1 and 4.2 to determine $Q_L$ and $Q_G$.

5.2 Distinction into categories of situations

As discussed before (4.1.2 and 4.3) the correlation parameter $C_N$ (or $C_{NWH}$) and the function $\eta_G$ (GLR) will depend on a few typical characteristics of building, heating installation and occupants:

- building: type of use (dwelling, office, ...);
  thermal mass (heavy weight, light weight);
- installation: e.g. convective heating or radiator heating;
- occupants' behaviour: yes/no (night) setback of thermostat;
  criterium for the use of solar shading;
  criterium for the use of night insulation;
  criterium for extra ventilation in case of overheating.

5.3 The unsteady state model DYWON

The computer programme DYWON, developed by TNO Institute of Applied Physics, Delft, for the unsteady state simulation of the energy consumption for heating of buildings is specifically suited for the often complicated situation of dwellings.
The dwelling can be divided into a number of rooms, with the possibility to exchange heat between the rooms by transmission and ventilation.

The thermal conduct of the wall elements is simulated by means of a finite difference method (RC-network). For each room a number of such constructive elements can be introduced, with for each element a menu of possibilities with respect to type (e.g. groundfloor, window, separation wall, etc.) and level of complexity for calculation (e.g. single layer, ventilated multi-layer system, with movable insulation, etc.).

For the radiation exchange between the constructions the programme is provided with a simple approximation in which the surfaces are assumed being part of complex geometries. If needed, (more) exact view factors can be used as input data or separately calculated. With the known view factors, the radiation exchange factors are calculated; in case of e.g. movable blinds this calculation is repeated when the surface properties are changed.

The convective and radiative heat transfer coefficients are considered temperature dependent.

The heating installation consists of boiler-unit coupled with radiators or convectors and/or separate heating units. The required temperature level is determined by given values for local and/or central thermostats or manually operated controls.

The various boundary conditions by occupants' behaviour can be specified as 24 hours patterns of hourly values. This is the case for:
- natural ventilation (option: windspeed dependent);
- mechanical ventilation (option: pre-heated);
- internal heat loads (convective, radiative);
- set point of thermostatic valve per radiator/convector;
- room thermostat;
- window treatments: use of night insulation and/or solar shading (option: solar intensity dependent).

The calculation procedure can be done on an hourly basis or in shorter time steps if desired.
The thermal balance for the room air is found by an iteration process in which the heating installation plays an important role: depending on the type of control, the heat supply to the (central) heating system and/or the (e.g. water) flows through the ornaments are adapted iteratively until a weighted mean of air and radiant temperature corresponds to the set-point of the thermostat involved. In case of no heat supply the system or individual ornaments (e.g. closed radiators) will gradually give off the heat accumulated in the (part of the) system.

If the option of shorter time steps is chosen the iteration can be replaced by a straightforward calculation in which for each short time step the heating system and/or the ornaments are switched on and off.

The heat flows for each constructive element are calculated directly by matrix-inversion.

This calculation process has the advantage over e.g. a response method, that it allows all kind of changes in the room network during calculation, like temperature dependent coefficients or movable shadings, curtains, a.s., without practical limitations. Moreover, all temperatures and heat flows at each node are in principle accessible for analysis. The disadvantage is the higher computer time per calculation; the computer time can however be restricted by exploiting the flexibility of DYWON, by a.o. appropriate choice in number of constructions and their complexity level.

Results from comparisons with other unsteady state computer models can be found in the report IEA Annex III, Subtask A [18] and the report on step 4 of this Annex XII [2].

5.4 Calculation series

The calculations can be divided into three categories, each category containing calculation cases belonging to different sub-categories of situations as mentioned under 5.2.
Category -a- concerns a large series of calculations on dwellings. These series were focused on the influence of windows. To this extend calculations were performed with 17 different combinations of glazing, solar shading and night insulation. Also other characteristics were varied, to detect the window's influence under widely varying indoor conditions.

In fact this series of calculations was carried out within the framework of a previous national study. However, in that study the annual heat demand values were used to derive a correlation based simplified method, valid for the Netherlands only, (see [13], [19], [20], [21]; here we used the also available monthly results).

Category -b- concerns a shorter series of calculations which consists of variations around a reference case calculation used for the comparison of computer models within step 4 of the project [2]. The reference case concerns a highly insulated room. In contrast with the reference case, these calculations were carried out with a radiator heating system instead of convective heating and with the De Bilt climate instead of Geneva.

Varied were window type, size and orientation, the control of the heating system and the mass of the room.

Category -c- concerns again a larger series of calculations on typical office rooms. These calculations, as category -a-, were performed within the framework of a previous national study ([14]). In this study a correlation based simplified method was derived on a seasonal basis, valid for the Netherlands only. Again, here we used the still available monthly results. This series of calculations was not focused on the influence of windows. Nevertheless, apart from a high number of variations in the other characteristics, also window size, type and orientation were varied.
5.5 **Category dwellings -a-**

**Main characteristics:**

Dwellings (both single family and appartments).
- Convective heating system.
- Thermostat controlled by air temperature.
- If present, shadings down when incident solar radiation exceeds 300 W/m² on the window.
- No increased ventilation in case of overheating.
- Night insulation present between sun set and sun rise.

**Subcategories:**

a-1: - Masonry type (heavy weight),
  - Night set back;

a-2: - Masonry type,
  - Continuous heating;

a-3: - Wooden frame type (light weight),
  - Night set back;

a-4: - Wooden frame type (light weight),
  - Continuous heating.

**Calculation cases:**

The characteristics of the 17 different window combinations can be found in table 9.
Table 10 shows a survey of all calculation cases with the description of the characteristics which were varied.
In appendix 2 a table can be found with all the steady state characteristics which were required for the calculation of the heat loss $Q_L$ and heat gain $Q_G$. 
Table 9. Characteristics*) of the 17 different window combinations used in category -a-

<table>
<thead>
<tr>
<th>Type</th>
<th>Glazing</th>
<th>Solar shading</th>
<th>Night insulation</th>
<th>Thermal transmittance $U$ (W/m²K)</th>
<th>Solar factor $g$(-)</th>
<th>$r$(-)</th>
<th>$z$(-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>single clear</td>
<td>none</td>
<td>none</td>
<td>5.9</td>
<td>0.80</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>as 1</td>
<td>internal blinds</td>
<td>light colour</td>
<td>5.9</td>
<td>0.80</td>
<td>1</td>
<td>0.58</td>
</tr>
<tr>
<td>3</td>
<td>as 1</td>
<td>as 2</td>
<td>internal blinds, slats closed</td>
<td>5.9</td>
<td>0.80</td>
<td>0.75</td>
<td>0.58</td>
</tr>
<tr>
<td>4</td>
<td>as 1</td>
<td>internal blinds</td>
<td>black/reflect.</td>
<td>5.9</td>
<td>0.80</td>
<td>0.61</td>
<td>0.59</td>
</tr>
<tr>
<td>5</td>
<td>as 1</td>
<td>none</td>
<td>well closed curtain</td>
<td>5.9</td>
<td>0.80</td>
<td>0.64</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>as 1</td>
<td>none</td>
<td>well closed curtain, Al.-coated</td>
<td>5.9</td>
<td>0.80</td>
<td>0.41</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>as 1</td>
<td>as 4</td>
<td>blinds as 4 curtain as 6 but not well closed</td>
<td>5.9</td>
<td>0.80</td>
<td>0.47</td>
<td>0.59</td>
</tr>
<tr>
<td>8</td>
<td>as 1</td>
<td>with low E coating</td>
<td>as 4</td>
<td>3.6</td>
<td>0.71</td>
<td>0.58</td>
<td>0.70</td>
</tr>
<tr>
<td>9</td>
<td>as 1</td>
<td>as 4</td>
<td>as 4, but with insulated slats</td>
<td>5.9</td>
<td>0.80</td>
<td>0.44</td>
<td>0.59</td>
</tr>
<tr>
<td>10</td>
<td>double clear</td>
<td>none</td>
<td>none</td>
<td>3.2</td>
<td>0.70</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>as 10</td>
<td>as 2</td>
<td>none</td>
<td>3.2</td>
<td>0.70</td>
<td>1</td>
<td>0.69</td>
</tr>
</tbody>
</table>
Table 9. continued.

<table>
<thead>
<tr>
<th>Type</th>
<th>Glazing</th>
<th>Solar shading</th>
<th>Night insulation</th>
<th>Thermal transmittance</th>
<th>Solar factor</th>
<th>r-value insul.</th>
<th>z-value shading</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>as 10</td>
<td>as 4</td>
<td>as 6</td>
<td>3.2</td>
<td>0.70</td>
<td>0.63</td>
<td>0.70</td>
</tr>
<tr>
<td>13</td>
<td>as 10</td>
<td>none</td>
<td>none</td>
<td>1.8</td>
<td>0.66</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>with low E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>triple clear</td>
<td>none</td>
<td>none</td>
<td>2.2</td>
<td>0.57</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>as 14</td>
<td>as 4</td>
<td>as 4</td>
<td>2.2</td>
<td>0.57</td>
<td>0.82</td>
<td>0.81</td>
</tr>
<tr>
<td>16</td>
<td>as 10</td>
<td>as 9</td>
<td>as 9</td>
<td>3.2</td>
<td>0.70</td>
<td>0.59</td>
<td>0.67</td>
</tr>
<tr>
<td>17</td>
<td>as 10</td>
<td>none</td>
<td>external roller blinds, insulated</td>
<td>3.2</td>
<td>0.70</td>
<td>0.66</td>
<td>1</td>
</tr>
</tbody>
</table>

*) the presented thermal and solar properties are typical values for the indicated type; the values will in general differ from product to product, depending on the actual specifications.
Table 10. Survey of the calculation cases category -a-

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Window combination</th>
<th>Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-1</td>
<td>-base case, dwelling in appartm. bld.</td>
<td>x x x x x x x</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td>-variants: orientation N-S → E-W</td>
<td>x x x</td>
<td>FE</td>
</tr>
<tr>
<td></td>
<td>-internal heat evening doubled</td>
<td>x x x</td>
<td>FT+</td>
</tr>
<tr>
<td></td>
<td>-internal heat increased all hrs.</td>
<td>x x x</td>
<td>FT-</td>
</tr>
<tr>
<td></td>
<td>-no internal heat infiltration tripled</td>
<td>x x x</td>
<td>FV+</td>
</tr>
<tr>
<td></td>
<td>-base case, house in a row</td>
<td>x x x x x x x</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>-variant: internal heat halvened</td>
<td>x x x</td>
<td>WI-</td>
</tr>
<tr>
<td></td>
<td>-25% window area moved N → S</td>
<td>x x x</td>
<td>WG+</td>
</tr>
<tr>
<td></td>
<td>-ident and infiltration halvened</td>
<td>x x x</td>
<td>WG+ V-</td>
</tr>
<tr>
<td>a-2</td>
<td>-apartment, variants: continuous heating 21°C</td>
<td>x x x</td>
<td>FT+</td>
</tr>
<tr>
<td></td>
<td>-ident at 15°C</td>
<td>x x x</td>
<td>FT-</td>
</tr>
<tr>
<td></td>
<td>-house in a row, variants: continuous heating 20°C</td>
<td>x x</td>
<td>WT+</td>
</tr>
<tr>
<td></td>
<td>-ident at 15°C</td>
<td>x x</td>
<td>WT-</td>
</tr>
<tr>
<td></td>
<td>-continuous heating 20°C, infiltration halvened and 25% window moved N → S</td>
<td>x x</td>
<td>WG+ V-</td>
</tr>
<tr>
<td></td>
<td>-ident, but continuous heating at 15°C</td>
<td>x x x</td>
<td>WG+ V- T+</td>
</tr>
<tr>
<td>a-3</td>
<td>-apartment, variants: building mass decreased to 10%</td>
<td>x x x</td>
<td>FM-</td>
</tr>
<tr>
<td></td>
<td>-house in a row variants: building mass decreased to 10%</td>
<td>x x</td>
<td>WM-</td>
</tr>
<tr>
<td></td>
<td>-ident, plus infiltration halvened and 25% window moved N → S</td>
<td>x x</td>
<td>WG+ V- M-</td>
</tr>
</tbody>
</table>
Table 10. continued.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Window combination</th>
<th>Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-4</td>
<td>- apartment, variants: bld. mass decreased to 10% and cont. heating at 21°C</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>- bld. mass decreased to 10% and cont. heating at 15°C</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>- house in a row, variants: bld. mass decreased to 10%, infiltr. halvened, 25% window moved N→S, cont. heating at 20°C</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>- Idem, but heating at 15°C</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

5.6 Category dwellings -b-

Main characteristics:

- Dwellings (individual rooms considered).
- Radiator heating (radiators underneath window).
- Thermostat controlled by comfort temperature.
- If present, shadings down when incident solar radiation exceeds 500 W/m² on the window.
- Increased ventilation in case of overheating.

Subcategories:

b-1: - Heavy mass,
  - Night set back;

b-2: - Heavy mass,
  - Continuous heating;

b-3: - Light weight mass,
  - Night set back;

b-4: - Light weight mass,
  - Continuous heating.
Calculation cases:

Table 11 shows a survey of the calculation cases. Only the window size, type and orientation were varied.

More details can be found in appendix 2.

