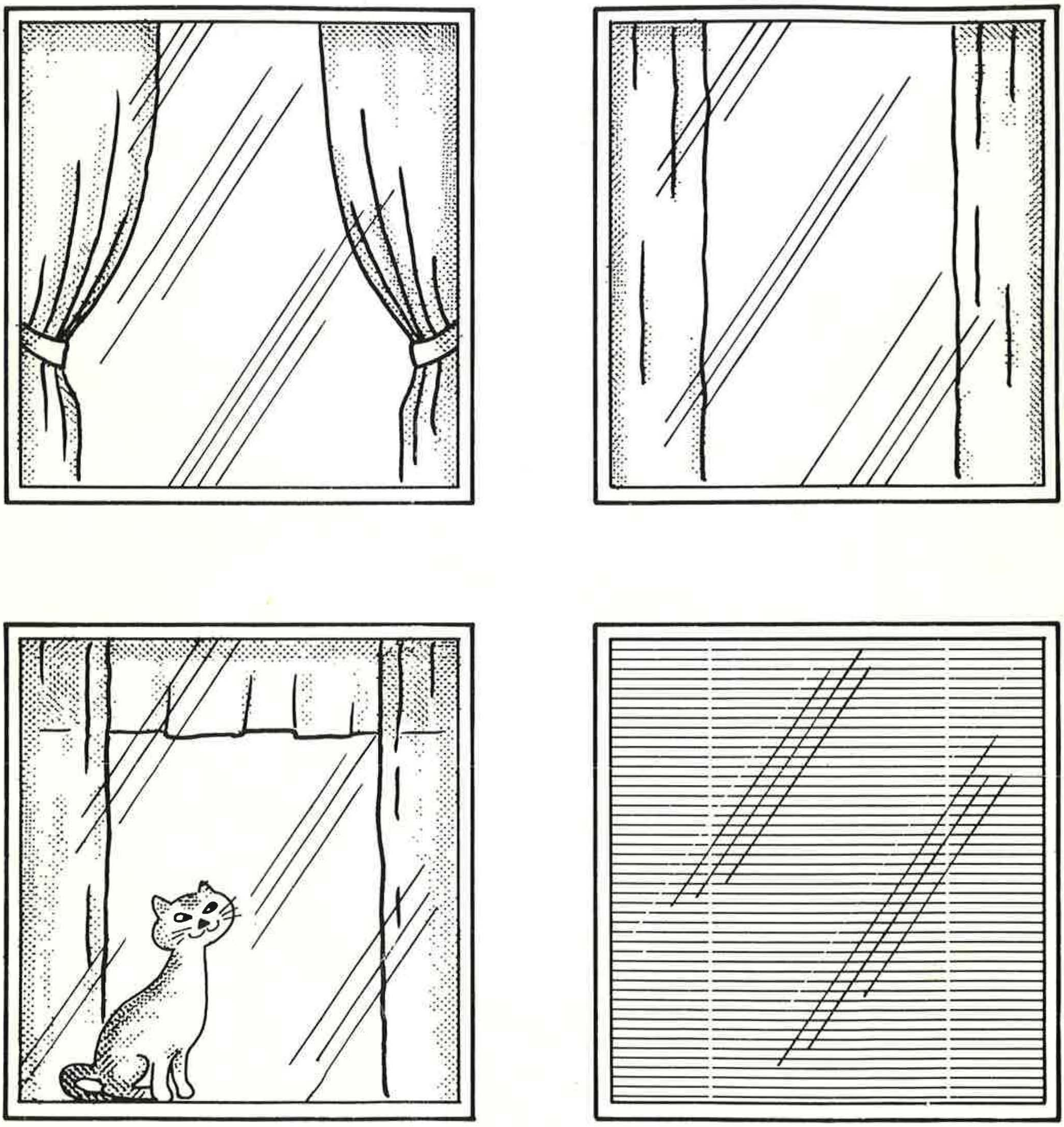
bulletin M83:21

THE NATIONAL SWEDISH INSTITUTE FOR BUILDING RESEARCH

RESIDENTS AND WINDOWS

2. Airing



Mats D Lyberg

Förteckning över meddelande/bulletin 1983

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Mats D Lyberg
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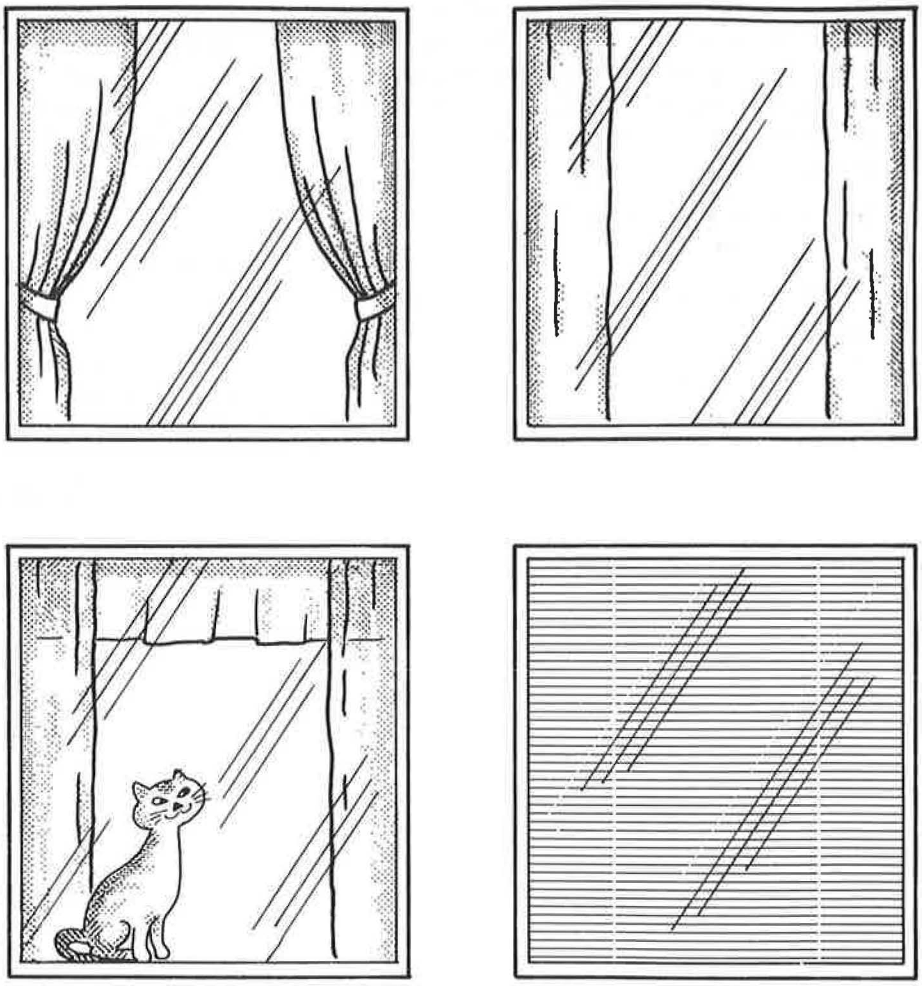
RESIDENTS AND WINDOWS

2. *Airing*



Mats D Lyberg

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EXELLAN GRAFISKA
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SAMMANFATTNING

Vädringsvanor i radhus och flerbostadshus har undersökts genom observation av fönster till 50 000 rum. Resultaten av denna undersökning jämförs med resultat från liknande studier i andra länder. Det visar sig att andelen rum med öppna fönster, n, är beroende av temperaturskillnaden inne- ute, ΔT, genom relationen $n*\Delta T=C$, dar C i alla undersökningar är en konstant med ett värde 2.2 ± 0.4 K.

Med detta resultat som utgångspunkt beräknas den genomsnittliga energiförlusten orsakad av vädring. Resultatet är, för en vindstyrka av 4 m/s och en temperaturskillnad av 20 K, för radhus 0.8 kWh/dag och för lägenheter i flerfamiljshus 0.5 kWh/dag. Osäkerheten i denna uppskattning kan nästan helt hänföras till bristande kännedom om storleken hos fönsterspringor vid vädring.

SUMMARY

The habits of airing have been examined by performing observations of windows belonging to 50 000 rooms in row- houses and multi- family residential buildings. The results are compared to observations performed in other countries. It is shown that the fraction of rooms having a window open, n, is related to the indoor- outdoor temperature difference, ΔT, through the relation $n*\Delta T=C$, where the constant C takes a value of 2.2 $\pm$ 0.4 K. for all investigations.

From this information the average energy losses in Sweden due to airing are calculated. The result is, assuming a wind speed of 4 m/s and a temperature difference of 20 K, that they amount to 0.8 kWh/day for row- houses and to 0.5 kWh/day for multi- family buildings. The uncertainty of this result is largely associated with lack of information about the size of window openings when airing is performed.

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INTRODUCTION

For the resident the control of ventilation may serve many purposes. Primarily it serves to control the rate of air change to preserve a high air quality for the hygiene and comfort. It may also serve to control the indoor temperature if the ventilation system is such that this can easily be done.

