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A closer look at the Heat Loss Calculation Standards

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Heat loss calculations belong to the oldest and most frequently used type of calculations in the heating and ventilating field. Many generations of designers have used them and they have served for the dimensioning of innumerable building installations.

Long ago the standardization of the calculation method was established in W-Germany, the United Kingdom and France. Many other countries used these standards, more or less adapted to their own situation. The purpose of the calculation is the correct dimensioning of the heating capacity of a room, so that the required room temperature can be realised at a given outdoor climate (design conditions).

The calculation method is mainly based on a steady state model. The heat loss through the room envelope and the losses by infiltration and ventilation are calculated, whereas correction factors should take care of a good accordance with the actual situation.

However in recent years problems have arisen with installations calculated this way because of insufficient capacity in certain circumstances. Two factors play a role.

First the increased degree of insulation due to energy crises which also leads to a better airtightness of buildings and consequently risen prices. It results in a lower specific heat capacity of the installation, which means that the sensitivity for the accuracy of the method and its correction factors increases considerably. Dynamic phenomena like the warming up of the building after an interruption of the heating are much more critical since the overcapacity - in an absolute sense - has decreased considerably. This necessitates an accurate consideration of the heat exchange process. All physical phenomena have to be described precisely to obtain the required accuracy.

The second factor involved is the demand by the occupants for higher quality of the indoor climate, which results in earlier complaints. Reliable and authorized methods should be available to judge the validity of these complaints.

A calculation standard could statisfy this need, if it suits the actual situation.

Since the present standards do not comply with all features of modern building design, many standards are under revision now.

With respect to the set up of a new Dutch standard an international exchange of ideas and activities in this field has been suggested as being fruitful. Therefore comparisons between the Dutch proposal and W-German, Belgian and British standards have been conducted.

Present Situation

Previously The Netherlands used the W-German standard for heat loss calculations (DIN 4701).

In 1977 recommendations for the design of installations were published by the Institute for the Study and Stimulation of Research (ISSO) in the field of building services, based on DIN 4701, edition 1959. This Dutch semi-standard has not been brought into agreement with the 1983-edition of DIN 4701 since a taskgroup started in 1972 with the setting up of an official Dutch standard. The new standard has been influenced considerably by experiences gained during the last seven years. Experiences, which deal with complaints about installations. These complaints, concerning too low room temperatures, led to the conclusion that the present standards show certain shortcomings if used for the dimensioning of installations in modern buildings. The complaints occur both in residential and office buildings, especially with intermittent heating and after night setback in well-insulated and airtight buildings.

These results are also confirmed by British experiences, whereas the CIBSE-Guide 1986 states: "With increasing levels of thermal insulation of the building fabric the ratio of the thermal storage capacity (admittance) to the transmission loss (U-value) will increase and therefore a larger plant margin than hitherto considered necessary may be required."

Intermittent Heating

Apparently the problems, described above, are caused by insufficient installation capacity in case of intermittent heating or night setback, so that the space temperature cannot be re-established in an acceptable period of time.

Strictly speaking this is not a shortcoming of the calculation method, but the problem is, that the building occupant is not familiar with these backgrounds.

On one hand he expects that the sophisticated control equipment realises comfortable indoor conditions in all circumstances, so the equipment was sold to him, and on the other hand he is indoctrinated by energy conservation campaigns, telling him to set back the thermostat at night. In this energy conservation pattern, long heating up times do not fit, but short heating up times result in long periods of discomfort, due to a lack of overcapacity. Therefore, the conclusion is, that the present complaints result more from ignorance of the possibilities of the installation - and consequently incorrect operation - than

shortcomings of the calculation standards.
The question remains how far should these standards take into account the consumers behaviour. Or, in other words, to which extent should standards follow the social developments.

The present W-German standard (DIN 4701-1983) does not acknowledge intermittent heating any longer. Nor does the Belgian standard NBN-B62-003.

The choice to exclude or include intermittent heating and night setback (night setback also is intermittent heating, however with a fixed minimum temperature) is very essential for the way of calculation. The sense of intermittent heating and night setback lies in the possibility of energy economy.

