ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

3rd AIC Conference, September 20-23 1982, London, UK

PAPER 22

HEAT LOSSES FROM SMALL HOUSES DUE TO WIND INFLUENCE.

GUNNAR AHLANDER

Royal Institute of Technology
Department of Heating and Ventilating
Brinellvägen 60
100 44 STOCKHOLM
Sweden

SYNOPSIS

The heat losses from small houses, due to transmission and ventilation, are estimated. The estimation is based up on the house owness daily readings of electricity and water meters, and their notes on behaviour influencing the energy use. Consideration is taken to heat supply from insolation and from people. Hot water losses are calculated from use of water and use of household machinery. Besides the estimation of the heat losses, Q, wind and temperature in the area is registrated. The three parameters, local wind velocity, v_l, temperature difference between inside and outside, $\Delta\theta$, and specific heat loss, $Q/\Delta\theta$, are adapted to following relation

$$Q/\Delta\theta = A+B\cdot\Delta\theta^{1/2} + C\cdot v_l + D\cdot v_l^{4/3} \qquad (1)$$

According to this model, the heat losses consist of transmission heat loss, wind and temperature influenced ventilation (through ducts, window and doors) and wind and temperature influenced infiltration (through cracks).

When the constants A,B,C and D have been solved for the different houses, the relation (1) is used for estimating possible energy saving by windreduction. It is found that a windreduction to 0,5 - 2,0 m/s will give an energy saving between 3,3 and 9,4 % during the year. Some of this saving may also be achieved by tightening the houses.

SYMBOLS

v	= wind velocity, m/s
$\Delta\theta$	= temperature difference, K
U	= coefficient of thermal transmittance, W/m^2K
h	= surface transfer coefficient, W/m^2K
δ	= thickness, m
λ	= coefficient of thermal conductivity, W/m^2K
V	= air flow, m^3/s
Δp	= pressure difference, Pa
Q	= energy per day, Wh/day
A	= area, m^2
q	= gravitation constant, m/s^2
z	= distance, m
$\Delta\rho$	= density difference, kg/m^3
qs	= energy ratio
τ	= transmission factor
ψ	= shadowing factor
ϕ	= reduction factor
ρ	= density, kg/m^3
c_p	= heat capacity, Ws/kg,K
t	= time, h

Index

o	= outside
i	= inside
c	= convection
t	= transmission
l	= local
v	= ventilation
w	= wind
inf	= infiltration
V	= vertical
H	= horizontal
s	= solar

HEAT LOSSES FROM SMALL HOUSES DUE TO WIND INFLUENCE

A lot of research work has been carried out, concerning the wind effects on air infiltration into buildings. The air infiltration is equivalent to the ventilation rate in natural ventilated houses and has usually been stated as the number of air-changes per hour. A common way to measure this ventilation rate has been to use tracergas techniques.

An assumed relation between wind velocity and ventilation rate is that the ventilation rate is linear to the wind velocity. So did Bahnfleth[1] among others adapt his measuring data to the relation

$$q = A_1 \cdot v + B_1 \cdot \Delta\theta \qquad (1)$$

But other relations are also assumed. Peterson[2] for instance used the relation

$$q = A_2 \cdot v^{0,8} + B_2 \cdot \Delta\theta \qquad (2)$$

In both these assumptions consideration has been taken to the thermal draft, caused by the density difference between outside and inside air. In the two examples above, the wind and temperature induced ventilation rates are added up. An addition of the wind and temperature induced pressures is also often done.

Investigations of the wind influence on total heat loss of the buildings are more rare. A work of Frank[3] is, however, dealing with the relation between wind velocity and energy consumption for a number of buildings. Frank used old measurement datas on the weekly consumption of energy and mean wind velocity during the actual-week. The results he found were of the type shown in figure 1.

One of the buildings had an energy consumption that increased with approximately 90 % as the wind velocity increased from calm condition to the mean wind velocity during the measuring period, 3,2 m/s. The other buildings got procentual increases of the same order, between 38 - 95 %. In Frank's investigation, that dealed with multifloor buildings, no consideration was taken to the thermal draft.

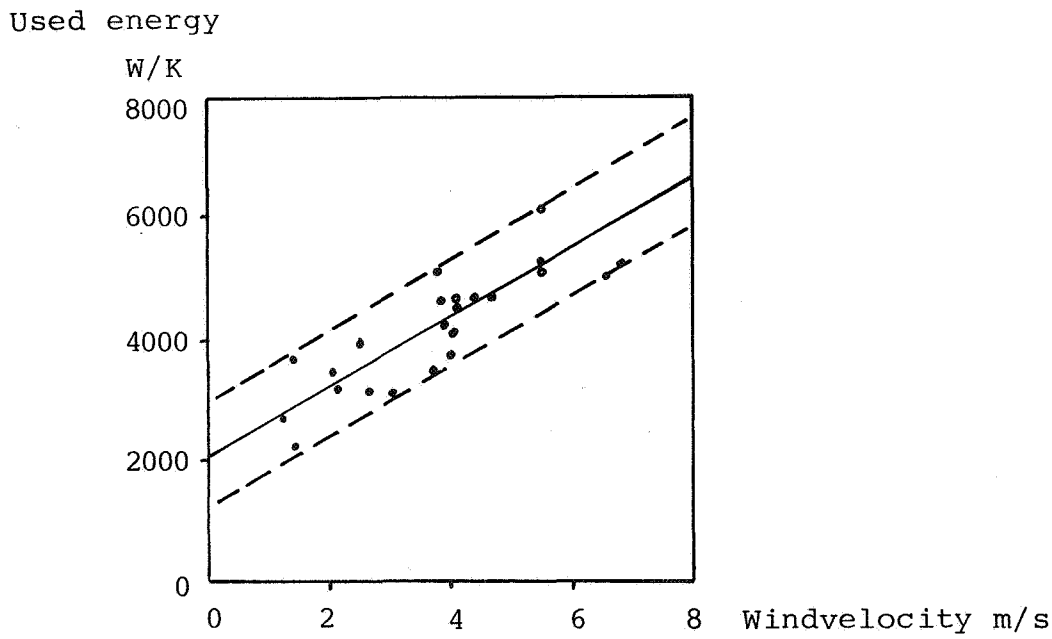

Figure 1.