Table 11. Survey of the calculation cases in category -b-

<table>
<thead>
<tr>
<th>Category</th>
<th>Building type</th>
<th>Heating regulation</th>
<th>Window*</th>
<th>Identification code</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H= heavyw. mass</td>
<td>N= night set back</td>
<td>Type of glazing</td>
<td>Size in % of floor area</td>
</tr>
<tr>
<td>b-1</td>
<td>H</td>
<td>N</td>
<td>single clear single clear</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>N</td>
<td>single clear single clear</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>N</td>
<td>double clear double clear</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>N</td>
<td>double clear double clear</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>N</td>
<td>triple with low E triple with low E</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>N</td>
<td>single clear single clear triple with low E</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>N</td>
<td>single clear single clear triple with low E</td>
<td>20</td>
</tr>
<tr>
<td>b-2</td>
<td>H</td>
<td>C</td>
<td>double clear</td>
<td>20</td>
</tr>
<tr>
<td>b-3</td>
<td>L</td>
<td>N</td>
<td>single clear single clear triple with low E</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>N</td>
<td>single clear single clear triple with low E</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>N</td>
<td>single clear single clear triple with low E</td>
<td>20</td>
</tr>
</tbody>
</table>

* All with internal blinds down at hours with incident radiation $\geq 500\ W/m^2$. 
5.7 **Category offices -c-**

**Main characteristics:**

- Office rooms, not mechanically cooled.
- Convective heating system.
- Thermostat controlled by air temperature.
- If present, shadings down when incident solar radiation exceeds 300 W/m² on the window, excluding on weekend days.
- No increased ventilation in case of overheating.
- Thermostat set back outside office hours and during weekends.

**Subcategories:**

c-1: Heavy weight;  
c-3: Light weight;  
c-5: Extra heavy weight.

**Calculation cases:**

The office room is a conventional, moderately insulated office module.

In appendix 2 and in reference [14] more detailed information can be found.

The main types of variations were:

- window area, type (single/double, shading) and orientation;  
- mechanical ventilation and infiltration;  
- transmission;  
- internal gains.

The total number of calculations was 82. A few cases have been deleted here, because they were unrealistic and therefore difficult to fit into the categories; this concerned cases with extremely high window area in an office room at the corner of a building. Table 12 shows which characteristics were varied and how.
Table 12. Survey of the varied characteristics in the calculations of category offices -c-

| Orientation of the façade | for room at center of building façade: N = North  
| |  
| | O = East  
| | Z = South  
| | W = West  
| | for room at corner of building façade: combinations: NO, ZO, ON, OZ.  
| Glass area | 1 = 30% of internally measured façade area  
| | 2 = 55%  
| | 3 = 75%  
| Window type | 1 = single glazing, internal blinds  
| | 2 = single glazing, external blinds  
| | 3 = double glazing, internal blinds  
| | 4 = double glazing, external blinds  
| | blinds down during office hours at \( q_s > 300 \text{ W/m}^2 \).  
| Lighting | 0 = 0 W/m²  
| | 1 = 15 W/m²  
| | 2 = 30 W/m²  
| Special cases | L = building mass = 0.1 x original mass  
| | H = building mass = 3.0 x original mass  
| | D = room under roof  
| | V = infiltration and mechanical ventilation increased with factor 3  
| | VC = infiltration constantly 240 m³/h, mechanical ventilation 0 m³/h  
| | VN = infiltration increased with factor 3  

The symbols refer to the codes used to identify each case; see appendix 2
5.8 Results

5.8.1 Correlation process

For each category of situations the monthly heat demand values, $Q_{HD}$, obtained by the unsteady state calculations are compared with the total amounts of gain $Q_G$ and losses $Q_L$, which are determined with the equations from chapter 4. According equations (5) and (7) the correlation can be carried out on $\eta_G$ against GLR, for $\eta_G$ is simply $\eta_G = (Q_L - Q_{HD})/Q_G$ and GLR is, also by definition, equal to $Q_G/Q_L$. Each month of each calculation case yields a point $\eta_G$, GLR; the best fit curve through these points leads to a $\eta_G$(GLR) curve like the curve presented in figure 6 (section 3.3).

There are, however, two complications:

Complication 1, error analysis:

For small values of $Q_G$ (e.g. months with little solar radiation) the value of $Q_{HD}$ will be almost equal to the value of $Q_L$. In the determination of $\eta_G$ (see above) the small difference between $Q_{HD}$ and $Q_L$ will be divided by the small value for $Q_G$. The effect is that minor deviations in $Q_L$ or $Q_{HD}$ will be blown up in $\eta_G$.

For example, if GLR = 0.10 it is expected that $\eta_G = 1.0$, which means that $Q_{HD}/Q_G = 9.0$

$$\eta_G = (Q_L - Q_{HD})/Q_G$$
$$= Q_L/Q_G - Q_{HD}/Q_G$$
$$= 10.0 - 9.0 = 1.0$$

If, by second or third order effects, $Q_{HD}/Q_G$ deviates only one percent from the value 9.0, then $\eta_G$ deviates 10 percent from the expected value 1.0.

One will observe this effect in the figures of the next sections.

A better basis for finding a best fit curve is by taking the relation between the relative overheating $dT_R$ and GLR:

for each month of each calculation case the value of $dT_R$ is determined with the help of equation (13): $dT_R = (Q_G + Q_{HD})/Q_L$. 
Now, a deviation in $Q_{\text{HD}}$ in case of small $Q_G$ will appear in $dT_R$ in a realistic way. Only in case $Q_{\text{HD}}$ is small, then a large relative error in $Q_{\text{HD}}$ (though small in absolute terms) will change into a small relative error in $dT_R$.

For example, if GLR = 0.90 and $Q_{\text{HD}}/Q_L = 0.19$ : $dT_R = 1.09$;

a deviation of 10 percent in $Q_{\text{HD}}$ leads to a deviation of less than 2 percent in $dT_R$.

However, this is exactly the tendency which one would like to see: a small absolute error in $Q_{\text{HD}}$, though large in relative terms when $Q_{\text{HD}}$ is small, will appear as a small error in $dT_R$.

The $\eta_G$ (GLR) curve can be derived easily from the relation between $dT_R$ and GLR (see equation (12)).

Complication 2, $Q_L$ and the parameter for thermostat setback

The parameter for thermostat setback, $C_N$ (or $C_{\text{NWH}}$ for offices) has yet to be determined.

However, the value for $C_N$ (or $C_{\text{NWH}}$) is already needed in $Q_L$. Therefore, the full procedure is as follows: a whole range of possible $C_N$ (or $C_{\text{NWH}}$) values is scanned; for each value of $C_N$ ($C_{\text{NWH}}$) the points $dT_R$, GLR are determined and the best fit curve $dT_R$ as function of GLR is calculated. The $C_N$-value which yields the best fit curve with the least root mean square deviation is selected as the "true" value.

5.8.2 Selected function to describe the utilization curve

Figures 7 and 8 show the shapes of the expected curves for $\eta_G$ (GLR) and $dT_R$ (GLR) respectively:

I low GLR:
the utilization of gains is 100 percent in case of low gains compared to the losses: $\eta_G = 1$;
there is no overheating : $dT_R = 1$.

III high GLR:
the gains are (much) larger than the losses; the heat demand is zero;
from the equation (5) it follows: $0 = Q_L - \eta_G \cdot Q_G$,
so: $\eta_G = 1/\text{GLR}$;
and with equation (12) \( dT_R = 1 + (1 - \eta_G)GLR \):
\[ dT_R = GLR. \]

II intermediate zone:
in the ideal situation all gains are utilized 100 percent until the gains exceed the losses \((GLR \geq 1)\); from that point the heat demand is zero: so there is no intermediate zone. In a real situation however, the utilization factor will decrease gradually, see figure 7. The relative overheating will gradually rise, see figure 8.

**Figure 7.** The gain utilization factor \( \eta_G \) as function of the gain loss ratio \( GLR \)

**Figure 8.** The relative overheating \( dT_R \) as function of the gain loss ratio \( GLR \)
An appropriate function has to be chosen to describe the utilization curve in the second zone in mathematical terms. The function should meet the following demands:

The function should:
- be continuous;
- not show abrupt changes at the transition point between zone I and II (first derivative should be continuous);
- not be too complex;
- be sufficiently flexible to cover a wide range of possible curve shapes;
- yield a good fit through the points.

A few possible functions will be discussed:

a. \( \eta_G = a - b \cdot \text{GLR} \)  
\( dT_R = 1 + (1 - a) \cdot \text{GLR} + b \cdot \text{GLR}^2 \)

See figures 9 and 10.
The \( \eta_G \) (GLR) curve is a straight line; for most categories this appeared to lead to unsatisfactory results.

b. \( \eta_G = b + (1 - a)/\text{GLR} \)  
\( dT_R = a + (1 - b) \cdot \text{GLR} \)

This type of function was used in the seasonal simplified methods developed at the TPD (see [13], [14], [15], [16]):

\( Q_{HD} = a \cdot Q_{out} - b \cdot Q_{in} \); \( a \) and \( b \) were derived from the best fit straight line through the points representing the seasonal \( dT_R \) as function of \( Q_{in}/Q_{out} \).

\( Q_{in} \) is identical with \( Q_G \), \( Q_{out} \) is slightly different from \( Q_L \).

However, figure 9 clearly shows that the monthly utilization factor is not represented satisfactory with a curve according to this function, because of the abrupt change from the value \( \eta_G = 1 \).
Figure 9. Illustration of the effect of the choice of mathematical function for the utilization curve.

Figure 10. Illustration of the effect of the choice of mathematical function for the relative overheating curve.
c. \( \eta_G = a / \text{GLR} + b + c \cdot \text{GLR} \)  
\[ \text{dTi} = (1 - a) + (1 - b) \cdot \text{GLR} - c \cdot \text{GLR}^2 \]  
(39a, 39b)

See figures 9 and 10.
The change from \( \eta_G = 1 \) to \( \eta_G < 1 \) appeared too abrupt.

d. \( \eta_G = \frac{P_1 + P_2 \cdot \text{GLR}^{P3}}{1 + P_2 \cdot \text{GLR}^{P3+1}} \)  
(40)

This type of function is used by Barakat to get best fit curves for similar kinds of utilization factor versus gain loss ratio curves. See [9], [10]. In [9] and [10] it is shown that this type of function leads to very satisfactory curves. However, the function is rather complex; it is in general not possible to understand the kind of difference between two utilization curves from a comparison of the respective parameter values.

e. \( \eta_G = 1 - e^{-1 / \text{GLR}} \)  
\[ \text{dT}_{\text{i}} = 1 + \text{GLR} \cdot e^{-1 / \text{GLR}} \]  
(41)

This type of function can be found in an annex to a recent ISO draft proposal [7]. See figures 9 and 10. The function is simple and clear; however, in this form it leaves no room to distinguish between different categories. Therefore, in [8] it is proposed to add a parameter \( K \):

f. \( \eta_G = 1 - e^{-K / \text{GLR}} \)  
\[ \text{dT}_{\text{i}} = 1 + \text{GLR} \cdot e^{-K / \text{GLR}} \]  
(42)

The function is however still not flexible enough. Therefore, for the analysis of the results of this study a similar function was tried, with a second parameter \( D \):

g. \( \eta_G = 1 - e^{-K / (\text{GLR} - D)} \)  
(43a)

\[ \text{dT}_{\text{i}} = 1 + \text{GLR} \cdot e^{-K / (\text{GLR} - D)} \]  
(43b)
See figures 9 and 10.
This function appeared to be a quite satisfactory compromise with respect to the requirements mentioned before. Therefore the correlations were carried out with this function and thus the parameter values $K$ and $D$ were derived for each category of situations.

5.8.3 Results

In table 13 the results of the correlation procedure are presented: for each of the categories the value for the thermostat setback correction $C_N$ (offices $C_{NWH}$) and the parameters for the utilization curve, $K$ and $D$.

For the category -c-, offices, it appeared necessary to apply the correction for cold surfaces, introduction section 4.1.4. Again for offices a value $C_{NWH}=1$ for the thermostat setback correction has been used as a basis for the correlation procedure; no attempts have been made to optimize the $G_{NWH}$-value.

A graphical presentation is given in the figures 11-20. Each of the figures gives for a certain category the following curves:

a. the monthly gain utilization factor, $\eta_G$, as function of gain loss ratio GLR;

b. the monthly relative overheating, $dT_R^*$, as function of gain loss ratio GLR;

c. the monthly heat demand, $Q_{HD}$, divided by the heat loss $Q_L$ to get a dimensionless number - as function of gain loss ratio GLR;

d. the annual heat demand as a summation of monthly heat demands calculated with the simplified method, compared to the annual heat demand calculated with the unsteady state computermodel DYWON. In the figures the standard deviation is presented as an indicator for the mean deviation.

Unit: MWh.
Table 13. The results of the correlation procedure for each of categories of situations.

<table>
<thead>
<tr>
<th>Category -a-:</th>
<th>* dwellings</th>
<th>* convective heating</th>
<th>* thermostat controlled by air temp.</th>
<th>* threshold for solar shading: incident rad. 300 W/m²</th>
<th>* no increased ventilation in case of overheating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcategories:</td>
<td>C_N</td>
<td>K</td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a-1. - masonry type</td>
<td>0.91</td>
<td>1.36</td>
<td>0.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- night setback</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a-2. - masonry type</td>
<td>0.97</td>
<td>1.35</td>
<td>0.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- continuous heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a-3. - wooden frame type</td>
<td>0.88</td>
<td>1.22</td>
<td>0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- night setback</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a-4. - wooden frame type</td>
<td>0.97</td>
<td>1.19</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- continuous heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category -b-:</th>
<th>* dwellings</th>
<th>* radiator heating</th>
<th>* thermostat controlled by comfort temp.</th>
<th>* threshold for solar shading: incident rad. 500 W/m²</th>
<th>* increased ventilation in case of overheating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcategories:</td>
<td>C_N</td>
<td>K</td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b-1. - heavy mass</td>
<td>0.90</td>
<td>1.19</td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- night setback</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b-2. - heavy mass</td>
<td>1.00</td>
<td>1.70</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- continuous heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b-3 - lightweight mass</td>
<td>0.92</td>
<td>1.10</td>
<td>0.37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- night setback</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category -c-:</th>
<th>* offices (not mechanically cooled)</th>
<th>* convective heating</th>
<th>* thermostat controlled by air temp.</th>
<th>* threshold for solar shading: 300 W/m² (only office hours)</th>
<th>* no increased ventilation in case of overheating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcategories:</td>
<td>C_{NWH}</td>
<td>K</td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c-1. - heavy weight</td>
<td>1.0</td>
<td>1.55</td>
<td>- 0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c-3. - light weight</td>
<td>1.0</td>
<td>1.14</td>
<td>- 0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c-5. - extra heavy weight</td>
<td>1.0</td>
<td>1.64</td>
<td>- 0.16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
a. gain utilization factor $n_G$
as function of GLR.

b. relative overheating
dT_R as function of GLR

c. dimensionless monthly heat
demand $Q_{HD}/Q_L$ as function
of GLR.

d. verification of annual heat
demand calculated with the
simplified method against
original computer calculation
results.