The Dutch standard committee calculated many cases for the determination of the appropriate heating-up time. These calculations were done by using an extensive computer program which accounts for all kinds of temperatures in the room and for dynamic phenomena. In the investigated cases the rate of oversizing and night setback were varied, just like the insulation and the mass of the building fabric.

It is clear that the rate of oversizing influences the heating up time significantly as shown in table 1. The heating up time is calculated for the situation that the air temperature is 20°C at 08.00 hours.

Over-sizing %	Heating up time, h after weekend	PMV Monday, 01.00 hrs
12	12,0	-0,06
20	11,2	-0,06
30	9,9	-0,06
40	8,6	-0,06

Table 1. Heating up time in hours, medium weight structure, normal insulation, 14°C nighttemperature

The rate of oversizing has practically no influence on the energy aspect as is illustrated by the data from table 2.

Over-sizing	Night-temperature °C			
%	20	17	14	11
12	100	93	90	89.5
20	100	93	90	89
30	100	93	90	89
40	100	93	89.5	89

Table 2. Relative heat requirements for one week at design conditions, medium weight structure, normal insulation

Contrary to the rate of oversizing the night setback has a clear impact on the heating requirements as can be seen from table 2 as well as the role of the weight of the structure, see table 3.

Night temp. °C	Type of structure Heavy	Medium	Light
20	100	100	100
17	93	93	93
14	92	90	87
11	92	89	83

Table 3. Relative heat requirements for one week at design conditions, normal insulation

From these results it can be concluded, that intermittent heating leads to energy economy, resulting from the lower room temperature during the period of reduced operation. Heavy constructions are unlikely to give any large economy of fuel, since the indoor temperature only drops slightly during the interruption period. The same applies to heavy insulation; here the indoor temperature also drops only slightly.
It may be clear that the type of installation also is an important factor considering the application of intermittent heating. Plants with rapid response e.g. warm air heating are most suitable for this purpose; those with long time constants like embedded floor panel systems, are least suitable.

Which approach for a new standard?

It appears that modern building results in low heating capacities, which make a more accurate calculating method necessary.
The new Dutch standard has tried to follow a fundamental approach; hoping that justified simplifications could be derived from it, which are indispensable for a manual calculating method.
The approach was split up in three steps:
- transmittance
- ventilation and infiltration
- heating up phenomena

Transmittance

For transmittance the climate conditions at the inside and outside play a role, just like the heat resistance of the room partitions.

The heat loss by transmittance is calculated as:
$Q_T = \Sigma U.A (T_r - T_e)$
in which
Q_T = heat loss by transmittance (W)
A = surface (m^2)
U = thermal transmittance (W/m^2K)
T_e = design outside air temperature (°C)
T_r = $\frac{1}{2} T_{ai} + \frac{1}{2} T_m$ dry resultant temperature
T_{ai} = inside air temperature (°C)
T_m = mean surface temperature (°C)
The various standards have different approaches for corrections regarding matters like cold walls effect.
A comparison of the Dutch (NEN 5066), the W-German (DIN 4701-1983), the Belgian (NBN-B62-003) and the British (CIBSE-Guide 1986) standards for a reference room show the following deviations, table 4.

Standard	Normal insulation	Heavy insulation
NEN 5066	120	111
DIN 4701-1983	107	106
NBN-B62-003	110	110
CIBSE-Guide	100	100

Table 4. Relative heatlosses by transmittance for reference room

Ventilation

Which part of the heating demand is

due to ventilation depends on the:
- ventilation requirements
- infiltration

It is necessary that a standard for heat loss calculation contains a clear description of which ventilation standards or guide-lines, the requirement refers to, and which air leakage requirements are applicable.

The heat loss caused by ventilation and/or infiltration is calculated as:

$Qv = \dot{V}.\rho.c. (T_{ai} - T_e)$ [W]

in which
ρ = density of air (kg/m^3)
c = specific heat of air (J/kg.K)
$\dot{V}$ = volumetric flow rate (m^3/s)

The volumetric flow rate $\dot{V}$:
- in case of mechanical air supply all standards (NEN, DIN, NBN, CIBSE) state:
  - the mechanical air supply, as far as the supply temperature is lower than the room temperature. (difference between T_e and air inlet temperature has to be taken into account)
  - plus the infiltrated air flow (in the NBN limited to n = 0,3 [h^{-1}] apart from overpressure).