1. Wind influence

The wind influences the heat losses from a building not only by increased air-infiltration. One can breifly divide the wind influence into four parts,

influence on the U-values

influence on the air-infiltration

influence on the ventilation

influence on the mechanical ventilation

1.1 Influence on the U-values

The transmission heat losses through a building's walls and windows depend on the U-values of the building's different construction materials. The U-value of a building material can be expressed as

$$\frac{1}{U} = \frac{1}{h_o} + \sum_k \frac{\delta_k}{\lambda_k} + \frac{1}{h_i} \qquad (3)$$

where h_o and h_i are the transfer coefficients for the outer and inner surfaces respectively

δ_k is the thickness of k:th material layer with the conductivity λ_k

The transfer coefficients consist of a radiation and a convection part. The convection part of h_o can be approximated as

$$h_{o,c} = 10 \cdot v^{0,6} \qquad (4)$$

where v is the air velocity along the surface.

A rised wind velocity will thus increase the convective part of the outer transfer coefficient. The heat loss from the building will then get higher. This is, however, only true if the surface temperature is higher than that of the air. During clear nights well insulated building parts may have a surface temperature that's lower than the outdoor airtemperature. In this case, the heat losses will decrease with rising wind velocity. In figure 2 calculated percentage changes in the heat loss from windows and walls are presented. The figure is valid for windows and walls with the nominal U-valves 2,0 and 0,25 W/m^2K respectively. The different curves are for two cloudiness-conditions.

1.2 Influence on the air-infiltration

The wind induced pressures on a building's surfaces are, together with the temperature dependent pressures, the main forces governing the natural ventilation of a building. A higher wind velocity will increase the over- and underpressures on the building, and with that the ventilation rate. In a building with mechanical ventilation system, the wind induced natural ventilation will intend to give a ventilation rate that diverges from the desired. The wind influence on the air infiltration depends on both the induced pressure, the number of openings and cracks in the building, their distribution and their flow characteristics. The pressures induced are highly dependent on wind direction, surrounding terrain and buildings and the turbulence of the wind.

Air flow through an opening will follow the relation

$$V = k_1 \cdot \Delta p^n \qquad (5)$$

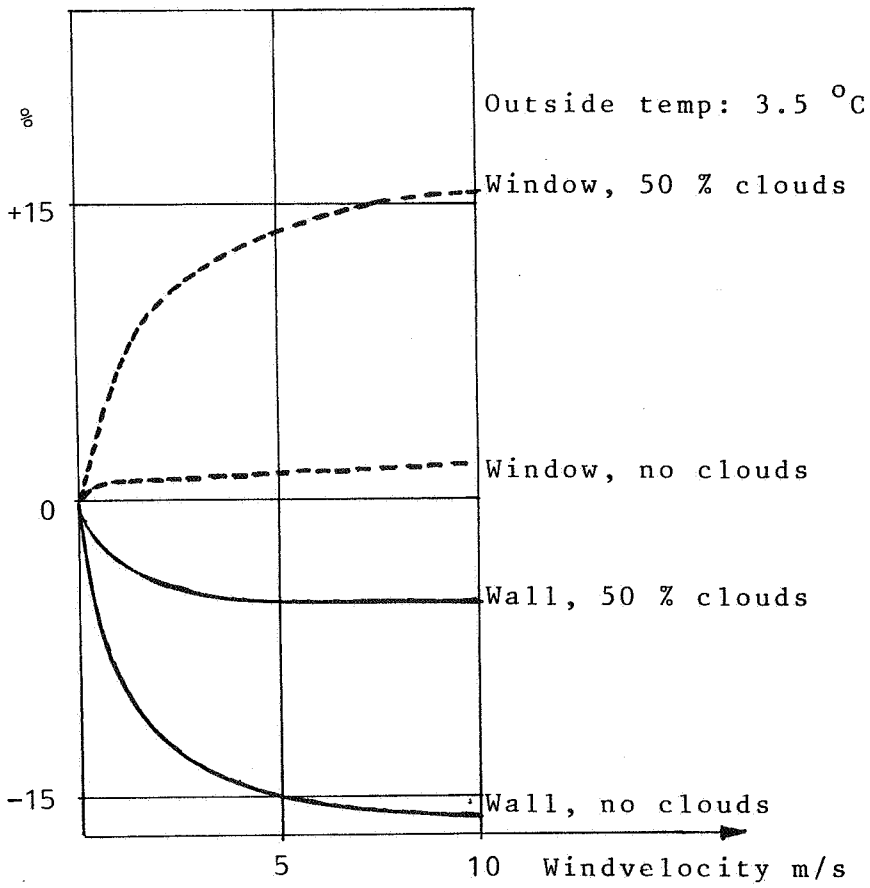

Figure 2.

where k_1 is a constant depending on the size of the opening

n is an exponent depending both on the shape of the opening and the acting pressure Δp

Since the acting pressure, Δp, is proportional to the dynamic pressure of the free wind, $\frac{1}{2} \rho v^2$, the air flow through the openings in the building can be expressed as

$$V = k_2 \cdot v^{2 \cdot n} \qquad (6)$$

where k_2 is a constant depending on both the constant k_1 and the transfer between dynamic pressure and acting pressures on the building.

1.3 Influence on the insulation

Insulation in walls and roof has to be well installed. Otherwise there may be a possible air-movement through the insulation space. This air movement will increase the heat transmission through the wall or roof. Nominal values on insulation materials conductivity are determined in laboratory tests, where the air movement through the insulation is minimized. Air movement, through the insulation space, can be caused either by the temperature difference between the insulations both sides or by wind. To reduce the wind influence it's important to have a windtight layer on the outside of the insulation.