In this Report we will mainly be interested in the energy aspect of airing. The determination of energy losses by airing is no easy task. It requires information about

1) The frequency of airing

2) The rate of air change when airing is performed

3) The indoor- outdoor temperature difference

The determination of the first item above requires field measurements. Information about the second item can be collected by laboratory or field experiments. However, it will often be necessary to have information also about the geometrical properties of the opening when airing is performed in order to determine the actual rate of air exchange. The temperature difference is easily measured.

The frequency of airing can not be expexted to be constant. It will probably depend on factors associated with the outdoor and indoor climate like indoor and outdoor temperature, wind speed and direction, indoor and outdoor humidity, sunshine etc. It will also be influenced by the presence of a mechanical ventilation system. Factors like the residents´ presence at home and the frequency of cooking can also be expected to be of importance.

From an energetic point of view the interesting relation is the one between the frequency of airing and the indoor- outdoor temperature difference. In this Report we will therefore concentrate on the determination of this relation and its impact on energy consumption.

EXPERIMENTAL METHODS

For the determination of the frequency of airing three experimental methods have been used. They are, in decreasing order of importance:

1) observations

2) direct measurements

3) interviews.

Observations are performed by an observer walking around a number of buildings during the day, observing the number of open windows on each facade. Studies of this kind have been performed where the observations have been made every hour for a period of one year.

The use of observations is a flexible method. It can be used for intense observations of a small number of buildings, or for observations of a large number of buildings at a limited number of occasions. The drawbacks of observations are that they can not be performed at night; it is a time- consuming method if many observations are to be made, and it requires a skilled observer to determine when windows are ajar.

Possible alternatives to observations are the use of TV cameras or the recording of the building facades by photographic means. These methods have probably not been used in practice.

Direct measurements generally involve the use of magnetic switches to record when a window is closed. Photocells can also be used for this purpose. Direct measurements give a very detailed picture of when, and for how long, the resident is airing. However, in general it is not possible to determine how large the size of the openings are. This technique has usually been applied only when a comparatively small number of dwellings have been studied.

Temperature measurements can also be applied for the recording of when a window is opened. Thermometers placed near the window or close to the floor will sense the change of the air temperature. In this case it may be more difficult to determine when a window is closed.

Survey techniques can also be used. The resident can be asked about how often and when he opens windows. The answer will depend on the season. The resident will in general tell about his behaviour during the last days or last few weeks.

It is of interest to compare the results from investigations where observations and interviews have been used simultaneously. If it turns out that performing interviews is a reliable method for the determination of the frequency of airing during the day, it is also to be expected that the information about the nocturnal habits of airing is to be trusted. This is of interest when observations can not be performed at night.

Laboratory measurements of the flow through open windows will in general give a value that is too large. This is due to the fact that external turbulence creates an unsteady flow which, together with other mechanisms, results in an imperfect mixing of the room air with the air entering through the window. This air flow will depend on wind speed, temperature difference between interior and exterior air, wind direction, geometric properties of the building facade, position of the window on the facade and to what extent the window is open.

Some attempts to determine the air flow through a window, open or ajar, have been made in model scale (1 and 2). They indicate that the actual flow will only be about 40 % of the theoretically calculated one. Fits of experimental data on the rate of air change in inhabited dwellings when airing is performed yield similar results (3).

EARLIER STUDIES

In 1951 Dick and Thomas (4) investigated the window-opening habit observing 15 houses at an exposed site during 26 weeks of the heating season. They found that the mean number of open windows would correspond to an average air-change rate of 2.5 air changes per hour during occupation versus 1.5 when all windows were closed. Although there were large variations in window habits from house to house and from day to day, it was apparent that there was an underlying relationship between window opening and the external climate.

Dick and Thomas claim that the external temperature alone accounted for over 70% of the observed variance in the number of vents and casements open and that a further 10% of the variance could be attributed to wind speed. Dick and Thomas also investigated houses at a sheltered site in the same manner and there obtained similar results. The window opening habits caused an increae in the average air change rate per hour from 0.9 to 2. In this case the observations were supplemented by reports from the tenants on the windows they kept open at night. It was found that on the average these reports corresponded with the observations by day except that the windows downstairs were kept closed at night. In the investigated houses the indoor temperature was about 14°C during the heating season. It can be assumed that most of the houses were occupied all the day.

In 1977 Brundrett (5 and 6) undertook a similar study of 123 houses in Northern England. Findings similar to those of Dick and Thomas were obtained. A good correlation between window-opening and outdoor air moisture content was found. It was also found that the occupation of the housewife influenced the window-opening behaviour. Those housewives out at work were associated with only half the number of open windows compared with the number opened by those who stayed at home. Also the size of the family was of importance.