Figure 11. Category a-l; explanation: see table 13.
a. gain utilization factor $n_G$ as function of GLR.

b. relative overheating $d_{TR}$ as function of GLR.

c. dimensionless monthly heat demand $Q_{HD}/Q_L$ as function of GLR.

d. verification of annual heat demand calculated with the simplified method against original computer calculation results.

Figure 12. Category a-2; explanation: see table 13.
a. gain utilization factor $\eta_G$ as function of GLR.

b. relative overheating $dT_R$ as function of GLR.

c. dimensionless monthly heat demand $Q_{HD}/Q_L$ as function of GLR.

d. verification of annual demand calculated with the simplified method against original computer calculation results.

Figure 13. Category a-3; explanation: see table 13.
a. gain utilization factor $\eta_G$
as function of GLR.

b. relative overheating $d_T$ as function of GLR.

c. dimensionless monthly heat demand $Q_{HD}/Q_L$ as function of GLR.

d. verification of annual demand calculated with the simplified method against original computer calculation results.

Figure 14. Category a-4; explanation: see table 13.
a. gain utilization factor $\eta_G$ as function of GLR.

b. relative overheating $dT_R$ as function of GLR.

c. dimensionless monthly heat demand $Q_{HD}/Q_L$ as function of GLR.

d. verification of annual demand calculated with the simplified method against original computer calculation results.

Figure 15. Category b-1; explanation: see table 13.
Figure 16. Category b-2; explanation: see table 13.
a. gain utilization factor $\eta_g$ as function of GLR.

b. relative overheating $dT_R$ as function of GLR.

c. dimensionless monthly heat demand $Q_{HD}/Q_L$ as function of GLR.

d. verification of annual demand calculated with the simplified method against original computer calculation results.

Figure 17. Category b-3; explanation: see table 13.
a. gain utilization factor $\eta_G$ as function of GLR.

b. relative overheating $dT_R$ as function of GLR.

c. dimensionless monthly heat demand $Q_{HD}/Q_L$ as function of GLR.

d. verification of annual demand calculated with the simplified method against original computer calculation results.

Figure 18. Category c-1; explanation: see table 13.
a. gain utilization factor \( \eta_g \) as function of GLR.

b. relative overheating \( dT_R \) as function of GLR.

c. dimensionless monthly heat demand \( Q_{HD}/Q_L \) as function of GLR.

d. verification of annual demand calculated with the simplified method against original computer calculation results.

Figure 19. Category c-3; explanation: see table 13.
a. gain utilization factor $\eta_G$
as function of GLR.

b. relative overheating
\[ dT_R \] as function of GLR.

c. dimensionless monthly heat
\[ \frac{Q_{HD}}{Q_L} \] demand as function
of GLR.

d. verification of annual
\[ SDEV = 0.043 \text{ MWh} \]
demand calculated with the
simplified method against
original computer calculation results.

Figure 20. Category c-5; explanation: see table 13.
5.9 Discussion

From the figures 11-20 the following general conclusions can be drawn:

**Distinction between categories:**

The distinction in categories appears to be well chosen: each category is represented by a distinct set of parameters C_N, K and D, resulting in utilization factor and relative overheating curves which are typical for that category.

**Accuracy of annual heat demand:**

The agreement between the summation of monthly heat demands calculated with the simplified method and the annual heat demand from the original DYWON unsteady state calculations is good, as the figures 11d-20d show. Both the individual deviations and the standard deviation are small.

**Reliability of monthly results:**

The scatter of the points in the presentation of the monthly results indicate that despite a good agreement on an annual basis, the discrepancies on a monthly basis are not negligible.

Firstly, however, one should realize, that the deviation in n_G in the low GLR range may be large, but their influence on the heat demand is small, because the gain itself is small; as already pointed out in section 5.8.1 the d_T_R (GLR) function shows the scatter around the curves in a better proportion.

Possible causes for the scatter are:

- some "carry-over" effect between the months: heat accumulated in one month and utilized in the next month;
- second order effects in the unsteady state calculations, like:
  * U-values and solar transmittance factors are temperature dependent; in the simplified method a fixed value is used;
  * bandwidth of 0.5 K in thermostat control in case of radiator heating;
  * distinct temperatures for indoor air and surface temperature of each construction, so the various heat loss terms have different indoor temperatures;
* hourly patterns of e.g. internal heat gains, which may have a different effect for different cases.

- simplifications in the equations of the simplified method, like:
  - the correction factor for thermostat setback (see discussion in section 4.1.2);
  - the change in the window's U-value in case of solar shading is neglected for simplicity reasons.

From the scatter in the figures 11c-20c it can be concluded that the inaccuracies in monthly heat demands are in general 5 percent or less of the heat loss. This means that in case of a small heat demand, in case of high amount of gains, the relative error in the heat demand can be much larger. One should however realize that the result of any method to predict the heat demand would be subject to percentually large uncertainties: the heat demand is a small difference between two large numbers. The absolute error will be small.

Therefore, an error in monthly $Q_{HD}$ of 5 percent of the value of $Q_L$ is quite satisfactory.

A comparison of the results for the various categories leads to the following observations:

**effect of building mass:**

A higher building mass leads to a higher utilization factor, particularly in case of continuous heating (category a-2 versus a-4). In case of thermostat setback the positive effect of a better accumulation of solar energy is combined with the negative effect of a less effective setback; the heavy weight building cools off less quickly, but loses more heat during the night.

A comparison of categories c-3 and c-5 shows, that adding extra mass into an already heavy weight building does not have a significant influence.

**effect of building type:**

Particularly in case of a heavy weight building, the utilization factor is for offices much lower than for dwellings: the solar heat accumulated during daytime cannot be utilized during the evenings because of the thermostat setback during non-working hours.
effect of thermostat setback:

it is difficult to read from the presented curves the effect of the thermostat setback on the utilization factor; this is due to the fact that the thermostat setback influences, via $Q_L$, the position on the GLR-axis.

The values in table 13 for $C_N$ for the categories with night setback compared with the values with continuous heating show the influence on the heat losses: the heat loss is 6-10% lower, depending on building mass and type of heating installation.

One would expect for continuous heating a value $C_N = 1$; however, for the categories a-2 and b-4 the best fit was reached for slightly lower values, probably compensating for other, second order, effects.

For offices, the value $C_{NWH} = 1$ has been used as a basis for the correlation procedure; no attempts have been made to optimize the $C_{NWH}$-value.

effect of type of heating system and control:

in case of night setback the utilization factor is higher for the category -b- (radiator heating) than for the category -a- (convective heating); in case of continuous heating the situation is reversed. The differences are, however, only significant for the light weight mass situations (b-3 versus a-3).
6. APPLICATION OF THE SIMPLIFIED METHOD

6.1 Single zone situation

If a specific situation fits into one of the categories for which the correlation parameters have been derived (C_N or C_{NWH}', for the thermostat setback, and K and D for the utilization factor curve), then the simplified method can directly be applied to calculate the monthly heating requirements.

To this extend the specifications of the building, occupants' behaviour and type of heating installation and control are to be used as well as the monthly integrated climate data (e.g. from the tables in section 4.4) in the equations of sections 4.1 and 4.2. This leads to monthly values of the total heat loss in a no gain situation, Q_L, and the total heat gain, Q_G.

With equation (5): Q_{HD} = Q_L - \eta_G \cdot Q_G

and the relation between the utilization factor \eta_G and the gain loss ratio GLR = Q_G/Q_L, the monthly heating requirements Q_{HD} are easily determined.

The derivation of the correlation parameters was based on series of calculations with the unsteady state model DYWON. DYWON has the capability to deal with situations in which different zones (rooms or other spaces), with different conditions have an interaction by exchange of ventilation or transmission heat flows.

Nevertheless, all calculations have been carried out with single zone situations, with only heat exchange between the considered zone and the outdoor environment. Whereever relevant, also heat losses to the ground via the groundfloor were taken into account; also accumulation of heat into walls, floor or ceiling separating the zone from identical zones was taken into account, but on a monthly basis the integrated heat flows through these zone boundaries are negligible.
Real multizone situations would have made it unnecessarily complicated to determine the correlation parameters: complicated, because the interaction between the conditions in the different zones would disturb the correlation process severely (the variables are not independent); unnecessarily complicated, because there is no principle difference between a single and a multi-zone situation.

The next section describes how to use the simplified method in a multi-zone situation.

In chapter 7 results of the application of the method in a multi-zone situation are presented and compared with multi-zone DYWON runs carried out on the same cases.

Final remark:

The correlation parameters have been derived for different categories of situations, some of these with a large variety of widely different cases. All calculations, however, have been carried out for the Dutch climate.

Nevertheless, there is no reason to expect that application for other climatic conditions would lead to significantly different $\eta_G$ (GLR) curves. This confidence is based on the fact that each calculation case of the previous chapter consisted of seven monthly results with quite a spread in weather conditions. A different climate just means a different position on the GLR-axis.

Of course, one should be cautious in extrapolating to conditions which differ basically from those assumed in the calculations.

6.2 Multi-zone situation: the TPD Correlation based Multi-zone calculation method TCM-heat

In principle the set up of the heat balance for a particular zone in a multi-zone situation is not different from the set up in a single zone situation. The heat losses by transmission and/or ventilation to other indoor spaces are an inseparable part of the sum of all transmission and ventilation heat losses of the considered zone. The term $\hat{\theta}_e$ in the equations of section 4.1 is the temperature of the adjacent space.
If the temperature of the adjacent space is higher than the temperature of the considered room the particular heat loss term is negative. It would, however, be wrong to consider such negative losses as part of the heat gains to the considered room: the heat loss terms, either "positive" or "negative", are a linear function of the temperature difference; the internal and solar gains are independent of the temperature difference, as shown in the equations of sections 4.1 and 4.2.

NB: actually, it would have been more correct (but less transparent) to use the terms autonomous heat flows (gains) versus temperature dependent heat flows (± losses).

The only practical difficulty is, that in a multi-zone situation the temperature \( \theta_e \) of the adjacent zones may not be known beforehand, but have to be calculated by applying the simplified method to those zones too. Due to the interaction between the zones an iterative procedure is needed to solve the heat balances for all zones.

The following procedure leads to the desired results:

1. For each heated zone the most appropriate curve \( G_N(\text{GLR}) \) and setback correction \( C_{N-} \) or \( C_{NWH} \) values are selected (for example from table 13). Calculate the mean minimum temperature (see section 4.1.1 and 4.1.2). As a first approximation it is assumed that \( \theta_i,\text{real} = \theta_i,\text{min} \).

2. For each of all zones the sum of solar and internal gains \( Q_G \) are calculated (see section 4.2) and the overall specific heat loss coefficient per degree K temperature difference, \( H_L \) (see section 4.1.5).

3. For each of all zones the weighted mean ambient temperature, \( \theta_a \) is calculated (see section 4.1.5).

4. For each heated zone the minimum heat losses \( Q_L \) can now be calculated simply with equation (4):

\[
Q_L = H_L \int (\theta_i,\text{min} - \theta_a) \, dt
\]
As a next step the value for GLR can be determined and the utilization factor, $\eta_G$ from the selected curve. Equation (10) introducing the relative overheating $dT_R$ can be used in this stage to calculate the real mean zone temperature, $\bar{\theta}_{i, real}$:

$$\bar{\theta}_{i, real} = \bar{\theta}_a + dT_R(\bar{\theta}_{i, min} - \bar{\theta}_a) \quad (\circ C) \quad (44)$$

with $dT_R$ determined according to equation (12).

For each unheated zone the real mean zone temperature can easily be derived from the heat balance equation (3), with zero heat demand, and equation (4) for the heat loss $Q_{L, real}$:

$$0 = H_L(\bar{\theta}_{i, real} - \bar{\theta}_a) dt - Q_G \quad (MJ)$$

So:

$$\bar{\theta}_{i, real} = (Q_G + H_L dt \bar{\theta}_a)/H_L dt \quad (\circ C) \quad (45)$$

The temperatures according to equations (44) and (45) are the newly approximated temperatures which are only valid if the assumed mean ambient temperatures are valid. So:

5. Repeat the procedure starting from 2, using as $\bar{\theta}_e$ in case of adjacent zone the newly approximated temperature for that zone. This iteration can be stopped if the newly approximated temperatures are not different from the temperatures used at the start of the last iteration step.

6. For the heated zones the heat demand can be determined with equation (3).

7. The procedure can be repeated for the next month or 4 weeks period. The procedure of this TPD Correlation based Multi-zone calculation method which has received the name TCM-heat has been illustrated with a flow-chart in figure 21.

Although it is basically a hand calculation method the procedure as shown in figure 21 can only be carried out by hand in case of single zone situations, or multi-zone situations with a minimum of interactions between the zones.

In general, a computerized version of the procedure will be required. A Fortran-version of TCM-heat has been written in order to be able to carry out the calculations with TCM-heat which are presented in the next two chapters.
The listing of the programme is given in appendix 3. The main data sets presented in the previous chapters, like the monthly climate data, various window types and the correlation parameters for the different categories have been adopted in the programme.
Figure 21. Flow chart to illustrate the calculation procedure of the TPD Correlation based Multi-zone calculation method (THb-heat).

