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DISTRIBUTION OF ENERGY CONSUMPTION
FIELD MEASUREMENT IN 11 DETACHED DWELLINGS OF THE SAME DESIGN

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Introduction

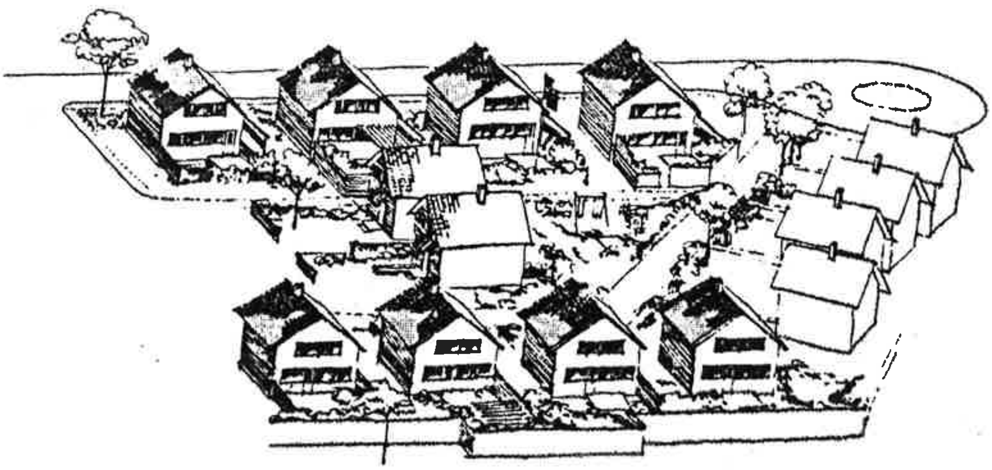
Measurements of the distribution of energy consumption in buildings made in Trondheim 1976-80 indicated that the measured heat loss factor is considerably less than the factor calculated according to the Norwegian Standard for heat loss calculations, NS3031. In order to confirm these results we decided to carry out measurements and calculations of energy consumption in 11 detached dwellings of equal design in order to have a better statistical material. The conclusions in this paper are based on these measurements together with some other previous results.

Project description

The houses

The 11 detached dwellings are at random selected from a group of 66 nearly identical dwellings built 1980-81, situated on a plain 165 meters above sea level in Trondheim. They are all 1 1/2 story timber frame houses with a basement made in concrete. The ground area is 60 m2, and the living area 120 m2. The walls and roofs are insulated with 150 mm mineral wool quality A, the floor between ground level and basement with 200 mm. The outside of the house are covered with wooden boards, the inside are covered with plaster boards. The houses are ventilated by an extractor fan and adjustable vents in the upper window frame in each room.

The transmission heat loss factor is calculated according to the Norwegian Standard (NS3031) (1). The average value is 149 W/K.



From the area.

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Experimental scheme

* We rented each house for a periode of 24 hours, from 12 a.m. to 12 a.m. next day, and made the measurements with no people in the house. The ventilation was set as it was in ordinary use.

* The heating was made with electric wall heaters automaticly controlled to a constant indoor temperature 20° C, in all living rooms.

* The air change rate were measured by use of tracer gas N2O (dinitrogenoxyd). Gas was portioned out in the afternoon and in the evening, and it was stirred by use of electrical fans.

* For the data collections we used an automatic logger, LOKE (2), and an outdoor wetherstation on the site. Besides this we photograped the buildings own kWh-meter each hour. These kWh-meters are calibrated to a max deviation of 2 %.

* We used the period after midnight until 6 a.m. when the airchange rate and the power demand was most stabil to calculate the measured transmission heat loss factor Hm (W/K).

$$Hm = \frac{Q - 0.33 \cdot n \cdot V \cdot \Delta T}{\Delta T \cdot h}$$

where
Q = Energy consumption in period h (kWh)
n = Measured airchange rate (h^{-1})
V = Heated Volume (m3)
ΔT = Ti - Tu = Average temperature diff indoor - outdoor (K)
h = Period

* The air tigntness was checked separately according to the n50-test (NS8200). We also examined the building with a thermovision camera in order to find leaky points.