1.4 Influence on the mechanical ventilation

The pressures on the building's surfaces, induced by wind, may also affect the mechanical ventilation, With an exhaust-air system, the exhaust air-flow is influenced by the outside pressure at the place of the air-intake. Supply and exhaust-air systems are disturbed if the inlet and outlet openings are placed in zones with different outside pressure.

2. A model for heat losses from a small house

A model for the heat losses has to contain the two parts governing the heat loss, i.e. transmission and ventilation. In this model, the ventilation part has been divided into two parts. One called ventilation, with which is meant the air-flow through ventilation ducts, windows, doors and other bigger openings. The other called infiltration and consisting of the air-flow through cracks.

2.1 Transmission

If the insulation is assumed to be unaffected by wind, and the outer transfer coefficients to have a neglect able importance, the transmission heat loss from the building can be expressed as

$$Q_t = \sum_k U_k \cdot A_k \cdot \Delta\theta \qquad (7)$$

where U_k is the U-value of the k:th building part with the area A_k

Since U_k and A_k can be considered as constant, the transmission heat loss, Q_t, can be expressed as

$$Q_t = A \cdot \Delta\theta \tag{8}$$

where A is a constant.

2.2 Ventilation

When there's an air flow through ducts and similar, the exponent n in equation (6) can be taken as 1/2. The pressure Δp, causing the air-flow, may be caused by either temperaturedifference between inside and outside, $\Delta\theta$, or wind-velocity in the vicinity of the building, v_1. The temperature difference gives cause to a pressure difference between inside and outside that may be written as

$$\Delta p = g \cdot z \cdot \Delta\rho \tag{9}$$

Where g is the gravitation constant

z is the distance from the neutral level (the level where inside and outside pressures are equal, see figure 3)

$\Delta\rho$ is the density difference between outdoor and indoor air

Since the density difference $\Delta\rho$ is approximately proportional to the temperature difference, $\Delta\theta$, the ventilation air flow will be proportional to $\Delta\theta^{1/2}$. Thus the ventilation heat loss due to thermal forces can be expressed as

$$Q_{v,\theta} = B \cdot \Delta\theta^{1/2} \cdot \Delta\theta = B \cdot \Delta\theta^{3/2} \tag{10}$$

where B is a constant.

The ventilation air-flow caused by wind may be expressed in accordance with equation (6) with the exponent

$n = 1/2$. i.e.

$$V = k_2 \cdot v_l^{2 \cdot 1/2} = k_2 \cdot v_l \tag{11}$$

The ventilation heat loss due to wind influence can then be expressed as

$$Q_{v,w} = C \cdot v_l \cdot \Delta\theta \tag{12}$$

where C is a constant.

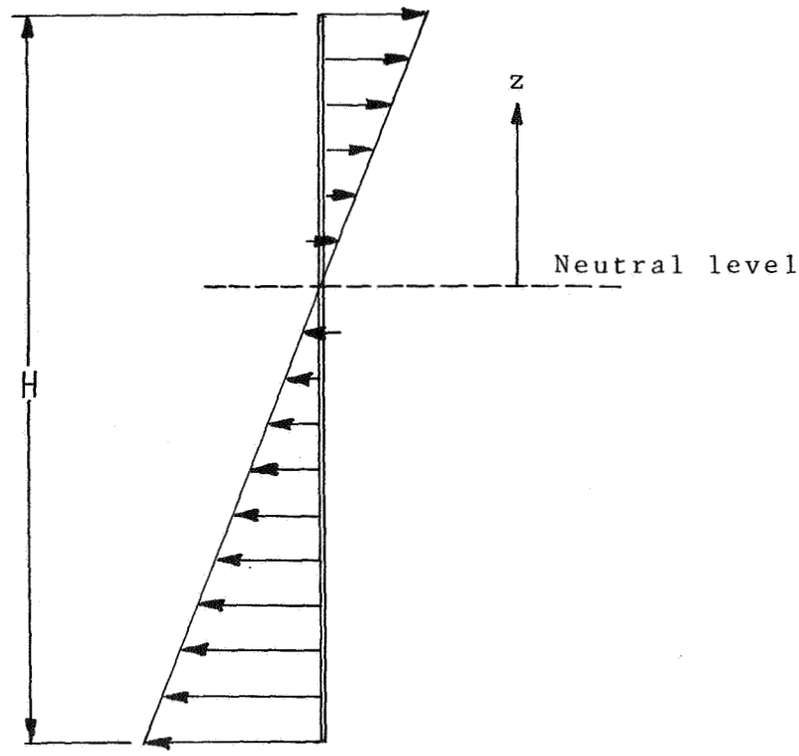

Figure 3.

2.3 Infiltration

The variation in the temperature-difference between inside and outside, $\Delta\theta$ is relatively small between different days. The exponent n, in equation (5), is therefore of less importance. The temperature-dependent part of the infiltration through cracks can be included in equation (10). The wind influenced infiltration flow will, in accordance with equation (4) and with the exponent $n = 2/3$, be

$$V = k_2 \cdot v_l^{2 \cdot 2/3} = k_2 \cdot v_l^{4/3} \tag{13}$$

The exponent 2/3 is a good approximation for characterizing the air flow through a building's all cracks, see Peterson[4]. The heat loss due to infiltration will now be

$$Q_{inf,w} = D \cdot v_l^{4/3} \cdot \Delta\theta \tag{14}$$

where D is a constant.

Summing up the four parts above will give the buildings total heat loss, due to transmission and ventilation, as

$$Q = Q_t + Q_{v,\theta} + Q_{v,w} + Q_{inf,w} = A \cdot \Delta\theta + B \cdot \Delta\theta^{3/2} + C \cdot v_l \cdot \Delta\theta + D \cdot v_l^{4/3} \cdot \Delta\theta \tag{15}$$

3. Measuring method

The heat loss due to transmission and ventilation, Q, in relation to wind velocity, v_l, and temperature difference, $\Delta\theta$, has been investigated. The investigation was made in an area of 79 small houses, in the south of Sweden. Twenty electrically heated houses, of two different types, were involved, ten of each type. The houses, which had two floors and a living area of 150 m^2 and 190 m^2 respectively, were spread on a hill, unprotected from the surrunding flat country in W-, SW and S-directions, see figure 4.