In a single zone application the iteration loop IZ is a single step calculation.
7. VERIFICATION OF THE SIMPLIFIED METHOD TCM-HEAT IN A MULTI-ZONE CALCULATION AGAINST DYWON

7.1 Introduction

The developed simplified method TCM-heat could be validated against measured energy consumption in a real building. However, it would require an extreme effort to measure sufficient quantities in order to be able to compare the measured and calculated results and to evaluate possible discrepancies. Instead of a comparison with measurements TCM-heat has been compared with the result of an hour by hour computer calculation in a complicated multi-zone situation, using the computer programme DYWON which also was used to develop the simplified method. For a description of DYWON: see section 5.3. Of course, with this approach possible deviations of DYWON results from a real situation remain undetected. Nevertheless, a verification in a complicated multi-zone situation will reveal the sensitivity of the results for the simplifications and approximations in the simplified method.

7.2 Description of the selected calculation cases

For the comparison a situation has been selected which has a maximum of possibilities for the simplified method to fail:
- dwelling subdivided into 5 zones (living room, kitchen, bedrooms North and South and attic);
- highly insulated heavy mass house in a row (with relatively large mutual influences between the zones); see figure 22;
- radiator heating system with thermostatic valves on the radiators and a room thermostat in the living room controlling the burner;
- radiators placed in front of the façades underneath the windows;
- thermostat night set back on all thermostats;
- indoor venetian blinds on the windows, used during hours with incident insolation exceeding 500 W/m²;
- curtains on all windows closed between sunset and sunrise;
- increased ventilation at mean dwelling temperature above 26°C;
- unheated attic;
Figure 22. Example of the type of dwelling selected for the multi-zone calculations: one of the DHV Dutch reference dwellings [22].
- two variations: case A: unheated bedrooms;  
  case B: heated bedrooms;  
- daily internal heat patterns different per zone;  
- ventilation exchange between zones.

The geometrical data have been based on one of the Dutch "DHV-reference dwellings" for newly built dwellings ([22]), with some minor modifications. For the calculation the dwelling has been divided into 5 zones:
- living room, with a large South and a smaller North window;  
- kitchen, North façade;  
- bedroom, South façade (in fact two South bedrooms combined);  
- bedroom, North façade (in fact one bedroom plus bathroom combined);  
- attic, unheated, without window.

The main characteristics can be found in table 14.

7.3 Results of the DYWON unsteady state calculations

The monthly results of the hour by hour calculation with DYWON are shown in the figures together with the results of the simplified method TCM-heat. As an illustration of the unsteady state behaviour hourly results are shown in figures 23 and 24 for a (cloudy) day in autumn. Figure 23 shows the hourly heat supplied by the radiators in living room (a) and the bedrooms (b and c) and the energy consumed by the boiler (d). The living room temperature is regulated by a room thermostat controlling the boiler; the kitchen and bedrooms have thermostatic valves on the radiators. The figure clearly shows, for instance, how the radiators still give off heat while the boiler is already switched off (at 9.00 and 23.00 o'clock).

Figure 24 shows the various indoor temperatures, in comparison with the thermostat settings. The presented temperatures are the average values between air and mean surfaces (including the radiators) of the zone.
Table 14. Main characteristics of the selected calculation cases.

<table>
<thead>
<tr>
<th>Main geometry:</th>
<th>Floor area (m²)</th>
<th>Window area (m²)</th>
<th>South</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Living room</td>
<td>40.20</td>
<td>5.50</td>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>Kitchen</td>
<td>7.80</td>
<td>--</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>Bedroom S.</td>
<td>22.62</td>
<td>3.50</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Bedroom N.</td>
<td>22.62</td>
<td>--</td>
<td>3.50</td>
<td>--</td>
</tr>
<tr>
<td>Attic</td>
<td>45.24</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Typical U-values (W/m²K) | Ground floor: underneath insulated floor:
Window = 2.90 | parallel conductances of 0.12 W/m²K to groundwater (10°C) and 0.50 W/m²K to monthly averaged outdoor temperature.
Wall = 0.40
Roof = 0.20

Main occupants' data: thermostat setpoints (°C) | internal heat kWh/24hr. | ventilation m³/hour

<table>
<thead>
<tr>
<th></th>
<th>day</th>
<th>evening</th>
<th>night</th>
<th>from outside</th>
<th>from other zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living room</td>
<td>18.50</td>
<td>20.00</td>
<td>14.50</td>
<td>5.54</td>
<td>31</td>
</tr>
<tr>
<td>Kitchen</td>
<td>18.50</td>
<td>20.00</td>
<td>14.50</td>
<td>5.04</td>
<td>14</td>
</tr>
<tr>
<td>Bedroom S.</td>
<td>18.00*</td>
<td>18.00*</td>
<td>12.00*</td>
<td>1.12</td>
<td>23</td>
</tr>
<tr>
<td>Bedroom N.</td>
<td>18.00*</td>
<td>18.00*</td>
<td>12.00*</td>
<td>0.56</td>
<td>19</td>
</tr>
<tr>
<td>Attic</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0.00</td>
<td>39</td>
</tr>
</tbody>
</table>

* case B only

Temperatures: thermostat setpoints: hysteresis 0.5 K;
room thermostat: senses 60% air temperature and 40% mean surface temperature (including radiators);
radiator valves: 70 and 30% respectively;
comfort temperature defined as 60% air, 40% mean surface temperature (included radiators).

Climate: De Bilt, October 1964 - April 1965
The course of the temperatures also illustrates - even for such cloudy day - the unsteady state character. The peak temperature in the kitchen between 17.00 and 19.00 hour is, for instance, caused by the increased internal heat gains assumed during these hours for that zone. Also it is clearly to see how slowly the indoor temperatures drop during the night setback period.

7.4 Results obtained with the simplified method TCM-heat

A calculation has been carried out with TCM-heat, for all 7 months, for both cases A and B. The category for the night setback correction and for the $n_G$ (GLR) curve is category b-1 (see table 13). The results are presented in the figures 25-28, together with the monthly results of the DYWON.

In the next section the differences between the results with TCM-heat and DYWON will be discussed. Figure 25b, however, reveals already one of the dominant features of the selected calculation cases: the gain loss ratio GLR is high, particularly in autumn and spring. For instance in March the heat gains are almost as high as the losses and almost eight times as high as the heat demand.

Figures 26 and 28 show another dominant feature of the selected cases: the mean ambient temperatures as seen by the respective zones is much higher than the outdoor temperature. This is due to the large interaction between the zones. The small temperature difference between zone and ambient temperature implies that the real mean zone temperature is very sensitive for minor changes in the situation or for minor deviations in the ambient conditions.

7.5 Verification of TCM-heat against DYWON

7.5.1 Main results

In tables 15 and 16 the results of the calculations with DYWON and with TCM-heat are summarized. The difference in annual heat demand is only about 10 percent. This difference is very small, considering the very low absolute value of the heat demand: the energy consumption for space heating is, conversed to natural gas, in the order of a few hundred m³ per year only.
Figure 23. Illustration of energy consumption and heat supply by the central heating system. Calculated hourly values for a typical day in autumn (October 22, 1964); case with heated bedrooms.
Figure 24. Illustration of room temperatures compared with thermostat settings and outdoor air temperature. Calculated hourly values for a typical day in autumn (October 22, 1964); case with heated bedrooms. Presented room temperatures are comfort temperatures (weighted average of air and surfaces).
This confirms that the chosen calculation cases are indeed quite extreme; certainly for the current building tradition in the Netherlands.

Table 15 also shows that some deviation occurs in the distribution of the heat demand (in fact: the heat supplied by the radiators) over the zones. This is not surprising because of the high interaction between the zones: the zones are separated by uninsulated floors and walls and are furthermore interconnected by ventilation heat flows.

Table 16 shows the distribution of the discrepancy in heat demand over the months. The month March is the largest contributor to the discrepancy of 10 percent in annual heat demand. As pointed out in the previous section, the calculated heat demand in March is almost eight times smaller than the heat gains during that month.

Table 15. Verification of the simplified method TCM-heat against DYWON unsteady state calculations in a complicated multi-zone situation; heating requirements over the heating season for the total dwelling and the distribution over the heated rooms.

<table>
<thead>
<tr>
<th>Case</th>
<th>Method</th>
<th>Seasonal heating requirements total dwelling (MJ)</th>
<th>Distribution over the heated rooms (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>living room</td>
<td>kitchen</td>
</tr>
<tr>
<td>unheated</td>
<td>DYWON</td>
<td>8249</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>TCM-heat</td>
<td>7457</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td>difference (%)</td>
<td>- 10</td>
<td></td>
</tr>
<tr>
<td>bedrooms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>heated</td>
<td>DYWON</td>
<td>10547</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>TCM-heat</td>
<td>9597</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>difference (%)</td>
<td>- 9</td>
<td></td>
</tr>
</tbody>
</table>
Table 16. Verification of the simplified method TCM-heat against DYWON unsteady state calculations in a complicated multi-zone situation; distribution over the months of the discrepancy in calculated heating requirements for the total dwelling.

<table>
<thead>
<tr>
<th>Case</th>
<th>Distribution over the months of discrepancy in calculated heating requirements between DYWON and TCM-heat for the total dwelling (% of seasonal QHD*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>unheated</td>
<td></td>
</tr>
<tr>
<td>bedrooms</td>
<td></td>
</tr>
<tr>
<td>heated</td>
<td></td>
</tr>
<tr>
<td>bedrooms</td>
<td></td>
</tr>
</tbody>
</table>

*) defined as: \(100\% \cdot \frac{Q_{\text{TCM},\text{month}} - Q_{\text{DYWON},\text{month}}}{Q_{\text{DYWON},\text{season}}}\)

7.5.2 Discussion of the results in detail

The figures 25-28 present a comparison of monthly heating requirements and mean temperatures. Concerning the heat demand for the total dwelling the discrepancies are only significant for March and - to a less extend - for October. The monthly heat demand is calculated with the equation:

\[ Q_{\text{HD}} = (Q_L - \eta_G Q_G) \].

As figure 25 clearly shows, the values for \(Q_L\) and \(Q_G\) are an order of magnitude higher than \(Q_{\text{HD}}\), so any minor deviation in the determination of \(Q_L\), \(Q_G\) or \(\eta_G\) will result in a strongly exaggerated high relative error in \(Q_{\text{HD}}\) for that month. In absolute terms, and certainly in comparison with \(Q_L\) and \(Q_G\), the deviation is small.

NB: the fact that \(Q_{\text{HD}}\) in relative terms is so sensitive for minor deviations, is not a matter of applied procedure; it is purely a physical phenomenon which will occur in real situations too: in such case as assumed in this chapter any small change in e.g. occupants' behaviour or e.g. temperature of adjacent buildings may result in a relatively large change in the (still small) heat demand.
Figure 27 shows the discrepancies in the distribution of heat demand over the various zones, which was already discussed in the previous section.

The mean temperatures calculated with TCM-heat are generally in good agreement with the mean comfort temperature calculated with DYWON, though in some months the values are too low. The DYWON results are presented as a band; this band represents the difference between air and mean surface temperature. The simplified method TCM-heat knows only one indoor temperature. This is one of the possible causes for the deviation: the zone temperature calculated with TCM-heat is the temperature on which the heat losses are based. For instance, if ventilation losses are dominant the calculated temperature represents the air temperature. Or if, for instance, a window with high transmission losses 'sees' a cold floor surface inside the zone then the calculated temperature is more close to the low temperature of that floor.

A combination of underestimated temperatures and underestimated heat demand for the same month is an indication that the utilization factor for the gains is overestimated. This might be another cause for the deviations revealed by the figures. As figure 15a showed one should allow some uncertainty around the utilization factor curve: ± 5 percent of the value of $Q_L$ (see section 5.9).

A plausible third cause for deviation is the correction factor for the thermostat night setback. In section 4.1.2 the correction factor $C_N$ was discussed. It was concluded that a refinement could improve the adequacy of the correction for night setback to deal particularly with complicated multi-zone situations. The effect of a refinement would be limited, but would probably for the presented cases lead to a slight increase of mean indoor temperature, accompanied with an increase in heat demand.
The control of the heating system may also be a cause for some deviation. In figure 23 it can clearly be seen that if the burner is switched off, the radiator in the living room continues to give off heat until the water is cooled off. In fact, one could call this unutilized heat supply from the heating system; like the unutilized solar and internal gains it will lead to an increased mean indoor temperature (overheating). The original single zone DYWON calculations on which the parameters of category B1 are based would show the same phenomenon. One can, however, imagine that the influence of the inertia of the heating system can vary easily from situation to situation. Also the hysteresis of 0.5K in the thermostatic valves and room thermostat may lead for the DYWON results to incidental minor deviations from the setpoints (see figure 23).

Furthermore: the room thermostat in the living room controls the burner. On hours in which the living room has no heat demand, other rooms may experience a shortage of heat.

Finally, the deviation might partly be due to the difference in window and other building component characteristics. In DYWON the thermal and solar transmitted heat flows are calculated on an hourly basis. The indoor surface heat transfer coefficients are calculated each hour on the basis of the actual local temperature differences. The thermal and solar transmittances in the simplified method are constant U- and g-values, based upon assumed mean heat transfer coefficients. For example: the window U-value is assumed to be $U = 2.9 \text{ W/m}^2\text{K}$, based upon indoor heat transfer coefficient $h_i = 8 \text{ W/m}^2\text{K}$.

If, for the selected calculation case, the mean coefficient $h_i = 6$ instead of 8, then the mean thermal transmittance of the window is 10 percent lower than expected ($\overline{U} = 2.6 \text{ W/m}^2\text{K}$).
Summarizing, the following possible causes for the deviations can be identified:
- different "definition" of indoor temperature;
- error band around the utilization curve;
- inadequacy of the night setback correction approach.
- inertial effects of the radiator heating system;
- type of control of the heating system;
- deviation from nominal steady state characteristics (U and g).