- in case of natural air supply the standards NEN, DIN and CIBSE state:
  - the required ventilation if larger than the infiltration
  - or the infiltration if larger than the ventilation.

- in case of natural air supply the standard NBN-B62-003 state:
  - n = 1 [h^{-1}]
  - or 10 or 20 m^3/h per person if larger.

In conclusion, when a building is air-tight according to an air leakage standard, simple infiltration air exchange rates can be used and no calculation is necessary. When the airtightness quality of the building is unclear, there are only a few alternatives:

- try to calculate, simplified or with computer, the infiltration as well as possible
- try to measure the air-tightness of the building by pressurization methods.

The Dutch standard stresses the importance of airtightness standards for buildings, since it is the only reliable way (can be tested in practice). If there is not such a standard, the long way of calculation should be followed.

Heating up phenomena

For intermittently heated buildings as well as in the case of reduced heating by means of night thermostat setback the air temperature must rise to the required value in a certain period of time. Additional heat capacity over the capacity compensating the heat losses by transmittance and ventilation/infiltration is needed to warm up in an acceptable period of time.
Up till now the additional capacity is expressed as a percentage of the above mentioned heat losses. This means that in cases of increased degree of insulation and/or of more airtight buildings the additional capacity becomes smaller.

However the heat capacity of the structure at the inside of the room, by which the additional heat is determined, is almost the same and more or less independent of the degree of insulation. So it might be expressed that an addition as an absolute value will be a better approach. This is the way followed by the Dutch standard committee. The additional heat capacity must be calculated for each room separately. The specific additional heat capacity means the additional heat capacity per m^2 storing surface area of the room, including the area of furniture.

The committee has drawn up simplified calculation methods, which differ for residential and office buildings.
For residential buildings the following formulae are deduced:

$$T_{r\infty} - T_{ro} = (T_r - T_{ro})\,(1 - e^{-t/\tau})$$

$$\tau = a \,.\, e^{-bP}\,(T_r - T_{ro})$$

$$T_{r\infty} - T_{ro} = cP + T_r - T_{ro}$$

in which
T_r = the required resultant temperature (°C)
T_{ro} = the resultant temperature at the beginning of warming up (°C)
$T_r - T_{ro}$ = the required rise of resultant temperature, this equals the night setback minus 1,5 K
$T_{r\infty}$ = the resultant temperature after endless time (°C)
t = the preheat time (h)
τ = the time constant (h)
P = the specific additional heat capacity (W/m^2)
a, b and c are constants.
These constants depend on the type of heating system and the weight of structure of the room.
The formulae do not apply in the case of light weight structures.

The values of the constants a, b and c for the different heating systems and various weights of structure are given in tables. For a given rise $T_r - T_{ro}$ of the resultant temperature and a given preheat time t the specific additional heat capacity P can be calculated with the formulae by iteration, which is simplified by using tables.

The total additional heat capacity is found by multiplying the specific additional heat capacity P with the total storing surface area.

Results of measurement and calculation are shown in figure 1. In all cases measured and calculated values matched up well.

Compared to the Dutch standard, the W-German and Belgian standards assume continuously heating of the building at design conditions, so additional heat is not needed.
In the United Kingdom the CIBSE-Guide gives in a supplement an equation for the calculation of the additional capacity. This equation was derived from the admittance concept; e.g. the energy entering or leaving the surface for each degree of temperature swing in the room.
From table 5 it appears that the results of this theoretical approach are in good agreement with the Dutch method, which is based on experiments.