The families in the houses made daily notes on their total use of electricity and water, use of household machinery (such as washing machines) and other things important for the energy use. Figure 5 shows one family's notes for three days. (The total time of the investigation was between 23 - 27 days, depending on house). Out of the notes, a simple estimation of the houses heat loss, due to transmission and ventilation, was made.

3.1 Heat supply

Three sources contribute to the heat supply of a building. Besides the input of electricity (where also electricity to household equipment as stoves and ovens can be considered as heat supply to the building) it's

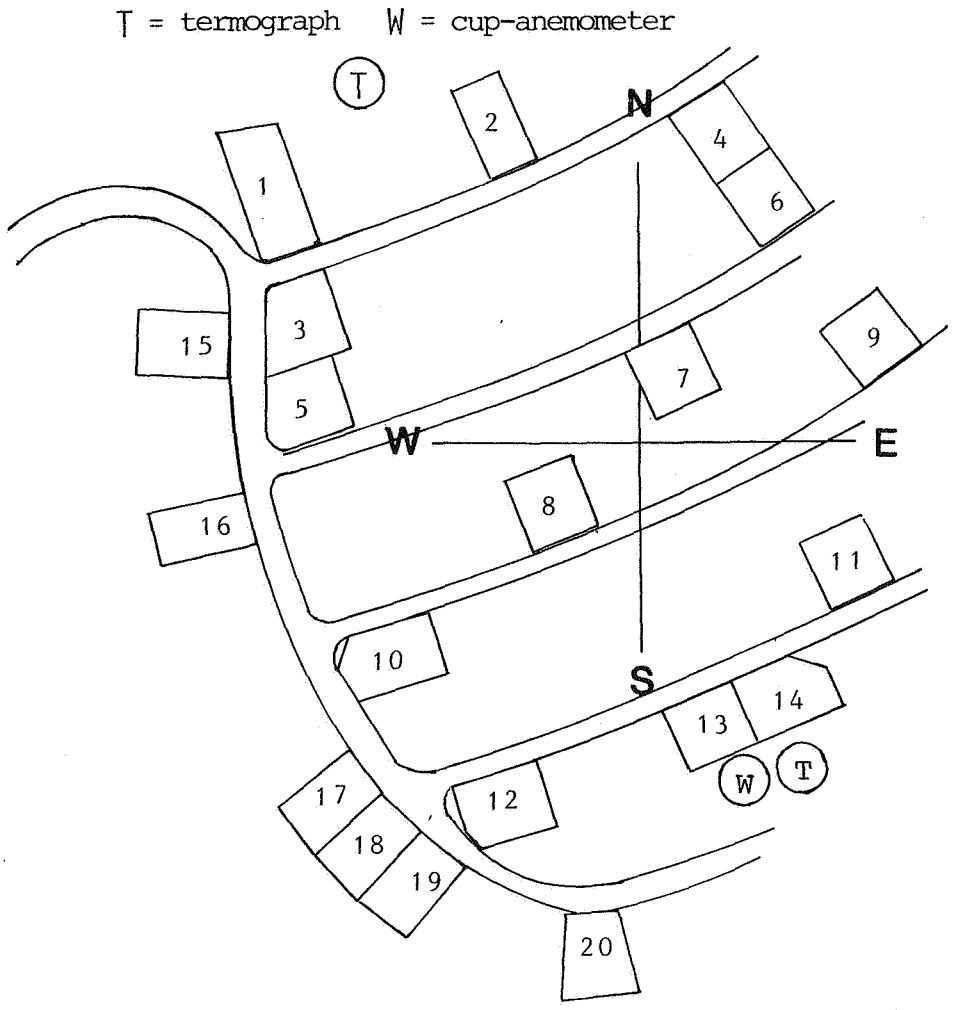

Figure 4.

the insolation through the windows and the heat emitted from persons. The electric heat supply was calculated due to the familie's notes on the used electricity. As supply for one day, the difference between the used electricity 7 am the following day and 7 am the actual day was used. The insolation through the windows was calculated from datas on house design (window-sizes and direction) and insolation from a nearby situated airport (10,5 km away). At the airport the solar radiation to a horizontal surface was registrated as energy amount per hour and per day. Since the insolation to vertical and horizontal surfaces may be assumed as linear to the cloudiness, M, it's possible to find a relation between the ratio Q_V/Q_H and the cloudiness for difference vertical directions and months of the year, see figure 6. Q_V and Q_H is the insolation to a vertical and to a horizontal surface respectively.

Date	Used amount of electricity 7 am kWh	Used amount of water m^3	Wash. mach. Number of runs	Dish. mach. Number of runs
26/1	84192.3	0.580		1
27/1	84310.3	0.902	3	1
28/1	84434.7	0.350		1

	Kitchen fan Time of use min	Drying cabinet Time of use min	Window opening Number of windows	Window opening Time min	Temperature °C
26/1	30		3	30	20
27/1	30	180			20
28/1	45				20

	Number of people at home Time: 0-2-4-6-8-10-12-14-16-18-20-22-24
26/1	4 3 2 4
27/1	4 3 2 0 3 4 3 4
28/1	4 3 2 4

Figure 5.