Nevertheless, the overall agreement between the results of TCM-heat and DYWON is quite satisfactory, if one takes into account that the deviations in distribution of heat demand over the zones and over the months and the deviations in mean zone temperatures are caused by the high gain/loss ratio in the concerned zone and month.
heating requirements

\[ Q_{HD} \]

a. total heat supplied by the radiators; comparison of unsteady state calculation with the simplified method.

b. total gains versus losses, showing that in autumn and spring the heat demand is a very small difference of two large numbers.

Figure 25. Verification of TCM-heat against DYWON unsteady state calculations in a complicated multi-zone situation; case with unheated bedrooms.
mean ambient temp. as seen by living-room θa

outdoor air temp. θe

living room temp. θi,real

mean indoor temperature of the living room and bedroom North.

Figure 26. Verification of TCM-heat against DYWON unsteady state calculations in a complicated multi-zone situation; case with unheated bedrooms; mean indoor temperature of the living room and bedroom North. The figure also shows the weighted mean ambient temperature, θa as experienced by the living room (weighted mean of outdoor, ground and adjacent rooms).
Figure 27. Verification of TCM-heat against DYWON unsteady state calculations in a complicated multi-zone situation; case with heated bedrooms. Presented are the heating requirements for the total dwelling, for the living room and for the South bedroom; the heating requirements are the amounts of heat supplied by the radiators.
Figure 28. Verification of TCM-heat against DYWON unsteady state calculations in a complicated multi-zone situation; case with heated bedrooms; mean indoor temperature of the living room and bedroom South. The figure also shows the weighted mean ambient temperatures as experienced by both rooms (weighted mean of outdoor, ground and adjacent rooms).
8. SENSITIVITY STUDIES WITH TCM-HEAT TO ILLUSTRATE THE INFLUENCE OF WINDOWS IN TYPICAL SITUATIONS

8.1 Introduction

As illustration of the possibilities of the simplified method TCM-heat a number of calculations have been performed. A reference dwelling has been selected and a number of characteristics have been varied which show the influence of the changes on the heat demand. In the selection of variations the emphasis was put on the effect of windows.

The number of variations is kept limited for two reasons:
1. the simplified method is easy to use for similar sensitivity analyses, using different assumptions or conditions;
2. a high number of variations would suggest that all possible situations have been covered; one of the most attractive aspects of TCM-heat is, however, that it provides the heat demand 'tailor-made' to a specific situation, taking into account from month to month the gain utilization factor as a function of the specific gainloss ratio, and the interaction with other zones.

8.2 Description of the reference case and the variations

The reference case has been based upon the dwelling used for the verification of TCM-heat in the previous chapter. Some details have, however, been modified to turn the quite "extreme" case into a "typical" case for highly insulated dwellings.

The modifications are:
- the ventilation rate has been changed from 0.50 to 0.80 air changes per hour;
- the house is assumed to be at the end of a row (semi-detached), instead of in the middle;
- the groundwater level is 3 meters below the groundfloor instead of 10 meters, resulting in a conductance of 0.33 instead of 0.12 W/m²K (see table 14).

The data for the reference case as used for the input in TCM-heat are presented in table 17. Figure 29 presents the 35 variations which were selected for the sensitivity analysis. The window type variations are explained in table 18.
Table 17. Reference case for the sensitivity studies: input data
the calculations with TCM-heat.
(see chapter 4 for the explanation of the symbols).

<table>
<thead>
<tr>
<th>Zone</th>
<th>Category*</th>
<th>θ_{set} (°C)</th>
<th>Aw (m²)**</th>
<th>Aop (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>E</td>
<td>W</td>
</tr>
<tr>
<td>1. living-room</td>
<td>b-1</td>
<td>19.1</td>
<td>5.5</td>
<td>0</td>
</tr>
<tr>
<td>2. kitchen</td>
<td>b-1</td>
<td>19.1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. bedroom South</td>
<td>b-1</td>
<td>18.0</td>
<td>3.5</td>
<td>0</td>
</tr>
<tr>
<td>4. bedroom North</td>
<td>b-1</td>
<td>18.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5. attic</td>
<td>-b-</td>
<td>unheated</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* : acc. to table 13
** : actually: glazing area
***: in fact: tilted roof, but only relevant for solar absorption
(influence is small).

<table>
<thead>
<tr>
<th>Zone</th>
<th>Type nr.</th>
<th>Façade</th>
<th>Roof (hor.)</th>
<th>Ground-floor**</th>
<th>To other zones</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>U_{op} (W/m²K)</td>
<td>U_{op} (W/m²K)</td>
<td>U_{fl} (W/m²K)</td>
<td>U_{WA} (W/K)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>θ_{op} (°C)</td>
<td>θ_{op} (°C)</td>
<td>θ_{op} (°C)</td>
<td>to 1</td>
</tr>
<tr>
<td>1. living room</td>
<td>46</td>
<td>0.40</td>
<td>0.80</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>2. kitchen</td>
<td>46</td>
<td>0.40</td>
<td>0.80</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>3. bedroom South</td>
<td>46</td>
<td>0.40</td>
<td>0.80</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>4. bedroom North</td>
<td>46</td>
<td>0.40</td>
<td>0.80</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>5. attic</td>
<td>--</td>
<td>0.40</td>
<td>0.80</td>
<td>0.20</td>
<td>0.50</td>
</tr>
</tbody>
</table>

* : see table 18
** : under floor: conduct. to 10°C: 0.33 W/m²K, to outdoor: 0.50 W/m²K.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Φ_{int} (W)</th>
<th>Ventilation (m³/h) from other zones</th>
<th>Idem from outdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>from 1</td>
<td>from 2</td>
</tr>
<tr>
<td>1. living room</td>
<td>230</td>
<td>--</td>
<td>0</td>
</tr>
<tr>
<td>2. kitchen</td>
<td>210</td>
<td>24.0</td>
<td>--</td>
</tr>
<tr>
<td>3. bedroom South</td>
<td>47</td>
<td>11.2</td>
<td>0</td>
</tr>
<tr>
<td>4. bedroom North</td>
<td>23</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5. attic</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Climates: TRY De Bilt (see section 4.4, table 3).
1-15: ref. case, with variation of window size and orientation:

1-6: S-N

7-15: E-W

16-24: Window type variations in living room and kitchen only:
16-18: glazing replaced by low U-glazing
19-21: as ref. case, but not solar shading.
(see table 18)

22-24: as ref. case, but no night insulation

25-27: Variations in the bedrooms:
25: South window size

26-27: glazing replaced by low U-glazing in whole dwelling

28-30: light weight building construction (cat. b-3):

31-36: unheated bedrooms:
31-33: as ref. case, but bedrooms unheated:

34-36: unheated bedrooms with 5 cm thermal insulation in bedroom floors

Figure 29. The variations on the reference case.
Table 18. The window types and glazing sizes used in the sensitivity studies. (see chapter 4 for the explanation of the symbols).

<table>
<thead>
<tr>
<th>Type and symbol in fig. 29</th>
<th>Description</th>
<th>(U^*) (W/m²K)</th>
<th>(g^*) (-)</th>
<th>(r^*) (-)</th>
<th>(z^*) (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>clear double glazing, (d=12) mm.</td>
<td>internal blinds, light curtain</td>
<td>2.9</td>
<td>0.70</td>
<td>0.78</td>
<td>0.68</td>
</tr>
<tr>
<td>idem as 46</td>
<td>none</td>
<td>2.9</td>
<td>0.70</td>
<td>0.78</td>
<td>1.00</td>
</tr>
<tr>
<td>idem as 46</td>
<td>idem as 46</td>
<td>none</td>
<td>2.9</td>
<td>0.70</td>
<td>1.00</td>
</tr>
<tr>
<td>double glazing, with low E coating on cavity side of inner pane</td>
<td>idem as 46</td>
<td>idem as 46</td>
<td>1.8</td>
<td>0.58</td>
<td>0.85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Glazing size (m²)</th>
<th>Living room</th>
<th>Living room</th>
<th>Bedroom frontside</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>frontside</td>
<td>backside</td>
<td></td>
</tr>
<tr>
<td></td>
<td>m²</td>
<td>% of floor area</td>
<td>m²</td>
</tr>
<tr>
<td>small</td>
<td>3.0</td>
<td>7</td>
<td>3.0*</td>
</tr>
<tr>
<td>medium</td>
<td>5.5*</td>
<td>13*</td>
<td>5.5</td>
</tr>
<tr>
<td>large</td>
<td>8.0</td>
<td>20</td>
<td>8.0</td>
</tr>
</tbody>
</table>

* = reference case

* the presented properties are typical values for the indicated type; the values will in general differ from product to product, depending on the actual specifications.
Table 19. Three examples of monthly results to illustrate the kind of output produced by TCM-heating; reference case.

January (Midwinter, low gains):

<table>
<thead>
<tr>
<th>month</th>
<th>zone</th>
<th>Temp.</th>
<th>Tamb.</th>
<th>Te</th>
<th>GLR</th>
<th>½G</th>
<th>DTR</th>
<th>DTA</th>
<th>QL</th>
<th>QLreal</th>
<th>OG</th>
<th>QHD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>C</td>
<td>C</td>
<td></td>
<td>C</td>
<td>-</td>
<td>-</td>
<td>C</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>17.4</td>
<td>11.9</td>
<td>2.5</td>
<td>0.39</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>2663</td>
<td>2633</td>
<td>1037</td>
<td>1626</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>17.4</td>
<td>13.9</td>
<td>2.5</td>
<td>0.72</td>
<td>0.99</td>
<td>1.01</td>
<td>0.03</td>
<td>862</td>
<td>870</td>
<td>623</td>
<td>247</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>16.5</td>
<td>13.1</td>
<td>2.5</td>
<td>0.23</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>1532</td>
<td>1532</td>
<td>349</td>
<td>1183</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>16.5</td>
<td>13.1</td>
<td>2.5</td>
<td>0.11</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>1412</td>
<td>1412</td>
<td>157</td>
<td>1255</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>12.7</td>
<td>12.7</td>
<td>2.5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>24</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>6468</td>
<td>6501</td>
<td>2190</td>
<td>4311</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

March (Early spring, some overheating):

<table>
<thead>
<tr>
<th>month</th>
<th>zone</th>
<th>Temp.</th>
<th>Tamb.</th>
<th>Te</th>
<th>GLR</th>
<th>½G</th>
<th>DTR</th>
<th>DTA</th>
<th>QL</th>
<th>QLreal</th>
<th>OG</th>
<th>QHD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>C</td>
<td>C</td>
<td></td>
<td>C</td>
<td>-</td>
<td>-</td>
<td>C</td>
<td>MJ</td>
<td>MJ</td>
<td>MJ</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>17.9</td>
<td>13.2</td>
<td>5.6</td>
<td>0.82</td>
<td>0.96</td>
<td>1.03</td>
<td>0.15</td>
<td>2192</td>
<td>2252</td>
<td>1756</td>
<td>467</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>18.2</td>
<td>14.9</td>
<td>5.6</td>
<td>1.09</td>
<td>0.84</td>
<td>1.17</td>
<td>0.49</td>
<td>698</td>
<td>816</td>
<td>761</td>
<td>56</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>16.8</td>
<td>14.3</td>
<td>5.6</td>
<td>0.63</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>1148</td>
<td>1149</td>
<td>724</td>
<td>425</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>16.8</td>
<td>14.3</td>
<td>5.6</td>
<td>0.36</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>1045</td>
<td>1045</td>
<td>373</td>
<td>671</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>14.0</td>
<td>13.7</td>
<td>5.6</td>
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April (Spring, small heat demand):

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8.3 Calculated annual heat demands

In table 19 the monthly results are presented for three different months for the reference case, as an example of the kind of output produced by TCM-heat.

Table 20 shows the annual heat demand for each of the 36 cases calculated with the simplified method TCM-heat.

The results have been presented in figure 30 as a function of the glazing area. In figure 30a this is the glazing area of the South window in the living room, in figure 30b the same window, but now turned to the East orientation; in figure 30c the bedroom South glazing area is the variable on the horizontal axis.

Comparison of the results leads to the following observations:

curve a: reference case:
(1+2+3) Effect of varying South glazing area: slight decrease in annual heat demand with increasing glazing area (roughly $-125 \text{ MJ/m}^2$).

curve b: as reference case, but increased glazing area on North façade of the living room:
(4+5+6) Compared with reference: increased heat demand as North glazing area increases ($+175 \text{ MJ/m}^2$). Effect of varying South glazing area: same tendency as in reference case (roughly $-110 \text{ MJ/m}^2$).

curve c: as reference case, but orientation of whole dwelling turned to East-West:
(10+11+12) Compared with reference: heat demand increased with about 1000 MJ; or: 57 MJ/m², mixed value for North-South and groundfloor + 1st floor. Effect of varying East glazing area: slight increase in heat demand with increasing glazing area (roughly $+60 \text{ MJ/m}^2$).
Table 20. Annual heat demand for the whole dwelling calculated with TCH-heat.

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Figure 30a. As function of the glazing area of the South façade of the living room in South/North orientation.

Figure 30. Annual heat demand for the whole dwelling as function of the variations on the reference case.

EXPLANATION:

- variations in living-room + kitchen
  - a. ref. (only glaz. area varied)
  - b. increased glazing north façade
  - f. low U-glazing
  - g. no solar shading
  - h. no night insulation

Variation in whole dwelling
  - k. light weight construction
  - l. unheated bedrooms
  - m. unheated bedrooms and insulated intermediate floor
Figure 30b. As function of the glazing area of the South oriented bedroom.