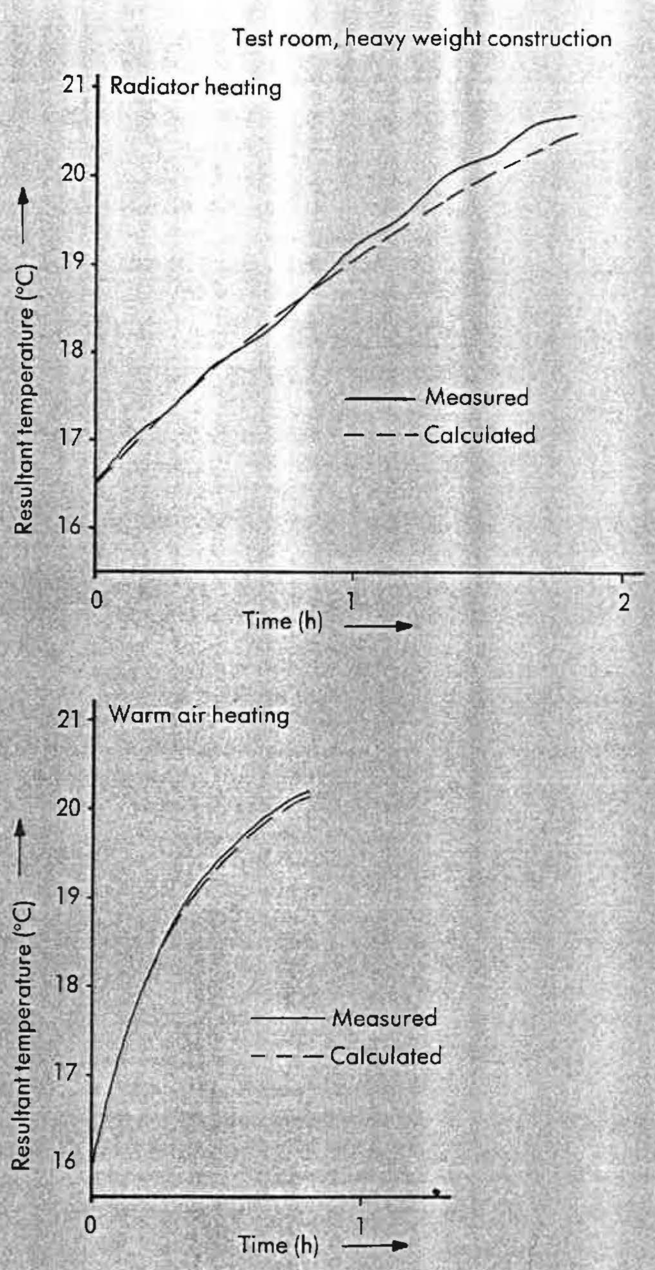

Fig. 1. Course of measured and calculated resultant temperature

Total heat loss

The heat loss calculations, prescribed in the various standards, are applied to an office room. To become comparable results the same design outdoor conditions are taken in all cases.

The results of these heat loss calculations are summarized in table 5.

Heat loss	Dutch	Belgian	W-German	British
Transmittance	477	452	426	402
Infiltration	194	147	175	229
Additional	463	–	–	448
Totally	1134	599	601	1079

Table 5. Heat loss of a reference room for the various standards

It appears that the sum of the heat losses by transmittance and infiltration is almost the same in all four cases. The British and the Dutch standard give an extra heat loss due to the additional heat capacity.

Conclusion

Most heating load calculation standards require a revision for reasons like new building methods (more insulation), technical developments (automatic control equipment), changing occupant behaviour and recommendations or even regulations for more energy economy.
The heating load calculation can be divided in three parts. For the transmittance part a good agreement with the occurring heat transfer processes can be found, when the dry resultant temperature is used as design temperature. This approach also takes into account the comfort of the occupants. For a correct handling of the ventilation and infiltration part air-tightness standards for buildings are necessary which are still failing in most countries.

The third part of the calculation, dealing with intermittent heating, is connected closely with the energy economy of the building. The necessary oversizing of the installation increases the investment costs but results in lower energy costs.

Some standards give the possibility for calculating the preheating time dependent on the rate of oversizing. The amount of energy savings is influenced by several factors like weight of building structure, degree of insulation, period of interruption and preheating time.

The standards do not give recommendations for these points. For a better understanding and application of this energy conservation option further investigations are of high importance.
This can also give an answer to the question, whether intermittent heating should be applied at outdoor design conditions which is denied by the W-German and Belgian standards. □