Consideration to shadowing was taken by the use of a shadowing factor ψ. This factor was set as either 1, for unshadowed facade, or 0,5 for partly shadowed facades. Use of venetian blinds and curtains was assumed to give a reduction of the insolation through southeast-south- and southwest orientated windows during days with more than 50 % clouds, i.e. M = 0,5 - 1,0. This reduction was expressed with the factor ϕ, set to 0,5 at above mentioned conditions and 1,0 otherwise. Transmission through the window-panes was taken in consideration by the use of a transmission factor τ. This was set to be 0,75 for 2-pane windows and 0,65 for 3-pane windows. Now the insolation through a window during the day can be calculated as

$$Q_s = q_s \cdot \tau \cdot \psi \cdot \phi \cdot Q_H \quad \text{Wh/day} \qquad (16)$$

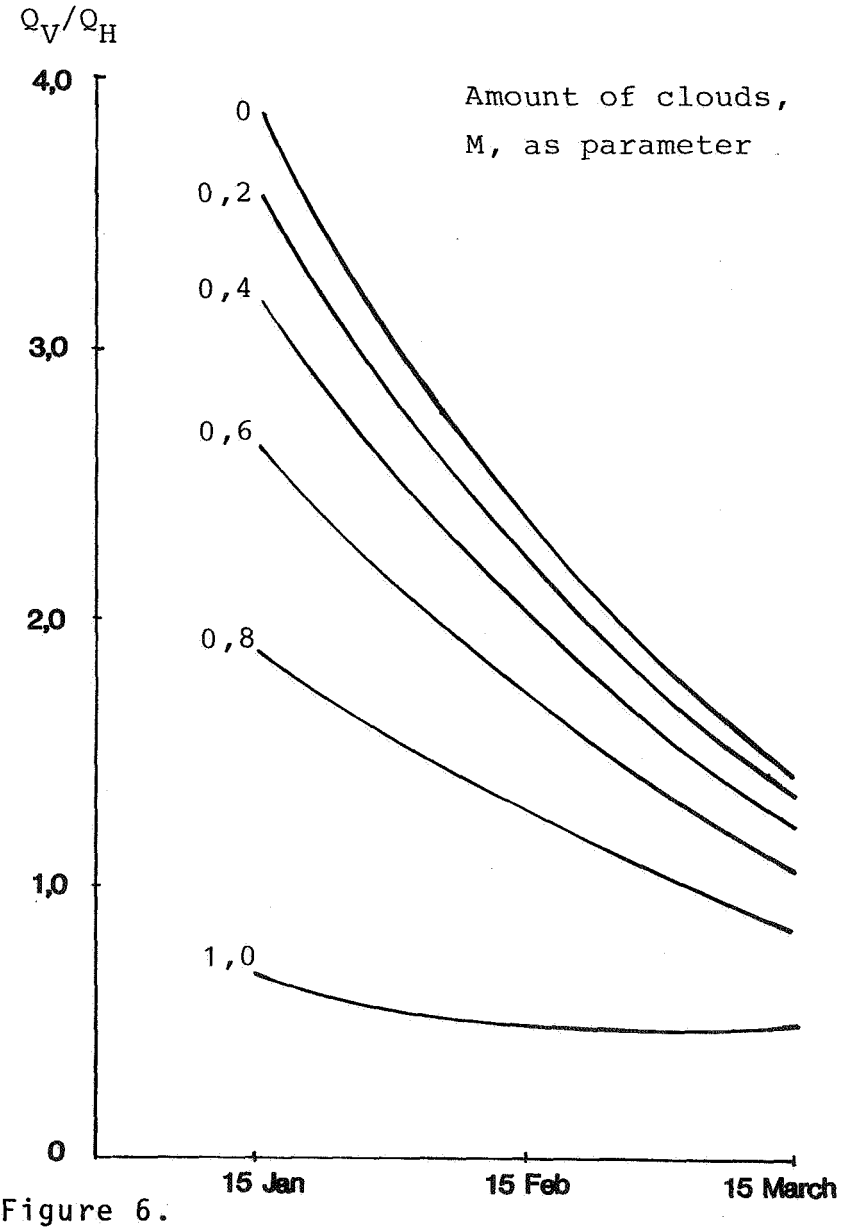

Figure 6.

Where q_s is the ratio Q_V/Q_H see figure 6

Q_H is the registrated insolation to a horizontal surface at the airport

With known direction and size of the building's windows this procedure made it possible to estimate the total heat supply during the day due to insolation. The person heat, i.e. the heat emitted from people in the house, was calculated from the familie's notes on number of people in the house during the day. Different people emit varying amounts of heat, depending on both the size and the age. As an average 90 W per person

was used when estimating the persons' contribution to the heat supply.

3.2 Heat losses

The main heat losses from the building, and also the heat losses we are interested to estimate, are the transmission and ventilation heat losses. Since these are difficult to measure directly, we have calculated them as the difference between heat supply and heat-losses due to other reasons than transmission and ventilation. These heat losses are hot water losses to the drain, when using washing- and dishing machines and during normal water consumption, warm-air losses, when using kitchen fan and drying cabinet, and heat losses due to window opening. The last two losses, warm air losses and heat losses due to window opening, are of course ventilation losses. But they are ventilation losses, not mainly dependent on the building and the weather conditions, but on human activities. They are therefore included among the heat losses above.

Hot water losses, from use of washing- and dishing machines, were calculated from producers datas on their products. Datas giving water consumption and used temperatures. Machinery used in the households were known trough an inquiry to the families at the start of the investigation. The water, not used in machines, was assumed to consist of 30 % hot water. 90 % of its energy was taken as heat loss to the drain. Heat losses, due to use of kitchen fan and drying cabinet, were also calculated out of producers datas, giving air flows and temperatures. Finally, heat losses due to window opening, were calculated with use of results from an investigation by Widegren-Dafgård[5]. According to these results, the air flow through a window opening, with height 1 m and with 0,3 m, is approximately 0,05 m3/s. Thus the heat loss during day can be calculated as

$$Q_w = 0{,}05 \cdot \rho \cdot c_p \cdot \Delta\theta \cdot t \quad \text{Wh/day} \qquad (17)$$

where ρ and c_p are density and heat capacity for air respectively

$\Delta\theta$ is temperature difference between inside and outside

t is the window opening time, according to family notes, see figure 5

When the heat supply and heat losses are calculated the heat losses due to transmission and ventilation, Q, can be determined for every house and day, see table 1.