Figure 30c. As function of the glazing area of the East façade of the living room in East/West orientation.
curve d: as c, but increased glazing area on West façade of the
living-room:
Compared with c: again, a slight increase with
increasing glazing area (roughly +65 MJ/m²). Effect of
varying East glazing area in this situation: roughly
+80 MJ/m²).

curve e: as d, but glazing area on West façade of living room
(13+14+15) increased furthermore:
Compared with d: heat demand increased with roughly
+90 MJ/m². Effect of varying East glazing area now:
roughly +110 MJ/m².

curve f: as reference case, but glazing in living room and
(16+17+18) kitchen replaced by glazing with better U-value:
Compared with reference: decrease in heat demand roughly
1250 MJ; or: -115 MJ/m², mixed value for North + South.
Effect of varying South glazing area: a strong decrease
in heat demand with increasing glazing area (roughly
-220 MJ/m²).

curve g: as reference case, but no solar shading in the living
(19+20+21) room and kitchen:
Compared with reference: decrease in heat demand roughly
460 MJ, or -85 MJ/m² of the South window (for the North
windows the climate factor \( F^0_{0.5} \) = 0: shading never
used). Effect of varying South glazing area: a stronger
decrease with glazing area compared to curve a: roughly
-175 MJ/m².

curve h: as reference case, but no night insulation in the living
(22+23+24) room and kitchen:
Compared with reference: increase in heat demand roughly
+800 MJ; or: +75 MJ/m² (mixed value for North + South).
Effect of varying South glazing area: a weaker decrease
with glazing area compared to curve a: roughly
-60 MJ/m².
curve i: as reference case, but increased glazing area in South bedroom:
(1+25)
Compared with reference: a decrease in heat demand of -150 MJ/m².

curve j: as reference case, but glazing in whole dwelling replaced by glazing with better U-value:
(26+27)
Compared with reference: a decrease in heat demand of around -2000 MJ; or: -110 MJ/m², mixed value for North + South and groundfloor + 1st floor. Compared with f: effect for the whole dwelling per m² about the same as effect for only the groundfloor per m².

curve k: as reference case, but lightweight construction instead heavy weight:
(28+29+30)
Compared with reference: around 900 MJ increase in annual heat demand. Effect of varying South glazing area in the living room: slight decrease in heat demand of around -110 MJ/m² with increasing glazing area.

curve l: as reference case, but bedrooms unheated:
(31+32+33)
Compared with reference: a strong decrease in heat demand, around -4000 MJ, or 25 percent of the original amount. The calculated mean temperature in the bedrooms in January is still 11-12 °C. Effect of varying South glazing area in the living room: again a slight decrease in heat demand with increasing glazing area (-100 MJ/m²).

curve m: as l, but with 5 cm. thermal insulation in the floor of the bedrooms:
(34+35+36)
Compared with l: again a strong decrease in annual heat demand: around -3000 MJ, or 25 percent of the value without insulation of the intermediate floor, but the mean temperature in the bedrooms in January has dropped to 7-8 °C. Effect of varying South glazing area in the living room: only a very slight decrease in heat demand with increasing glazing area (around -50 MJ/m²).
8.4 Indication of overheating

The simplified method TCM-heat also provides the monthly values of dTA for each zone: the mean (absolute) overheating: the number of degrees K that the mean zone temperature exceeds the thermostat value, after correction for the temperature drop due to night setback (see definitions in section 3.5). In the examples in table 19 for the reference case typical values can be found. The highest value there is 1.4 °C, for the kitchen in April. A number of variants have a lower annual heat demand. This is the result of one or more of the following effects:
- higher gain utilization curve (see k);
- lower thermostat values (see l);
- lower overall loss coefficient (various cases);
- higher ambient temperatures (various cases);
- more gains (various cases).

With the first two kinds of variations a decrease in monthly heat demand is not accompanied with an increase of the monthly mean zone temperature. In the three last mentioned kinds of variations a decrease in monthly heat demand implies that the monthly mean zone temperature rises, unless the gainloss ratio is still sufficiently low to have a gain utilization factor nG = 1.

A few examples of the mean overheating are presented in figure 31. The presented values are for the month April, for both the living room and the South bedroom. It is difficult to judge the results presented in figure 31, because the relation between peak temperatures and the presented mean values is (still) unknown. Nevertheless, the various cases can be compared on a relative basis. Some interesting cases (see figure 31):

curve m: The cases with the highest overheating in the living room are at the same time the cases with the lowest heat demand: unheated bedrooms and insulated intermediate floor. Despite the fact that the added insulation thickness is much less than the insulation already provided in ground floor, walls and roof.
curve g: The cases without the indoor blinds applied in the living room and kitchen also lead to a relatively high overheating, even more than the cases with low U-glazing in those two zones (curve f), despite the fact that - on an annual basis! - the latter cases have a lower heat demand (see figure 30a). It is also typical to see the influence of the absence of blinds in the living room on the overheating in the South bedroom.

curve k: The influence of the building mass on the monthly mean temperature rise appears to be very small: the influence of the glazing area (and thus the GLR-value) is here much larger than the effect of the lower gain utilization curve $\eta_C$ (GLR) itself.

8.5 Discussion

For the selected reference case an increase of the glazing area of the double glazed South window has a (small) beneficial effect on the annual heating requirements. This is valid for both the living room and the South bedroom, if heated (curves a and i). If no night insulation is applied the beneficial effect is less (curve h); if glazing with a better U-value is applied the effect is larger (curve f). But the effect of an increase of the glazing area also depends on the particular situation. The values for the decrease in annual heat demand presented in the previous section vary for the same type of glazing (double glazing, with night insulation and solar shading) between -50 MJ/m² (curve m) and -125 MJ/m² (curve a). Figure 31 shows the effect on overheating: the potential beneficial effect on an increased glazing area is in the cases of curve m for a bigger part "dissipated" in the form of overheating than in the cases represented by curve a.

This illustrates the advantage of the tool TCM-heat now being available: the effect of a certain measure can be calculated "tailor-made" to the particular situation.
Figure 31a. As function of the glazing area of the South façade of the living room in South/North orientation.

EXPLANATION:

- variations in living-room + kitchen
  - a. ref. case (only glaz. area varied)
  - f. low U-glazing
  - g. no solar shading

- Variations in whole dwelling
  - k. light-weight construction
  - m. unheated bedrooms and insulated intermediate floor

Figure 31. Some examples of the calculated value for the monthly mean overheating $dT_a$ in April, for the living room and the South bedroom.
Figure 31b. As function of the glazing area of the South oriented bedroom.
9. CONCLUSIONS

This report documented the activities and results of the Netherlands within Step 5 of the IEA R&D project "Windows and Fenestration".

A method has been introduced to calculate by hand monthly heat losses and gains. Simple correction factors have been introduced to deal with special situations. Particular attention was given to the influence of various types of window systems.

Correlation factors have been proposed to take into account unsteady state effects; the gain utilization factor $\eta_G$ as function of the gain loss ratio GLR and the correction factor for thermostat setback during night ($C_N$) or during non-office hours ($C_{NWH}$). Furthermore a parameter $dT_R$, the mean relative overheating has been introduced, giving some indication of the overheating due to non-utilized gains.

The following novel aspects of the method compared to other existing methods were identified:

- the applicability of the method for office buildings without mechanical cooling;
- the applicability of the method in a multizone situation with exchange of heat by transmission and/or ventilation between different spaces;
- the rough indication of thermal comfort by the introduction of the relative overheating.

The main limitation of the method in comparison with some of the other methods is that passive solar elements other than "direct gain" fenestration, like collector storage walls, have not (yet) been included.

Series of parameter studies using the unsteady state computer model DYWON have been reported. The results of these calculations made it possible to quantify the correlation factors mentioned above.

With the correlation factors a simplified calculation method has come available to calculate the space heating requirements for a wide range of situations (TCM-heat).
The simplified method has been verified against a calculation with DYWON for two complicated multizone situations, in a highly insulated dwelling. Although the selected cases were quite extreme, the agreement in annual heating requirements for the whole dwelling appeared to be satisfactory. Some deviation occured in the distribution over the months due to the fact that for some months the heat demand is the very small difference between the much larger heat loss and almost equal gains. Some deviation also occured in the distribution over the zones, due to the strong interaction between the zones in the well insulated building.

Finally, examples have been presented of one of the possible applications of the method, namely to show the influence of window size, type and orientation on the energy consumption for space heating in a selected number of typical situations. These examples illustrated that the influence of a change in window size, type or orientation may depend on the actual conditions like, for instance, climate, type of use of the considered zone, insulation level and also the conditions in the adjacent zones.

With TCM-heat the influence of the window on energy consumption can be calculated "tailor-made" to a particular situation.

The introduced quantities mean relative overheating, $dT_R$, and mean absolute overheating, $dT_a$, appeared to be useful indicators for the thermal comfort situation. The relation with peak temperature, however, has not been investigated.

Although TCM-heat is basically a hand calculation method, the calculation is inevitably complicated in case of a multizone situation. With the Fortran-version of TCM-heat, however, also complex multizone situations can be dealt with easily.

Technisch Physische Dienst

Ir. H.A.L. van Dijk

Delft, December 1987
REFERENCES


[16] ISSO research rapport 3, Vereenvoudigde berekeningsmethode en richtwaarden voor het energiegebruik in gebouwen, deel 1, verwarming van woningen, (Simplified calculation method and target values for the energy consumption in buildings, part 1, heating of dwellings), The Hague, October 1986.


7. LIST OF PARTICIPANTS IN ANNEX XII

The underlying report is a record of the activities carried out by the Netherlands within the framework of Step 5 of the IEA Research Project Annex XII, Windows and Fenestration.

The participants in Annex XII are:

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<tr>
<td>P. Wouters</td>
<td>Belgian Building Research Institute</td>
<td>Lombardstraat 41 B-1000 BRUSSEL</td>
<td>BELGIUM</td>
</tr>
<tr>
<td>H. Erhorn,</td>
<td>Fraunhofer Institut</td>
<td>Nobelstrasse 12 D-7000 STUTTGART 80</td>
<td>FR GERMANY</td>
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<tr>
<td>R. Stricker,</td>
<td>für Bauphysik, Dir.Prof.Dr.-Ing.</td>
<td></td>
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<tr>
<td>M. Szerman</td>
<td>habil, K.A. Gertis</td>
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<tr>
<td>F. Brunello</td>
<td>Istituto di Fisica Tecnica</td>
<td>Viale Ungheria 43 I-35100 UDINE</td>
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<tr>
<td>K.Th. Knorr</td>
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<td>A. Nielsen</td>
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<td>J.B. Gay</td>
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<td>T. Frank</td>
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<td>P.G.T. Owens</td>
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<td>J.H. Klems,</td>
<td>Lawrence Berkeley Laboratory</td>
<td>1, Cyclotron Road BERKELEY, CALIFORNIA</td>
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APPENDIX 2

Detailed description of the cases used in the series of unsteady state calculations.
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All cases with nights set back, \(U_{\text{r}} = 0.69 \text{ W/m}^2\text{K}, \) for code F \(\ldots U_{\text{r}} = 0.66 \text{ W/m}^2\text{K}, \) for code \(\ldots U_{\text{r}} = 0.63 \text{ W/m}^2\text{K}.\)
### Category a-2 Dwellings Masonry type (heavy weight)

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All cases without setback, $U = 0.69 \text{ W/m}^2\text{K}$, for code $F$...: $U = 0.66 \text{ W/m}^2\text{K}$, for code $W$...: $U = 0.69 \text{ W/m}^2\text{K}$

### Category a-3 Dwellings Masonry type (light weight, wooden frame)

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All cases with setback, $U = 0.69 \text{ W/m}^2\text{K}$. For code $F$...: $U = 0.66 \text{ W/m}^2\text{K}$, for code $W$...: $U = 0.69 \text{ W/m}^2\text{K}$

---

TPD nummer 712.003 blad - 109 -
### Category b-1 Dwellings Masonry type (heavy weight)

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All cases with night setback

For all cases $A_{n} = 12.5 m^2$, $V = 45 m^3/h$, $Q_{int} = 230 W$, $A = 0 m^2$, $r = 1.0$, $O = 10.4 ^{0}C$

### Category b-2 Dwellings Masonry type (heavy weight)

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Case without Night setback

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All cases with night setback

For all cases $A_{n} = 12.5 m^2$, $V = 45 m^3/h$, $Q_{int} = 230 W$, $A = 0 m^2$, $r = 1.0$, $V = 0.59 W/mK$

For $A_{r} = 4.5 m^2$, $U_{n} = 0.59 m^3/h$, $Q_{int} = 230 W$, $A = 1.0 m^2$, $r = 1.0$, $Q = 0.59 W/mK$
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</tbody>
</table>

For all cases: U_{v} = 0.61 \, W/m^2K \quad U_{r} = 0.61 \, W/m^2K \quad \theta = 22^\circ \quad \frac{1}{1} \text{set/\text{min}}
**Category c-3 Offices light weight**

<table>
<thead>
<tr>
<th>Model</th>
<th>$A_{ws}$</th>
<th>$A_{wn}$</th>
<th>$A_{ww}$</th>
<th>$A_{fs}$</th>
<th>$A_{fn}$</th>
<th>$A_{fe}$</th>
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</tbody>
</table>

For all cases $U = 0.61 \text{ W/m}^2 \text{K}$, $U = 0.61 \text{ W/m}^2 \text{K}$, $G = 22 \text{ C}$, $z = 0.58$, $g = 0.80$, $r = 1 \text{ set day}$, $U_w = 5.9 \text{ W/m}^2 \text{K}$, $V = 10 \text{ m}^3$/h, $V = 70 \text{ m}^3$/h, $A_r = 0 \text{ m}^2$

**Category c-5 Offices extra heavy weight**

<table>
<thead>
<tr>
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<th>$A_{ww}$</th>
<th>$A_{fs}$</th>
<th>$A_{fn}$</th>
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<td>N311W</td>
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</table>

For all cases $U = 0.61 \text{ W/m}^2 \text{K}$, $U = 0.61 \text{ W/m}^2 \text{K}$, $G = 22 \text{ C}$, $z = 0.58$, $g = 0.80$, $r = 1 \text{ set day}$, $U_w = 5.9 \text{ W/m}^2 \text{K}$, $V = 10 \text{ m}^3$/h, $V = 70 \text{ m}^3$/h, $A_r = 0 \text{ m}^2$
APPENDIX 3

Listing of the FORTRAN version of the TPD Correlation based Multizone calculation method TCM-heat.

