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A METHOD FOR CALCULATING THE ENERGY CONSUMPTION IN BUILDINGS BY MEANS OF A DESK CALCULATOR

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A method for calculating the energy comsumption in buildings by means of a desk calculator.

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There are several methods for calculating energy consumption for the heating of buildings. Some of these methods are very complicated and consequently use of computer analysis is necessary. Other methods are more simple, but on the other hand the results are very inaccurate if the buildings are highly insulated. The method (1) described here is a simple one but do take "free heat" and heat accumulation into consideration. A maximum and a minimum energy consumption is calculated which states the marginal values. The results of the computer programmes will be found between these limiting values. This method is suitable for desk computers.

The method is developed from the Thermal Insulation Laboratory's computer program BA-4 (2) which calculates the heat balance of rooms based on hourly values from the "Reference Year" (3).

This program calculates also energy consumption but is difficult and expensive to use for calculations during the early lay-out of the building. The simplified method gives a prompt answer to the energy consumptions of different lay-outs.

1. Transmission loss.

From the knowledge of the actual building design, areas and U-value for the individual constructions are calculated. The transmission loss is calculated for every month as follows:

$$Q_T = \Sigma\, k \cdot A \cdot (T_i - T_u) \cdot n \qquad (1)$$

where Q_T = transmission loss (kWh)

k = U-value (W/m^2C)

A = area (m^2)

T_i = indoor temperature (C)

T_u = outdoor temperature (C)

n = hours per month/1000 (h)

As indoor temperature is used the temperature wanted f.inst. 21°C. As outdoor temperature is used the month average temperature according to figure 1. By heat loss to earth is used the earth temperature instead of outdoor temperature.

In order to calculate the temperature in the low-energy houses we have decided not to use the inner surface areas but instead use an area in the middle of walls, roof etc. This causes a greater area which partly corrects cold-bridges at corners and edges.

Shutters in front of the windows can be used to reduce transmission loss. This loss can be calculated by using a corrected U-value for these windows as follows:

$$k_{cor} = \frac{k(24 - \tau) + k_s \cdot \tau}{24} \qquad (2)$$

where k = U-value of the window without shutters (W/m^2C)

k_s = U-value of window with shutters (W/m^2C)

τ = hours/night - shutters are used

This calculation is on the safe side as the outdoor temperature during the night is lower than during the day. On the other hand when evaluating the period the shutters are used, consideration must be taken to the inmates' habitual behaviour and also the sunrise and sunset.

In calculations for Danish low-energy houses the shutters are considered to be used 14 hours/night during the period November to February, 12 hours/night in October and March and 10 hours in September and April.

When calculating the U-value of the window inclusive shutters consideration must be taken to the fact that the shutters are not completely effective. For instance a flow of outdoor air between window and shutter can occur. Normally, shutters are not much bigger than the window so consequently you will have a rather big area where multi-dimensional heat transport is found. Based on Danish experiences and measurings the nominal

U-value of the shutters ought to be reduced by 30-50%.

2. Ventilation loss.

This loss is calculated for each month i.e.

$$Q_v = v \cdot (1 - \eta) \cdot 0{,}34 \cdot (T_i - T_u) \cdot n$$

where Q_v = ventilation loss (kWh)

V = fresh air shift (m^3/h)

η = heat recovery (-)

0.34 = specific heat of air (Wh/m^3C)

When using heat recovery it is required that the house is tight; otherwise the expected energy saving cannot be achieved.

In calculations for low-energy houses the lowest fresh air change of 200 m^3/h is used and a heat recovery of 60% (corresponding to what is practically obtainable).

3. Heat supply.

"Free heat" from human beings and electrical appliances is calculated based on evaluation of the use of the building and the users' behaviour. A fixed day and night supply of "free heat" is assumed which may vary from month to month.

By fixing this amount it must be taken for granted that a part of the electric heating - f.inst. by cooking - is useless because a part is used for evaporation and another part is extracted as exhaust air. The amount of the heat supply will clearly relate to the use of the building and the inmates' habitual way of acting. In calculations for low-energy houses we have fixed this supply to 18 kWh/during day and night.

4. Climate data.

Supply from the insolation through the windows has been calculated with BA-4 based on the modified "Reference Year" (3) where surplus insolation in relation to an average year has been taken away during December, January, March and April. In the calculation the insolation through a 1 m^2 double pane is calculated in kWh/month when the windows are facing north, south, east and west. Furthermore, the monthly average temperature for outdoor air has been calculated according to the "Reference Year".

month	t_u °C	insolation kWh/m² north	south	east	west
Jan.	0.2	3.9	30.3	9.5	8.0
Febr.	-0.4	8.0	55.4	17.8	21.2
March	2.0	16.2	69.6	37.0	41.8
April	5.7	25.9	69.8	60.2	58.9
May	11.4	36.8	65.2	70.0	68.5
June	16.0	46.0	65.3	79.3	76.3
July	16.4	43.3	66.8	71.0	74.9
Aug.	16.1	32.2	62.3	57.4	56.8
Sept.	13.7	21.0	62.7	40.1	39.0
Okt.	9.2	11.4	46.5	21.6	22.3
Nov.	5.0	5.3	30.2	9.5	9.7
Dec	-0.4	3.5	28.5	7.3	6.3
year		253,5	652.6	480.7	483.7

Table 1. Climate data from Denmark

5. Insolation through windows.

Based on size and type of the windows the heat supplied to the building can be calculated by the values of the insolation mentioned in the previous section.

$$Q_s = \Sigma A \cdot S \cdot I \qquad (4)$$

where Q_s = insolation (kWh)

A = glass area of the window (m^2)

S = shading coefficient f.inst.

normal 2 layer pane $S = 1.0$

normal 3 layer pane $S = 0.9$

I = insolation (kWh/m^2)

In the previous sections it was assumed that the windows were facing the four points of the compass and that the buildings had no overhang and/or rib. If the windows are facing other directions the insolation has to be calculated in the actual direction.