Parameters influencing the heat loss factor

In field measurements several parameters will affect the result. When we compare with the standard for calculation we must compensate for some of these parameters.

Wind

The wind affects on a buildings heat loss in several ways:
- extend surface thermal resistance
- extend radiation towards clear sky
- air infiltration in the insulation material
- air exchange in and out of the building
- interference with simple ventilation systems

For a timber frame wall insulated with 100 mm mineral wool, changes in the outside surface resistance factor with no wind and strong wind means a change in k-value from 0.40 to 0.41 W/m2·K (3). For a window with two layer of glass it means a change in k-value from 2.7 to 3.2 W/m2·K.

During cold weather and clear sky, specially in dark winternights the wind can decrease the heat transmission. Ahlander (4) has shown examples of a reduction of 15% for a well insulated wall (k-value 0.25 W/m2K) with no wind compared with 10 m/s wind during clear sky condition.

Air circulation in mineral wool is caused by wind and thermal forces. The effect depends on the insulation materials porosity (air resistivity), insulation faults and the quality of the windbreaker. We have no methods to calculate this effect, but we can discover insulation faults and leaking points with a thermovision camera.

Infiltration is also caused by wind and thermal forces. There exist several emprical matematical models for calculating the infiltration quantity. We made the measurements with different forced ventilation rate in the houses, and we can therefore not use this kind of model for our houses. For each house we have measured the total (infiltration + ventilation) airchange rate. The corrections for wind were done according to (not matematically correct) a formula found for 1 house in Trondheim after several measurements (2).

Sun

The measurements were made at the time of the year when the sunshine at 63 °N are minimum, and it will therefore have no effect on the measurements made during the night.

Thermal conductivity

The Norwegian Standard (NS3031) gives values for λ = thermal conductivity for different materials. The values are based on laboratory tests with a safety factor of about 10%. The safety factor shall conpensate variation in workmanship, etc.

The values for mineral wool are calculated according to the formula

$$\lambda n = (\lambda_{10} + \frac{\lambda kg + \lambda_{10}}{2}) \cdot (1 + 0.015 \cdot 1) + 0.003$$

where λ_{10} - thermal conductivity according to standard (W/m·K)

1 - airpermability according to standard (kgm/Ns)

λkg - limit documented by the producer (W/m·K)

The thermal conductivity is based on a medium temperature 10°C in the construction. That means a indoor temperature 20 °C and outside 0 °C. The thermal conductivity will be lower with lower temperature. For the actual temperature intervall the thermal conductivity is roughly proporsional to the absolute temperature (K). The standard have specific rules for calculating constructions made of different materials.

Non-stationary conditions

Non-stationary conditions caused by changes in the outdoor climate, will be the parameter which has the strongest influence on the results. Changes in the temperature will create a time delay in load and energy demand. It will depend on the buildings thermal storage capacity. To eliminate this we can make contineous measurements over a long periode, or we can make measurements in several identical houses in order to get a statistical average.

Results

The measurements took place in the periode January 9-27. During that periode the outdoor temperature varied between +3 °C and -21 °C, and the medium windspeed varied between 0 and 6 m/s. We had stable climate conditions for 7 houses, reasonably good for 2 and great changes during the test-period for 2 houses. The air change rate and energy demand are found for a periode of 2-4 hours, all results are in the periode 00.00 to 07.00 a.m.

Heat loss factor - no corrections

The relationship between measured (Hm) and calculated (Hc) transmission heat loss factors are calculated as the aritmetic mean value $\bar{x} = \frac{1}{n} x_i$ where

$x_i = Hm/Hc$

and the differences are showed by calculating the standard deviation

$$s = \sqrt{1/n\Sigma(x_i - \bar{x})^2}$$

For 9 houses this gave a relationship $\bar{x} = 0.90$ with a standard deviation $s = 0.14$.

Heat loss factor - with corrections

After correcting the results to a medium temperature 10 °C, and for wind speed v = 2 m/s we got a relationship $\bar{x} = 0.91$ with a standard deviation $s = 0.12$.