This version has been written for the calculations with TCM-heat described in chapters 7 and 8 only.

No attempt has been made to produce a complete, widely applicable and user-friendly software version.

The listing of this FORTRAN-version is purely informative.
Program TCMHEAT
Created 87/12/04 TCMHEAT1:
max. number of zones extended.
other orientations added.
input changed. for test: TCM.IN1 available
climate as separate input file. For test: TCM.TRY1 available.
Author: H.A.L. van Dijk
Copyright:
TNO Institute of Applied Physics
Stieltjesweg 1, Delft, The Netherlands
Calculation of the HEAT requirements and temperatures in a Multizone situation
according to the TPD Monthly based calculation Method.
See publication IEA Annex XII, Step 5, December 1987

program limitations

see also report ! a.o. for the description of the various categories of
situations for which the given parameters values and
equations are valid.

other limitations of this program:
* general:
- for windows and opaque surfaces: 9 orientations
  have been defined: 8 vert. plus hor. ; opaque tilted roof
can be approximated by hor. or vert.: influence of absorbed
solar energy there is small.
- correction for cold surfaces not yet implemented:
  this would require the input of all bounding surfaces; not
only surfaces with heat exchange.
  this correction is needed only in case of convective heating
with room thermostat acting on air temp., which may lead to
uncomfortably cold zone conditions; therefore this correction
will only be used for comparison with other calculations where
such combination is assumed.

* offices:
- window insulation during non office hours not yet implemen-
ted.
- for mech. vent. and internal heat: 10 working hrs. per
working day assumed.

declarations

CHARACTER FILNAM*17, CODEB*10, CODEC*10, TEXT*78
INTEGER OR
DIMENSION TE1(12), TE2(12), QS1(12,9), QS2(12,9),
  FQ51(12,9), FQ52(12,9), FQ31(12,9), FQ32(12,9),
  D1(12), D2(12), FTN1(12), FTEN1(12), FVD2(12), FTWH2(12)
DIMENSION XUV(54), XGW(54), XRUN(54), XZSH(54)
COMMON/CLIZO/TE(9), QS(9,9), FQ(9,9),
  D(9), FTN(9), FTEN(9), FVD(9), FTWH(9), DTFAC(9)
COMMON/ZCHAR/AW(9,9), AOP(9,9), UFAC(9), UROOF(9), ABSF(9), ABSR(9),
  UAADJ(9,9), AFL(9), UFL(9), YGR(9), YGRE(9), TGR(9), HL(9)
COMMON/ZCOND/TI(10), TIOLD(9), TA(9), TG(9), TIMIN(9), TISNWH(9),
  TIS(9), QI(9), QIS(9), V(9,10), WN(9,10)
COMMON/WIZO/KW(9), UW(9), GV(9), R(9), Z(9)
COMMON/METH/KCAT(9), CN(9), CNWH(9), KK(9), DD(9), QL(9), QLREAL(9),
  QG(9), QHD(9), GLR(9), CG(9), DTR(9), DTA(9)
COMMON/ZTOT/QLT(9),QLRLT(9), QGT(9), QHDT(9)
COMMON/BLD/ QLB(12), QLRLB(12), QGB(12), QHDB(12)
COMMON/BZTOT/QLBT, QLRLBT, QGBT, QHDBT

Characteristics of window combinations, type (KW) 1-54:
types 1-20: see report table 9 (used for category -a-)

TPD
types 21-25: window types used for category -b-, see table 11

types 26-30: values for a North orientation

types 31-35: values for a South orientation

types 36-40: not used

Types 41-45: values used for category -c-, see report table 12

Types 46-55: values used in the verification (chapter 7) and in the sensitivity studies (chapter 8 of the report)

DATA XUW/7*5.9,3.6,5.9,3*3.2,1.8,2.2,2.2,3.2,3.2,3*0.,
# 5.8,2.9,0.,1.9,1.4,5*0.,5.8,2.9,0.,1.9,1.4,
# 5*0.,5.9,5.9,2.9,2.9,0.,2.9,2.9,2.9,0.,
# 1.8,1.8,1.8,1.8/

DATA XGV/7*.80,.71,.80,3*.70,.66,.57,.57,.70,.70,3*,
# .78,.64,0.,.56,49,5*0.,.82,.71,0.,.62,.54,
# 5*0.,.80,.80,.70,.70,0.,.70,.70,.70,0.,
# .58,.58,.58,.58/

DATA XZSH/1.,.58,.58,.59,1.,59,70,.59,1.,.69,7,1,1.,.81,
# .67,1,1.,3*0.,
# .56,70,1,1.,77,76,5*0.,56,68,1,1.,74,.81,
# 5*0.,.58,21,69,19,0.,68,1,0,68,1,00,0,
# .76,1,0,76,1,00/

DATA XRUN/1.,1.,75,.61,.64,.41,.47,.58,.44,1,1.,63,1,1.,.82,
# .59,.66,3*0.,
# 1,1,1,1,1,1,5*0.,1,1,1,1,1,1,,
# 5*0,1,1,1,1,1,0,.78,.78,1,00,1,00,0,,
# .85,.85,1,00,1,00/

control of files

!!!LFNIB =10
!!!LFNIC =20
!!!LFNU =30
!!!LFNT1=3
!!!LFNT2=LFNT1
!!!OPEN(LFNT1)
!!!OPEN(LFNT2)

WRITE(LFNT2,1)
1 FORMAT(’give name of input file building data’,/)
READ(LFNT1,FMT=’(A)’,IOSTAT=IOS) FILNAM
OPEN(LFNB,FILE=FILNAM,STATUS=’OLD’,IOSTAT=IOS)

WRITE(LFNT2,2)
2 FORMAT(’give name of input file climata data’,/)
READ(LFNT1,FMT=’(A)’,IOSTAT=IOS) FILNAM
OPEN(LFNC,FILE=FILNAM,STATUS=’OLD’,IOSTAT=IOS)

WRITE(LFNT2,3)
3 FORMAT(’give name of output file’,/)
READ(LFNT1,FMT=’(A)’,IOSTAT=IOS) FILNAM
OPEN(LFNU,FILE=FILNAM,STATUS=’OLD’,IOSTAT=IOS)

**********************************************************************

KCATB: 29 or less: dwelling
30 or greater: office

MSTART,MEND: first and last month of calculation (e.g.: 10, 4 = oct.1-apr.30)

READ (LFNB,*) KCATB, MSTART, MEND

WRITE (LFNU,600) KCATB, MSTART, MEND
600 FORMAT(’0 general category:’,I5,/,
# ’ first month :’,I4,/,
# ’ last :’I4)

**********************************************************************

input of climata data

warning: for the time being only one type of climate:
either "dwelling" or "office" climate data can be used for the whole building.

READ (LFNIC,*) CODEC
IF (KCATB.LT.30) THEN
  READ (LFNIC,*) TE1, QS1, FQ51, FQ31, DI, FTN1, FTCN1
  WRITE (LFNU, 1050) CODEC, (M, M=1, 12),
  & ((Q51(M, OR), M=1, 12), OR=1, 9),
  & ((D1(M), M=1, 12), (FTN1(M), M=1, 12))
  ** 1050 FORMATTED (10, A10, /)
  & ' month : ', 12I8, /
  & ' Te : ', 12F8.1, /
  & ' Qs (or.) : ', 12F8.1, /
  & ' Fq5(or.) : ', 12F8.2, /
  & ' Fq3(or.) : ', 12F8.2, /
  & ' D : ', 12F8.1, /
  & ' FTn : ', 12F8.2, /
ELSE
  READ (LFNIC,*) TE2, QS2, FQ52, FQ32, D2, FWD2, FTCWH2
  WRITE (LFNU, 1051) CODEC, (M, M=1, 12),
  & ((Q52(M, OR), M=1, 12), OR=1, 9),
  & ((D2(M), M=1, 12), (FTWH2(M), M=1, 12))
  ** 1051 FORMATTED (10, A10, /)
  & ' month : ', 12I8, /
  & ' Te : ', 12F8.1, /
  & ' Qs (or.) : ', 12F8.1, /
  & ' Fq5(or.) : ', 12F8.2, /
  & ' Fq3(or.) : ', 12F8.2, /
  & ' D : ', 12F8.1, /
  & ' Fwd : ', 12F8.2, /
  & ' FTCWH : ', 12F8.2)
ENDIF

numerical calculation control data

NITER= max. nr. of iterations (e.g. 100)
BALCRI= iteration criterion in degrees C (e.g. .001)
KOUT=1: temperatures during iteration are listed in output (only for error-detection!!)

READ (LFNIB,*) NITER, BALCRI, KOUT

collect building characteristics, total and per zone;
determine occupants' behaviour;
determine heating system and control.

NIR= number of zones

READ (LFNIB,*) CODEB, NIR

DO 10 IR = 1, NIR
  KCAT= category, see explanation further on
  TISET= min. thermostat setpoint; will be ignored in case of category for unheated zones.
  TISNWH= set min. temp. during non-office hours (offices; other categories: zero value).
  NOR= number of orientations with window and/or wall and/or roof (of this zone)
READ(LFNIB,*) IHE,KCAT(IR),TISE(T),TISW(H),(IR),NOR

check:
IF(IHE.NE.IR) GOTO 99
DO 6 IHE = 1, NOR
A=area, W=window, OP=opaque
orientation: 1=S, 2=SE, 3=E, 4=NE, etc.,... 9=Hor.

READ(LFNIB,*) OR,AHE1,AHE2

AW(IR,IR)=AHE1
AOP(IR,IR)=AHE2
6 CONTINUE
KW=window type number (see data), U=U-value, ABS=solar abs.coeff.,
FAC=facade, ROOF=roof (flat roof only, see "Limitations" above.

READ(LFNIB,*) IHE,KW(IR),UFAC(IR),ABSF(IR),UROOF(IR),ABSR(IR)

IHE=KW(IR)
UW(IR)=XUW(IHE)
GW(IR)=XGW(IHE)
R(IR)=XRUN(IHE)
Z(IR)=XZSH(IHE)
FL=groundfloor,
GR=ground, Y=conductance from bottom of floor to:
C=ground water with constant temp. TGR, E=to outdoor temp.
UFL=U-value excluding outdoor surface coefficient, because ground-
floor is connected to the ground conductances YGRC and YGRE, not
to outdoor.
If no ground floor: zero values.

READ(LFNIB,*) APL(IR),UFL(IR),YGRC(IR),TGR(IR),YGRE(IR)

UAADJ=UA to/from adjacent zones
Attention: in case less than 9 zones: add zero values to get
still 9 values per line.

READ(LFNIB,*) (UAADJ(IR,J),J=1,9)

QII=internal heat, mean value in W., for dwellings: mean diurnal,
for offices: mean during 10 working hours.

READ(LFNIB,*) QII(IR)

V=ventilation, mean diurnal values; "from zone 10" is "from outdoor".
Warning: only ventilation TO the zone; FROM the zone is to be
ignored. Value in m3/h.
Attention: in case less than 9 zones: use zero values for the
ventilation from non-existent zones.
Ventilation from outdoor ALWAYS THE TENTH NR. OF THE LINE!

READ(LFNIB,*) (V(IR,J),J=1,10)

VM=mechanical vent., only during 10 working hrs. per working day.(cat.C);
other categories: fill in zero values.
Attention: see above (input V)

READ(LFNIB,*) (VM(IR,J),J=1,10)

10 CONTINUE

output building data:
reset values summated for whole building:
HTWB=0.
HTOPB=0.
HTAB=0.
HTFB=0.
HVEB=0.
HVAB=0.
HTOTB=0.

**Heading:**
WRITE(LFNU,1150)

1150 FORMAT('Output main thermal characteristics, per zone: ',/,'Sum of nominal heat loss coefficients (W/K) ',/,'Nominal: no correction for night insulation ',/,'no weighting with temp. adjac. zone, a.s. ',/,'to outdoor: gr. floor: to other zones: ',/,'Zone Transmiss. Vent. Transm. Transm. Vent. Total ',/,'Wind. Opaq. floor ',/)
QHDBT=0.
QHDBT=0.

start month loop:

MTOT=MEND-MSTART+1
IF (MTOT.LE.0) MTOT=MTOT + 12
DO 100 HRUN = 1, MTOT
M=MSTART+MRUN-1
IF (M.GT.12) M=M-12
DO 101 IR = 1, NIR

determination of parameters for the given category

CAT=A: dwellings, convective heating thermostat controlled by air temp. no extra vent. above 26 C, solar shading at 300 W/m² level (if present)

10=A0: unheated.
11=A1: masonry type, night set back
12=A2: masonry type, continuous heating
13=A3: wooden frame type, night set back
14=A4: wooden frame type, continuous heating

IF(KCAT(IR).EQ.10) THEN
CN(IR)=0.
CNWHR(IR)=0.
KK(IR)=0.
DD(IR)=0.
ENDIF
IF(KCAT(IR).EQ.11) THEN
CN(IR)=0.91
CNWHR(IR)=0.
KK(IR)=1.36
DD(IR)=0.29
ENDIF
IF(KCAT(IR).EQ.12) THEN
CN(IR)=0.97
CNWHR(IR)=0.
KK(IR)=1.35
DD(IR)=0.27
ENDIF
IF(KCAT(IR).EQ.13) THEN
CN(IR)=0.88
CNWHR(IR)=0.
KK(IR)=1.22
DD(IR)=0.13
ENDIF
IF(KCAT(IR).EQ.14) THEN
CN(IR)=0.97
CNWHR(IR)=0.
KK(IR)=1.19
DD(IR)=0.00
ENDIF

CAT=B: dwellings, radiator heating, thermostat on comfort temp. extra vent. above 26 C, solar shading at 500 W/m² level (if present)

20=B0: unheated.
21=B1: heavy mass, night set back
22=B2: heavy mass, continuous heating
23=B3: light weight mass, night set back