Table 1

Date	Heat supply El. Q_{el}	Pers. Q_p	Sol. Q_s	Heat losses (kWh/day) Water	Wash. Q_v	Dish.	Fan	Dry. Q_a	Windows Q_w	Heat loss kWh/day Q	Specific heat loss (kWh/K,day) $Q/\Delta\Theta$
Jan 12	105.0	6.3	0.6	8.1			0.2		0.3	103.3	4.87
13	69.7	5.3	7.4	2.1					0.4	79.9	3.43
14	118.1	6.1	0.8	3.6		1.3	0.3		0.3	119.5	5.69
15	92.3	4.9	3.7	2.5					0.3	98.1	4.81
16	89.6	5.5	7.2	6.3			0.6		0.3	95.1	4.55
17	78.7	4.9	2.1	2.9					0.9	81.9	3.44
18	83.3	6.5	8.0	5.6		1.3			0.4	90.5	3.30
19	83.2	6.0	2.2	5.8			0.4		0.4	84.8	3.50
20	97.0	6.2	6.1	5.5			0.4		0.4	103.0	4.09
21	90.5	7.6	7.7	2.7			0.5		0.4	102.2	3.80
22	75.9	6.7	5.6	3.3					0.9	84.0	3.80
23	70.2	6.2	1.2	4.0					0.3	73.3	3.72
24	80.6	8.4	0.9	6.0					0.3	83.6	4.38
25	93.1	7.9	1.0	11.5		1.3	0.4		0.4	88.4	4.68
26	64.8	7.5	7.4	5.4			0.4		0.7	73.2	3.18
27	70.3	6.4	8.3	2.8			0.2		0.7	81.3	3.73
28	75.3	5.8	0.7	2.9	1.9	1.3	0.2		0.3	75.2	4.25
29	69.8	6.2	0.7	2.5			0.2		0.6	73.4	4.01
30	73.9	6.4	0.8	3.9					0.3	76.9	4.27
31	76.6	6.5	0.7	3.0			0.3		0.6	79.9	4.37

In table 1 giving results for one of the 20 houses, the specific heat loss, $Q/\Delta\theta$, is also calculated. Wind direction and velocity, as well as the outdoor temperature, was registrated at a place in the south part of the area, see figure 4. A cup-anemometer on 5 m height, was used for wind registerations. Supplementary outdoor temperatures were also registrated at a place north of the area. Wind velocities at street level were measured with a handhold anemometer. These velocities were related to simultaneous cup-anemometer recordings, giving velocity ratios shown in figure 7.

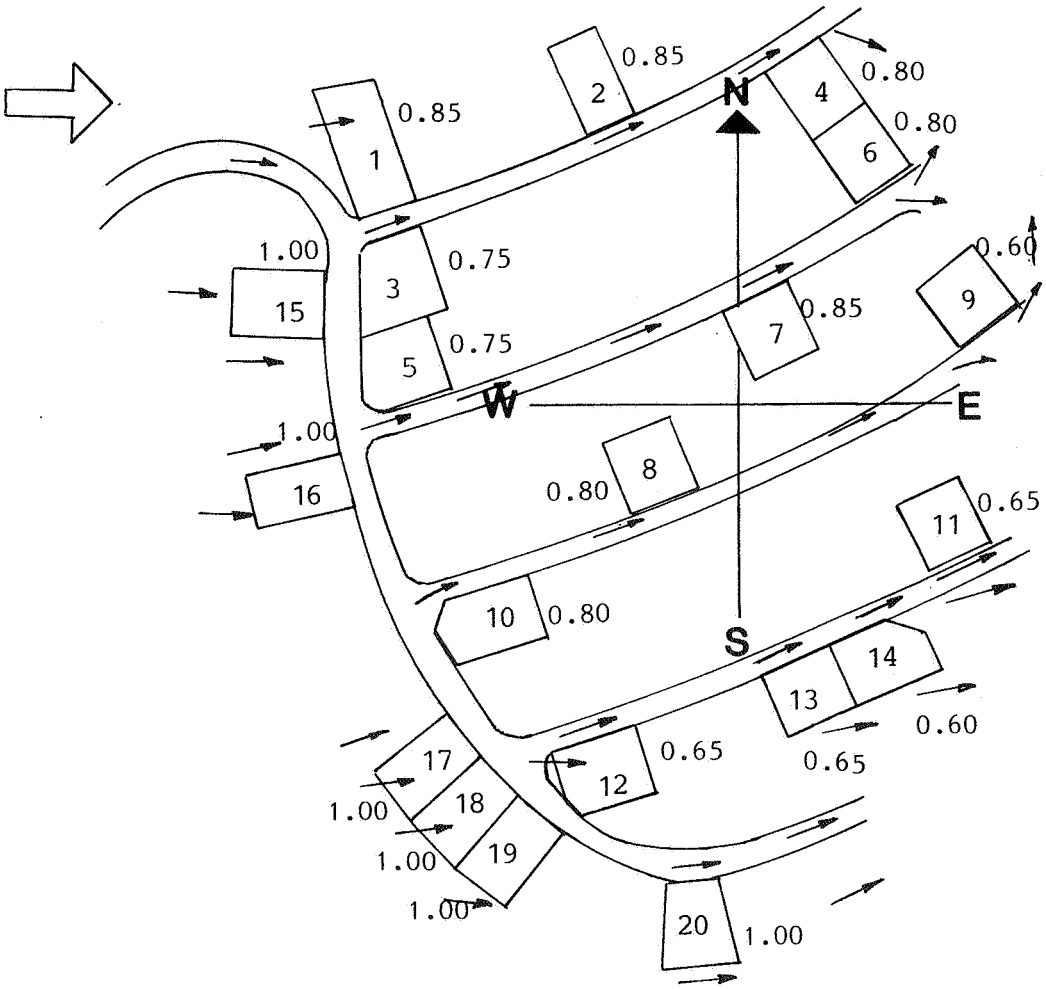

Figure 7.

These velocity ratios were determined at westwind, which was the dominating wind direction during the investigationperiod. They were later used to calculate local wind velocities, v_l, from the cup-anemometer recordings. For every house and day, we now had three

parameters, the specific heat loss during the day, $Q/\Delta\theta$, the mean local wind velocity during the day, v_l, and the mean outdoor-temperature during the day, $\Delta\theta$. These parameters are given for some days for one of the houses in table 2.