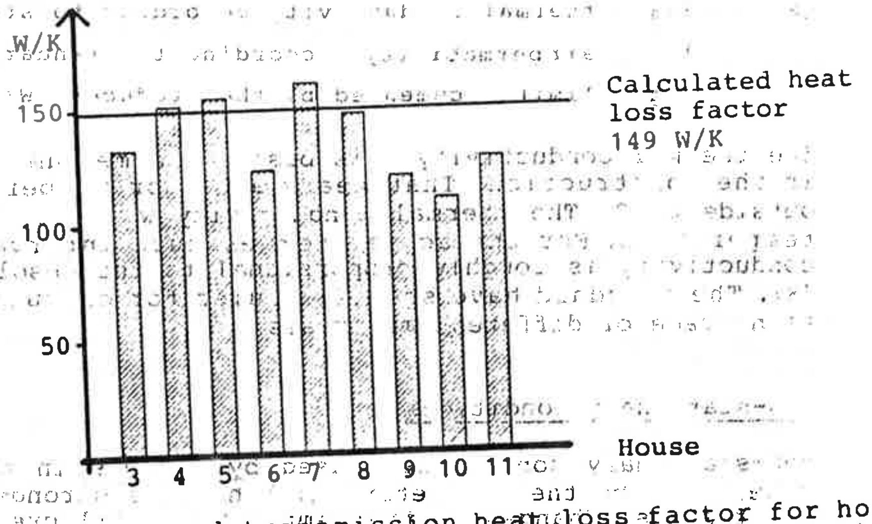

Fig.1 Measured transmission heat loss factor for house 3-11 corrected to standard medium temperature and windspeed.

During the project we observed that the basement temperature was nearly constant for each house and relativly similar for all the houses. This was even the case if the outside temperature varied up to 15 C during the 24 hours. The site was in this period covered with snow. This made us reconsider our first calculation of the transmission heat loss factor based on the standard method. This method calls for calculation of the heat loss from the inside livingroom through the basement to outdoor environment.

We decided instead to calculate the heat loss factor from the living room to the basement. In the basement we measured the temperature. In this way we had a "corrected calculated heat loss factor" for a building with a light part in wood and a heavy basementpart. This gave a realtionship $\bar{x}$ = 0.93 with a standard deviation s = 0.10.

Tab. 1. Relationship between measured and calculated transmission heat loss factor

House	3	4	5	6	7	8	9	10	11
Hm/Hc	0.91	1.02	1.06	0.84	1.08	1.0	0.85	0.79	0.94

<u>Air change rate and ventilation</u>

The use of vent inlets in the upper frame of the window varied from 0 to 10 out of total 15 vent inlets. The mechanical ventilation was used only in 3 houses, in the rest it was blocked or switched off by the occupants. The occupants had made it possible themselves to switch the fan off. This together with changes in temperature and wind made the air change rate vary between 0.2 and 0.7 air changes per hour with an average 0.45. Low temperature and high wind raised the air change rate.

The n50-test gave an average of 3.9. This is just below the Norwegian limit of 4.0, but lower than other tests done in many similar houses. Checking with thermovision camera showed no insulation faults, good airtightness by the windows but some weak points between the walls and roof. We did not find any marked thermal bridges.

Conclusions

* The measurements results for two of the houses were not taken into the average calculation because the outdoor climate changed considerably during the measuring periode. Correcting the results for 9 houses to a standard outdoor temperature and windspeed the average relationship between measured and calculated heat loss factors $\bar{x}$ = 0.93 with a standard deviation s = 0.10.

* The variation between the houses are mainly caused by non-stationary conditions in the measuring period. The airchange measurement can also differ with +- 10%, but that will only explain a little part of the variation. We don't think there are any great measurement faults, or influence of thermal bridges, humi-

dity and sun.

* In order to eliminate non stationary conditions, one will have to make contineously measurements of air change rate and energy demand for several days.

* The ventilation rate in similar dwellings varies considerably depending on the occupants personal habits.