IF(KCAT(IR).EQ.20) THEN
CN(IR)=0.
**determination of parameters for the given category**

**CAT=C**: offices (not mechanically cooled)
convective heating thermostat controlled by air temp
(30–39) no extra vent. above 26 C, solar shading at
300 W/m² (only offices hours) level

30=C0: unheated
31=C1: heavy weight
33=C3: light weight
35=C5: extra heavy weight

IF(KCAT(IR).EQ.30) THEN
    CN(IR)=0.
    CNW(IR)=0.
    KK(IR)=0.
    DD(IR)=0.
ENDIF

IF(KCAT(IR).EQ.31) THEN
    CN(IR)=0.
    CNW(IR)=1.0
    KK(IR)=1.55
    DD(IR)=-0.16
ENDIF

IF(KCAT(IR).EQ.33) THEN
    CN(IR)=0.
    CNW(IR)=1.0
    KK(IR)=1.14
    DD(IR)=-0.05
ENDIF

IF(KCAT(IR).EQ.35) THEN
    CN(IR)=0.
    CNW(IR)=1.0
    KK(IR)=1.64
    DD(IR)=-0.16
ENDIF

**climate data for this month and category and zone**
IF(KCAT(IR).LT.30) THEN
  TE(IR)=TE1(M)
  DO 111 OR=1,9
       QS(OR,IR)=QS1(M,OR)
  CONTINUE
  Warning: if offices and dwellings are mixed then the days do not match !!!
  D(IR)=D1(M)
  PTN(IR)=PTN1(M)
  PTEN(IR)=PTEN1(M)
  FWD(IR)=0.
  FTWH(IR)=0.
ENDIF
IF(KCAT(IR).GE.10.AND.KCAT(IR).LT.20) THEN
  DO 113 OR=1,9
       QF(OR,IR)=QF31(M,OR)
  CONTINUE
ENDIF
IF(KCAT(IR).GE.20.AND.KCAT(IR).LT.30) THEN
  DO 115 OR=1,9
       QF(OR,IR)=QF51(M,OR)
  CONTINUE
ENDIF
IF(KCAT(IR).GE.30.AND.KCAT(IR).LT.40) THEN
  TE(IR)=TE2(IR)
  D(IR)=D2(IR)
  PTN(IR)=PTN1(M)
  PTEN(IR)=PTEN1(M)
  FWD(IR)=0.
  FTWH(IR)=0.
  DTN(IR)=D(IR)*24.*.0036
  DTFAC(IR)=D(IR)*24.*.0036
ENDIF

** determine night set back correction and initial guess for real indoor temp. **
** only for heated zones: **
IF (KCAT(IR).GT.10.AND.KCAT(IR).LT.20) THEN
  TIMIN(IR)=CN(IR)*TISET(IR)+(1.-CN(IR))*TE(IR)
ENDIF
IF (KCAT(IR).GT.20.AND.KCAT(IR).LT.30) THEN
  TIMIN(IR)=CN(IR)*TISET(IR)+(1.-CN(IR))*TE(IR)
ENDIF
IF (KCAT(IR).GT.30.AND.KCAT(IR).LT.40) THEN
  TIMIN(IR)=(FTWH(IR)+(1.-FTWH(IR))*CNWH(IR))*TISET(IR)
  TIMIN(IR)=TIMIN(IR)+(1.-PTWH(IR))*(1.-CNWH(IR))*TISNWH(IR)
  ENDIF

** initial guess for zone temp. and temp. under groundfloor: **
TI(IR)=TIMIN(IR)
TG(IR)=TE(IR)
101 CONTINUE

** calculate sum of gains, per zone **
DO 201 IR=1,NIR
  QIS(IR)=0.
  HE=23.
  DO 121 OR=1,9
       QIS(IR)=QIS(IR)+(1.-Z(IR))*FQ(OR,IR))
       AW(OR,IR)*GW(OR)*QS(OR,IR)*DTFAC(IR)
       QIS(IR)=QIS(IR)+(1.-Z(IR))*FQ(OR,IR))
  IF (OR.LE.8) THEN
  vertical facades:
    IF (UFAC(IR).NE.0.)
      QIS(IR)=QIS(IR)+(ABSF(OR)/(HE/UFAC(IR)-1.))
  END
horizontal roofs:
often, horizontal will be a sufficiently accurate approximation also
for tilted roofs, because the value is relatively small.

ELSE

QIS(IR)=QIS(IR)+(ABSR(IR)/(HE/UROOF(IR)-1.))*
AOP(OR,IR)*QS(OR,IR)*DTFAC(IR)
ENDIF

IF(KCAT(IR).LT.30)
THEN
QG(IR)=QII(IR)*DTFAC(IR)+QIS(IR)
ENDIF

for offices:
QG(IR)=QII(IR)*FWD(IR)*(10./24.)*DTFAC(IR)+QIS(IR)
ENDF

HL is in fact equal to the value of HL*dt in the report

HL(IR)=O.
DO 131 OR=1,9
IF (KCAT(IR).LT.30)
THEN
HL(IR)=HL(IR)+(1.-(1.-R(IR))*FTEN(IR))*
AW(OR,IR)*UW(IR)*DTFAC(IR)
ENDIF
ENDIF

for offices: no ‘night’ insulation implemented:
HL(IR)=HL(IR)+
AW(OR,IR)*UW(IR)*DTFAC(IR)
ENDIF

for offices
HL(IR)=HL(IR)+
AFL(IR)*UFL(IR)*DTFAC(IR)
DO 133 J=1,10
HL(IR)=HL(IR)+.336*V(IR,J)*FTVH(IR)*DTFAC(IR)
133 CONTINUE

for offices
HL(IR)=HL(IR)+.336*VM(IR,J)*FTWH(IR)*DTFAC(IR)
133 CONTINUE

PRO MEMORIA: correction for cold surfaces in case of combination
convective heating and air temp. control (see also
however comments under "Limitations" above).

iteration loop start

TA(IR)=O.
DO 300 ITER=1,NITER
set switch for balance check and save previously guessed values:
KBAL=1
DO 251 IR=1,NIR
TIOLD(IR)=TI(IR)
251 CONTINUE
DO 301 IR=1,NIR
TA(IR)=0.
DO 141 OR=1,9
  IF (KCAT(IR).LT.30) THEN
    TA(IR)=TA(IR)+(1.-1(R(IR))*FTEN(IR)))*
    #
    AW(OR,IR)*UW(OR)*DTFAC(OR)*TE(OR)
   ENDIF
  IF (KCAT(IR).GE.30.AND.KCAT(IR).LT.40) THEN
    TA(IR)=TA(IR)+AOP(OR,IR)*UFAC(OR)*DTFAC(OR)*TE(OR)
   ELSE
    TA(IR)=TA(IR)+AOP(OR,IR)*UROOF(OR)*DTFAC(OR)*TE(OR)
   ENDIF
  CONTINUE
DO 142 J=1,NIR
  TA(IR)=TA(IR)+UAADJ(IR,J)*DTFAC(OR)*TI(J)
142 CONTINUE
DO 143 J=1,10
  TA(IR)=TA(IR)+.336*V(IR,J)*DTFAC(OR)*TI(J)
  #
  offices: no 'night' insulation implementd yet:
  TA(IR)=TA(IR)+
  #
  AW(OR,IR)*UW(OR)*DTFAC(OR)*TE(OR)
   IF (OR.LE.8) THEN
    TA(IR)=TA(IR)+AOP(OR,IR)*UFAC(OR)*DTFAC(OR)*TE(OR)
   ELSE
    TA(IR)=TA(IR)+AOP(OR,IR)*UROOF(OR)*DTFAC(OR)*TE(OR)
   ENDIF
143 CONTINUE

PRO MEMORIA: correction for cold surfaces in case of combination
convective heating and air temp. control (see "Limitations")

TA(IR)=TA(IR)/HL(IR)

calculate QL,GLR,CG,DT,TI for each heated zone
and TI for unheated zones

DO 301 IR=1,NIR
    QL(IR)=HL(IR)*(TIMIN(IR)-TA(IR))
    GLR(IR)=QG(IR)/QL(IR)
    relation for utilization factor:
    IF((GLR(IR)-DD(IR)).GT.1) THEN
      CG(IR)=1.-EXP(-KK(IR)/(GLR(IR)-DD(IR))
    ELSE
      CG(IR)=1.
    ENDIF
    in case GLR negative during iteration, due to negative QL, then heat
demand is certainly zero; let CG and DT be zero and calculate Ti directly.
    CG(IR)=0.
   ELSE
    CG(IR)=1.
   ENDIF
   calculation of the overheating with new value of GLR (and thus of CG) :
   IF (GLR(IR).GE.0.) THEN
     DTR(IR)=1.+(1.-CG(IR))*GLR(IR)
     TI(IR)=(TIMIN(IR)-TA(IR))**DTR(IR) + TA(IR)
     DTA(IR)=TI(IR)-TIMIN(IR)
   ELSE
    for negative QL, calculate as in case of unheated zone:
    TI(IR)=QG(IR)/HL(IR)+TA(IR)
    DTR(IR)=0.
    DTA(IR)=TI(IR)-TIMIN(IR)
   ELSE
unheated zones:
\[ TI(\text{IR}) = \frac{QG(\text{IR})}{HL(\text{IR})} + TA(\text{IR}) \]
\[ DTR(\text{IR}) = 0. \]
\[ DTA(\text{IR}) = 0. \]
ENDIF
QREAL(\text{IR}) = HL(\text{IR}) \cdot (TI(\text{IR}) - TA(\text{IR}))
QHD(\text{IR}) = QREAL(\text{IR}) - QG(\text{IR})

temp. under ground floor need to be calculated:
IF (AFL(\text{IR}).GT..01) THEN
\[ TG(\text{IR}) = UFL(\text{IR}) \cdot TI(\text{IR}) + YGRC(\text{IR}) \cdot TGR(\text{IR}) + YGRE(\text{IR}) \cdot TE(\text{IR}) \]
\[ TG(\text{IR}) = TG(\text{IR}) / (UFL(\text{IR}) + YGRC(\text{IR}) + YGRE(\text{IR})) \]
ENDIF

401 CONTINUE

output during iteration for error detection
IF (KOUT.EQ.1) THEN
WRITE(LFNU,1350)H,ITER,(TI(I),I=1,9)
1350 FORMAT(’ ’,215,9F8.3)
ENDIF

convergence check
set switch on off in case one or more zones aren’t yet in balance:
IF (ITER.NE.1) THEN
DO 501 IR=1,NIR
XHE=ABS(TIOLD(\text{IR}) - TI(\text{IR}))
IF(XHE.GT.BALCR1) KBAL=0
501 CONTINUE
ELSE
KBAL=0
ENDIF
IF (KBAL.EQ.1) THEN
sufficient convergence reached
SUMMATION OVER ALL ZONES (B = building)
QLB(M)=0.
QLRLB(M)=0.
QGB(M)=0.
QHDB(M)=0.
DO 551 IR=1,NIR
QLB(M)=QLB(M)+QL(\text{IR})
QLRLB(M)=QLRLB(M)+QREAL(\text{IR})
QGB(M)=QGB(M)+QG(\text{IR})
QHDB(M)=QHDB(M)+QHD(\text{IR})
551 CONTINUE
ADDITION TO TOTAL VALUES OVER ALL PERIODS
DO 601 IR=1,NIR
QLT(\text{IR})=QLT(\text{IR})+QL(\text{IR})
QLRLT(\text{IR})=QLRLT(\text{IR})+QREAL(\text{IR})
QGT(\text{IR})=QGT(\text{IR})+QG(\text{IR})
QHDT(\text{IR})=QHDT(\text{IR})+QHD(\text{IR})
601 CONTINUE
QLBT=QLBT+QLB(M)
QLRLBT=QLRLBT+QLRLB(M)
QGBT=QGBT+QGB(M)
QHDBT=QHDBT+QHDB(M)

output for this month
heading for output per month:
WRITE(LFNU,1501) CODEB, CODEC
1501 FORMAT('O',A10,'A10,/, ',
# ' month zone Temp. Tamb Te GLR CG DTR DTA ',
# ' or period C C C - - - C ',
# ' MJ MJ MJ MJ MJ')
DO 701 IR=1,NIR
WRITE(LFNU,1505) M,IR,TI(IR),TA(IR),TE(IR),
# GLR(IR),CG(IR),DTR(IR),DTA(IR),QL(IR),QLREAL(IR),
# QG(IR),QHD(IR)
1505 FORMAT('O',215,3F6.1,4F5.2,4F10.0)

701 CONTINUE
WRITE(LFNU,1510) QLB(M),QLRLB(M),QGB(M),QHDB(M),ITER
1510 FORMAT('O',5X,'total:',37X,4F10.0,/, 
# ' number of iterations needed:',I5)
GOTO 95
ELSE
continue with the iteration loop "300"
IF(ITER.EQ.NITER) THEN
WRITE(LFNU,1900) NITER
1900 FORMAT('O,'WARNING: iteration stopped by maximum =',I5,/, 
# ' convergence not reached; results can not be trusted!!')
ENDIF
ENDIF
300 CONTINUE
95 CONTINUE

100 CONTINUE

output total values for all periods

heading:
WRITE(LFNU,1620)
1620 FORMAT('O','total values all periods:/', 
# ',
# ' QL QLreal QG QHD,/', 
# ',
# ' MJ MJ MJ MJ MJ')
DO 801 IR=1,NIR
WRITE(LFNU,1630) IR,QLT(IR),QLRLT(IR),QGT(IR),QHDT(IR)
1630 FORMAT('O',5X,I5,38X,4F10.0)
801 CONTINUE
WRITE(LFNU,1640) QLB,QLRLB,QGB,QHDB
1640 FORMAT('O',5X,'total:',37X,4F10.0)
99 CONTINUE
END
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**7.VAR01 NW TCM.TRY.DW**

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number of iterations needed: 9

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