Table 2

Date	Temperature difference $\Delta\Theta$ K	Wind-velocity v_L m/s	Specific heat loss $Q/\Delta\Theta$ kWh/K,day
Jan 12	21.2	4.6	4.87
13	23.3	0.2	3.43
14	21.0	5.3	5.69
15	20.4	3.2	4.81
16	20.9	2.7	4.55
17	23.8	1.1	3.44
18	27.4	0.9	3.30
19	24.2	2.1	3.50
20	25.2	3.6	4.09
21	26.9	0.2	3.80
22	22.1	2.6	3.80
23	19.7	0.7	3.72
24	19.1	2.6	4.38
25	18.9	3.7	4.68
26	23.0	1.9	3.18
27	21.8	1.4	3.73
28	17.7	1.0	4.25
29	18.3	1.4	4.01
30	18.0	1.7	4.27
31	18.3	1.7	4.37

4. Results

The calculated parameters above have been analyzed using a relation according to equation (15). This can be circumscribed as

$$Q/\Delta\theta = A+B\cdot\Delta\theta^{1/2} + C\cdot v_l+D\cdot v_l^{4/3} \qquad (18)$$

Putting the calculated parameters for one house into eqaution (18) gives an equation system with as many equations as measuring days. Changing this equation system into a matrix equation will make it possible to solve the unknown matrix x, containing the constants A, B, C and D. With these constants known, we have a relation giving the specific heat loss for different wind velocities and temperature differences. Figure 8 shows this relation at three temperature differences for one of the houses.

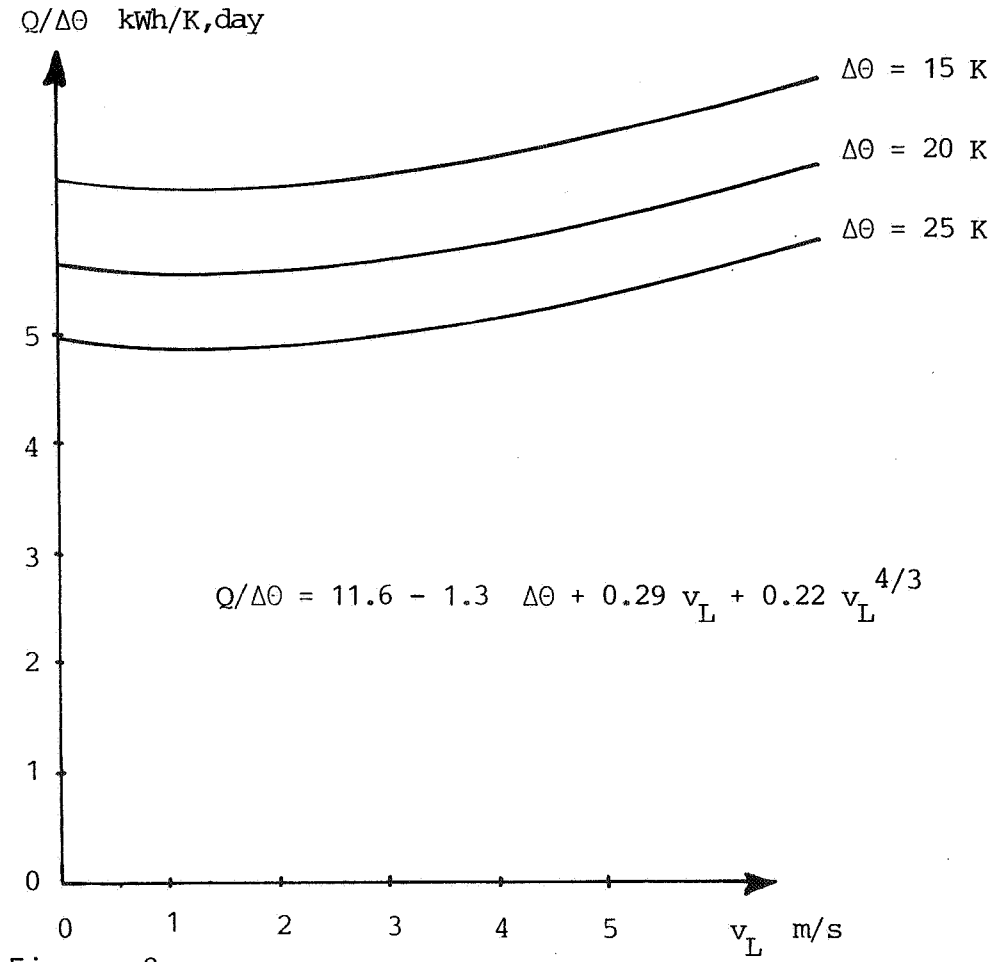

Figure 8.

The solution of the constants A, B, C and D, gives curves for the wind depending specific heat loss, that, for most of the houses, has a minimum. This minimum lies at wind velocities between 0,5 - 2,0 m/s. One can partly explain this minimum by the reduction of transmission heat loss with rised wind velocity that's possible during clear nights. The minimum may also be a result of the mathematical adjustment of the relation to the measuring datas.

The most surprising result is that the constant B is negative for all the 20 houses. Since the thermal forces increase with temperature difference, one would expect the specific heat loss due to this ventilation to increase with increased temperature difference. The constant B would then be positive. The only plausible explaination to the negative value of B is that the habits of the families change with outside temperature. With low outside temperature, and consequently high temperature difference $\Delta\theta$, people seem to be more inclined to keep their house tight.

Despite consideration has been taken to window opening, there is still a variation in opening width and opening time that's unknown. And above all there's an unknown variation in door-opening. Malik[6] found in an investigation similar tendencie. He found that an occupied house acted as if it had two different porosities. In cold weather the house was tighter than in mild. He thought that in mild weather, windows and doors are opened rather frequently and are closed carelessly, where as in winter, people make sure their windows and doors are closed tight.