If windows with overhang or rib are discussed the above calculated insolation will be too high but in many cases it is of no importance at all, because overhang and rib will just slightly affect the insolation during the winter, when the supply is most important for the final heat requirement. If correction for overhang and rib is wanted, tables have to be worked out for the normal overhangs, ribs, windowsizes and directions by calculation with the BA-4 program. If the building has big overhangs or something else will cast a shaddow, the windows facing south, east and west ought to be considered as facing north.

6. Limit values for the energy consumption.

When the energy consumption is calculated exactly the heat storage influence of the building will be of great importance. However, it is possible to define two limit values for the energy consumption. Maximum values correspond to a house without any heat capacity. Minimum values correspond to a house with a very high heat capacity.

The minimum energy consumption is calculated considering that heat gain from sun, electric appliances and persons for one month can be utilized 100% to cover transmission loss and ventilation loss. A house with such high heat capacity is practically impossible to build. If the heat gain is bigger than the consumption it will cause a useless heat surplus.

The maximum energy consumption is considerably more complexed to calculate. If a house has no heat capacity, a heat gain from the sun etc. can only be utilized if a heating requirement turns up. How large the utilization of the heat gain one can obtain can only be found through dynamic energy calculations (f.inst. BA-4). The formula (6) is found by regression. The energy consumption in this case can now be calculated from:

$$Q_{MAX} = f \cdot (Q_t + Q_v) \qquad (5)$$

$$f = 1 - 0.4027 \cdot \sqrt{\frac{A}{B}} + 0.08388 \frac{A}{B} \qquad (6)$$

where $A = Q_s$ total insolation

$B = Q_t + Q_v$ total heat loss

Note: If A is less than 15% of B then A can be utilized 100% $Q_M = B - A$.

Besides heat gain from insolation we have also heat gain from persons and electric appliances (shown in table 3). This

heat gain will normally be distributed in another way during the day so it is unreasonable just to use $Q_s + Q_e$ instead of Q_s in formula (6). For office buildings, however, this can be reasonable but not for apartment houses. For apartment houses it would be most reasonable to assume that the heat supply Q_E is independent of Q_s. In other words the energy consumtion can be reduced once more using the same formula:

$$Q_{MAX} = f \cdot Q_{MAX} \qquad (7)$$

where f is formula (6) with inserted values

$A = Q_E$

$B = Q_{MAX}$

By calculating $Q_{MAX} + Q_s + Q_E + Q_t - Q_v$ the useless heat surplus can be calculated. The surplus will cause an overheating unless special consideration is taken into account for overhangings, extra air change or the like.

7. Heat accumulation.

From the previous section a maximum and a minimum energy consumption is calculated. Between these two limits more exact and dynamic calculations will be found. The difference between the maximum and the minimum energy consumption can be relatively great. Therefore it is essential also to know where buildings with normal heat capacity are placed. From experience up till now regarding calculations for low-energy houses the following can be stated:

0%	Q_{MIN}
40-50%	with internal walls of bricks
50-60%	with internal walls of lightweight concrete
60-80%	with internal fibrous plaster
100%	Q_{MAX}

8. Example.

A one-family house with a living area of 140 m^2 with the following information:

transmission to earth 25.32 W/C

transmission to outdoor 143.6 W/C

air change 152.5 m^3/h

interior temperature 21°C
earth temperature 8°C
no heat recovery from the air change
no shutters in front of the windows
heat supply from electric appliances and persons ∿ 17.8 kWh/day
windows with 2 layers of glass divided by
3.2 m^2 facing north, 7.3 m^2 facing south
2.7 m^2 facing east and 3.1 m^2 facing west

By using the previously mentioned formula an energy account for the house can be calculated as follows:

month	Q_t	Q_v	Q_s	Q_E	Q_{MIN}	Q_{MAX}
Jan	2448	803	284	552	2415	2498
Febr.	2269	746	544	500	1971	2132
March	2256	734	789	552	1649	2016
April	1801	572	938	534	901	1495
May	1252	371	995	552	76	913
June	736	187	1075	534	0	426
July	718	178	1050	552	0	409
Aug.	750	189	889	552	0	451
Sept.	974	273	754	534	0	679
Okt	1487	456	503	552	888	1256
Nov	1873	598	293	534	1644	1788
Dec	2513	826	258	552	2529	2602
year	19077	5933	8372	6500	12073	16665

Table 2. Calculated energy account in kWh.

If the house has bricks in the interior walls the energy consumption will be about

$$Q_H = 12073 + 0.45 \cdot (16665 - 12073) = 14139 \text{ kWh/year}$$

9. Conclusion.

This method has been used for the calculation of energy consumption for Danish low-energy houses during the lay-out. The method can be used without any difficulty with desk calculators as Texas TI-59 + printer.

The calculation method gives possibility for an easy examination of the influence of different energy saving arrangements in buildings f.inst. heat recovery and several layers of glass in windows. The method can be used under different climatic conditions, if the climate data corresponds to table 1 and a regression formula equal to (6) to the actual climate is calculated.

References.

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