* Other measurements made in different buildings nearly similar to this case, have given a realtionship from 0.8 to 1.0 for full scale buildings, and for a smaller test house (4 m2 rooms) 0.7 to 0.8. We believe the low values in the test house are caused by a scale-effect.

* The measurements confirm that the Norwegian Standard (NS3031) for calculation of transmission heat losses is reasonably correct. The practical -values (thermal conductance) given for mineral wool in the standard have a "safety factor" of about 10% compared with laboratory test values (λ_{10}) to compensate for variations in workmanship etc. This seems reasonable, at least for load calculations, but may be to high for energy calculations.

References

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SUMMARY

T. Haugen: Distribution of energy consumption. In January 1984 we carried out detailed field measurements of the air exchange rate and total heat loss in 11 detached dwellings. The task was to find the relationship between measured and calculated transmission heat loss factors based on standard Norwegian calculations methods. For 9 houses the measurements were done under climatic stabile conditions. Correcting the results to a standard mean temperature and an outdoor medium windspeed,the average relationship between measured and calculated heat loss factors $\bar{x}$ = 0.93 with a standard deviation s = 0.10. We believe that the deviations are caused by non-stationary conditions during some of the testdays, but that these deviations are equalized in the average value. Airchange rate varied between 0.2 and 0.7 airchanges/h with an average value 0.45. These measurements, together with several others, confirm that the Norwegian Standard (NS3031) for calculation of the transmission heat losses is reasonably correct.

RESUME

T. Haugen: Distribution de la consommation de l'energie. Au mois de Janvier 1984, nous avons mesure le renouvellement d'air et la perte de chaleur dans 11 maisons identiques. Notre objectif était de décider la relation exact entre une perte de chaleur de transmission mesurée et une perte de chaleur de transmission théoriquement calulée d'après la méthode de calculation Standard Norvégienne. Dans 9 maisons, nous avons fait nos mesures dans des conditions climatiquement stables. En corrigeant les résultats de ces mesures a une température moyenne fixe et à une vitesse moyenne du vent a l'extérieur des maisons, nous avons trouvé la relation moyenne suivante entre la perte de chaleur de transmission mesuree et la perte de chaleeur de transmission calculée: $\bar{x}$ = 0.93, avec une déviation fixe de s = 0.10. Nous croyons que cette deviation est due a des conditions non stationnaires pendant quelques jours de teste, mais que la valeur moyenne est correcte tout de même. La ventilation a variée entre 0.2 et 0.7 de changement d'air/h. Ces mesures, avec bien d'autres, affirment que le Standard Norvégien (NS3031) comme méthode de calculation de perte de chaleur de transmission est relativement correcte.

KURZFASSUNG

T. Haugen: Verteilung der Energie-verbrauch. Im Januar 1984 wurden Feldmessungen vom Luftaustausch und totale Wärmeverlustfaktoren in 11 gleichen Einfamilienhäusern durchgeführt. Das Ziel war das Verhältnis zwischen gemessenen und theoretisch berechneten Transmisions Warmeverlustfaktoren festzustellen. Die Berechnung ist nach den Norwegischen Normen durchgefuhrt. Bei 9 Häuseren sind die Messungen bei stabilen klimatischen Verhaltnissen durchgefuhrt. Die gemessenen Werte sind zu einer standardisierten Durchschnittstemperatur und einer mittlerem Windgeschwindigkeit justiert. Das Verhältnis zwischen gemessener und teoretische berechneter Transmisionsvarmeverlust ist im Durchschnitt $\bar{x}$ = 0.93 mit einer Standardabweichung s = 0.10. Man meint, dass der Unterschied von nicht stationäre Verhältnisse kommt, aber man kann den Durchschnittsvert verwenden. Die Ventilation wechselte zwischen 0.2 - 0.7 Luftwechslungen pro Stunde, im Durchschnitt 0.45. Diese und andere Messungen bestätigen dass die Norwegische Normen (NS3031) fur Berechnung des Transmisionswärmeverlustes gute Ergebnisse liefert.