The percentage change of the specific heat loss, $Q/\Delta\theta$, is shown in figure 9 for all the 20 houses. The temperature difference is here 20K. Equations of the type (18) may be used to determine the possible energy saving from reducing wind influence. It can be calculated as the procentual difference between average heat loss during the investigation period and the heat loss at the wind velocity giving minimum specific heat loss, se figure 8 and 9. Since the average wind- and temperature conditions, during the investigation period, January and February, were approximately the same as the average conditions in this part of Sweden during heating season, the calculated possible energy-saving is a good estimation for the whole year. Table 3 gives the calculated possible energy saving in percents.

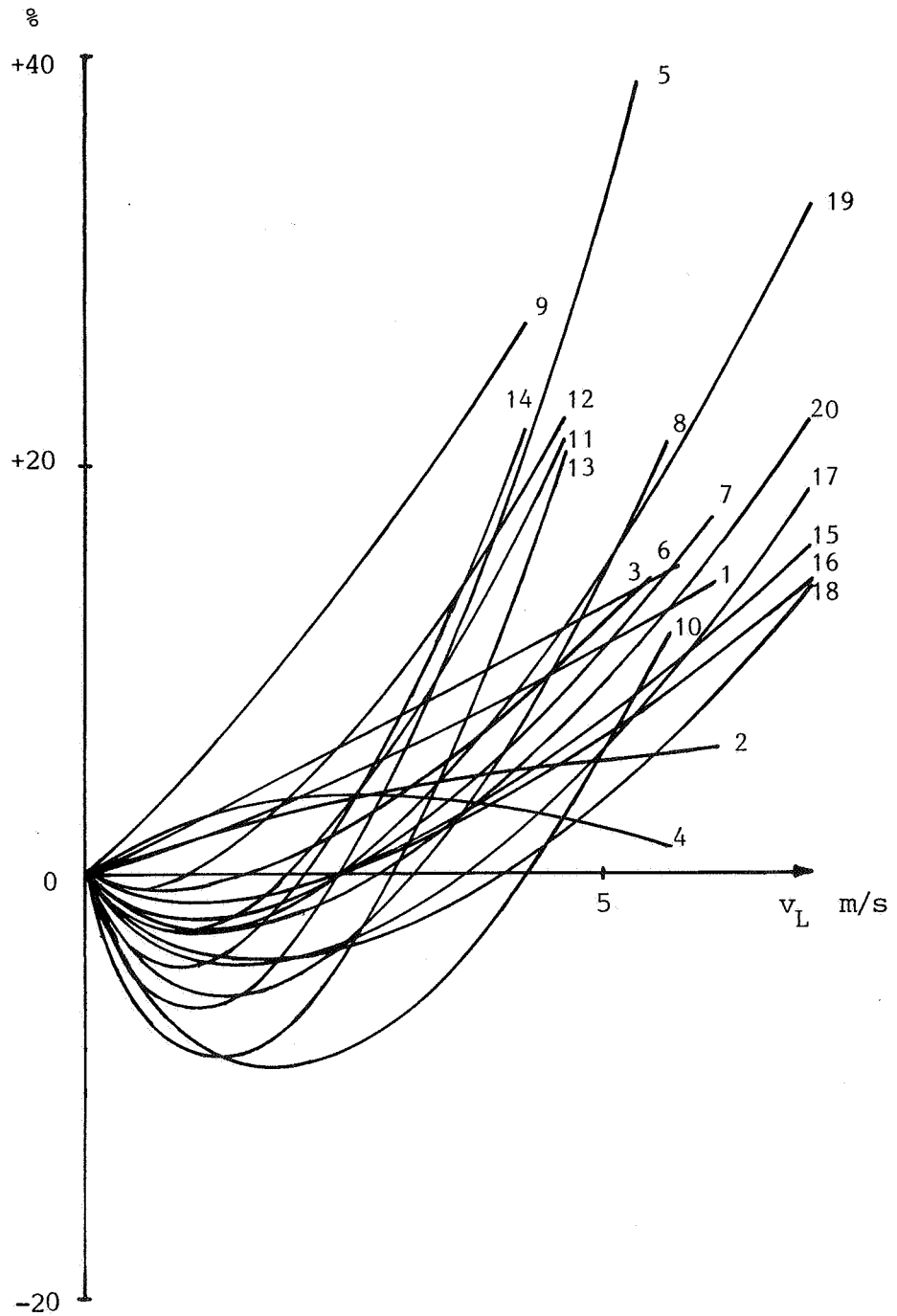

Figure 9.

The possible energy-saving is between 3,3-9,4 %. This energy saving may either be achieved by reducing the wind velocity to 0,5-2,0 m/s, or by tightening the house.

Table 3

House nr	Possible energysaving %
1	5.0
2	3.3
3	3.3
4	3.1
5	8.8
6	5.7
7	4.0
8	4.6
9	9.4
10	8.3
11	4.9
12	5.3
13	5.3
14	4.8
15	3.8
16	3.2
17	4.5
18	4.1
19	7.6
20	5.3

Figure 10.

1. BAHNFLETH, D.R. and MOSELEY, T.D. and HARRIS, W.S.
"Measurement of infiltration in two residences"
ASHRAE Trans. 63, 1957 pp 439-476

2. PETERSON, F
"The Ventilation of Dwellings"
6th Congress on Heating and Ventilation, Budapest 1970.

3. FRANK, W.
"Zu Frage des erhöhten Heizvärmeverbrauches bei Wind"
Gesundheits-Ingenieur, 99, Heft 1/2, 1978 pp 3-7.

4. PETERSON, F
"On flow in narros slots applied to infiltration"
3rd AIC Conference, London, 1982.

5. WIDEGREN-DAFGÅRD, K
"Fönstervädring i bostäder"
Tekniska Meddelanden från Institutionen för Uppvärmnings- och ventilationsteknik nr 170 9, 1980
pp 104-119.

6. MALIK, N.
"Field studies of dependence of air infiltration on outside temperature and wind"
Energy and Buildings 1, 1978, pp 281-292