A new experiment was undertaken on 24 houses where the occupants were at home all day. The houses were situated in Scotland and were all wooden, prefabricated Norwegian houses.

They were highly insulated and weather stripped. Observations of open windows were performed each day for one winter.

The author concludes that a possible hypothesis for the window-opening behaviour is moisture control. The indoor air temperature in these houses during the heating season was 16°C.

In an investigation in Sweden 1961 (7) the window opening behaviour in 200 flats was studied in three eight-storey residential buildings during one year. This study had been preceeded by an one-week pilot-study in another Swedish town.

The occupants were asked about their hour by hour window-opening habits during winter, spring and summer. From the answers one could conclude that about one third as many windows were open during the night as during the day independent of the season. A good correlation between window-opening and outdoor air temperature and between window-opening and sunshine was found. The average indoor air temperature at the observed flats in this investigation was about 22°C.

In Fig. 1 we present the results of the abovementioned investigation. If n denotes the fraction of rooms having an open window and ΔT denotes the indoor-outdoor air temperature difference, we have plotted n times ΔT versus ΔT. For ΔT greater than 5 K, $n^* \Delta T$ seems to take a constant value of about 2 K. There is also a rather good agreement between the results from the observations and from the interviews. It seems as if it is possible to obtain a rather good estimate of the window-opening behaviour from interviews, at least if they are conducted as in this investigation.

In another Swedish investigation (8) 23 households in different multi-family buildings were asked, among other things, about their window-opening habits. These interviews were conducted in a rather loose form and therefore are somewhat difficult to interpret. The interviews were conducted in April and May, and if one assumes that the occupants told about their window- opening habits during these months it is possible to interpret the results in the same manner as in Fig. 1. The outdoor air temperature then has to be taken as the average outdoor air temperature during these two months. The result agrees with the other investigations inside the errors.

From these interviews it is also possible to conclude that the number of open windows during the night was only somewhat less than during the day. There was no big difference between flats having only natural ventilation and flats equipped by mechanical exhaust or mechanical exhaust and supply ventilation systems. From these interviews it was found that the main reason for an occupant to open a window was not to increase the air change but to regulate the indoor temperature.

There also exist some other studies on window opening behaviour using survey techniques. In an American investigation (9) 1500 households were asked about their wintertime window-opening practices. About one third sometimes kept their bedroom window open at night, while all others almost never opened there windows during the night. There was also no great correlation between the window-opening practice and the number of heating degree days.

In a large Italian Survey (10) about 10 000 households were asked for how long time they kept their windows open in different rooms every day. For kitchen, bathroom and bedorom the average was about one hour and for other rooms somewhat less. In this case it is not clear what the external temperature was when the interviews were performed.

Direct measurements using magnetic switches has been applied in a Swiss study (11). In a residential building 16 flats were surveyed during one heating season. It was found that airing was more frequent at night than during the day.

A minor Swedish survey of about 50 SFD (12) gives the result that in 85% of the households the rooms are aired at least once every day. A Swedish study of 14 low-energy houses (13) included measurements of the use and control of the fans of the exhaust air system and interviews regarding the window-opening habits. It was found that the occupants used forced ventilation about two hours every day. Window-opening in the morning and the evening was still very frequent and when the ventilation system was felt to be insufficient windows were used to supply the wanted rate of air change.

Studies of variations in the occupants´ habits of airing have been performed (14). It was found that the variation between households in terms of their total daily window opening was greater than that within households. Their were indications that occupants adopt consistent airing patterns.

In an investigation of energy saving in two blocks of flats in Sweden the indoor temperature in one block was lowered by 3 K and the flow rate of the supply air was reduced by one half (15). The occupants were subjected to a general energy saving campaign. This lead to an immediate energy saving by 20%. When asked why they opened windows less about 75% of the inhabitants gave the reason that it was too cold in the flats for window-opening. The rest of the occupants aired less frequently in order to save energy. In another block the thermostats of electric radiators were preset resulting in a much smaller lowering of the indoor temperature than in the previous case. Here the rate of ventilation was not altered. In this case almost nine out of ten inhabitants stated that they opened windows less in order to save electric energy. The investigations cited above indicate that the exterior and interior air temperature are of important for the actual window-opening habits.

The heating system of the residential building and the properties of the wall insulation may also influence the window-opening habits of the occupant. In dwellings where the indoor temperature can rise quickly after closing of the window the occupant will find that window-opening does not lead to lower indoor-temperatures and he will therefore have no compunction in opening the windows.

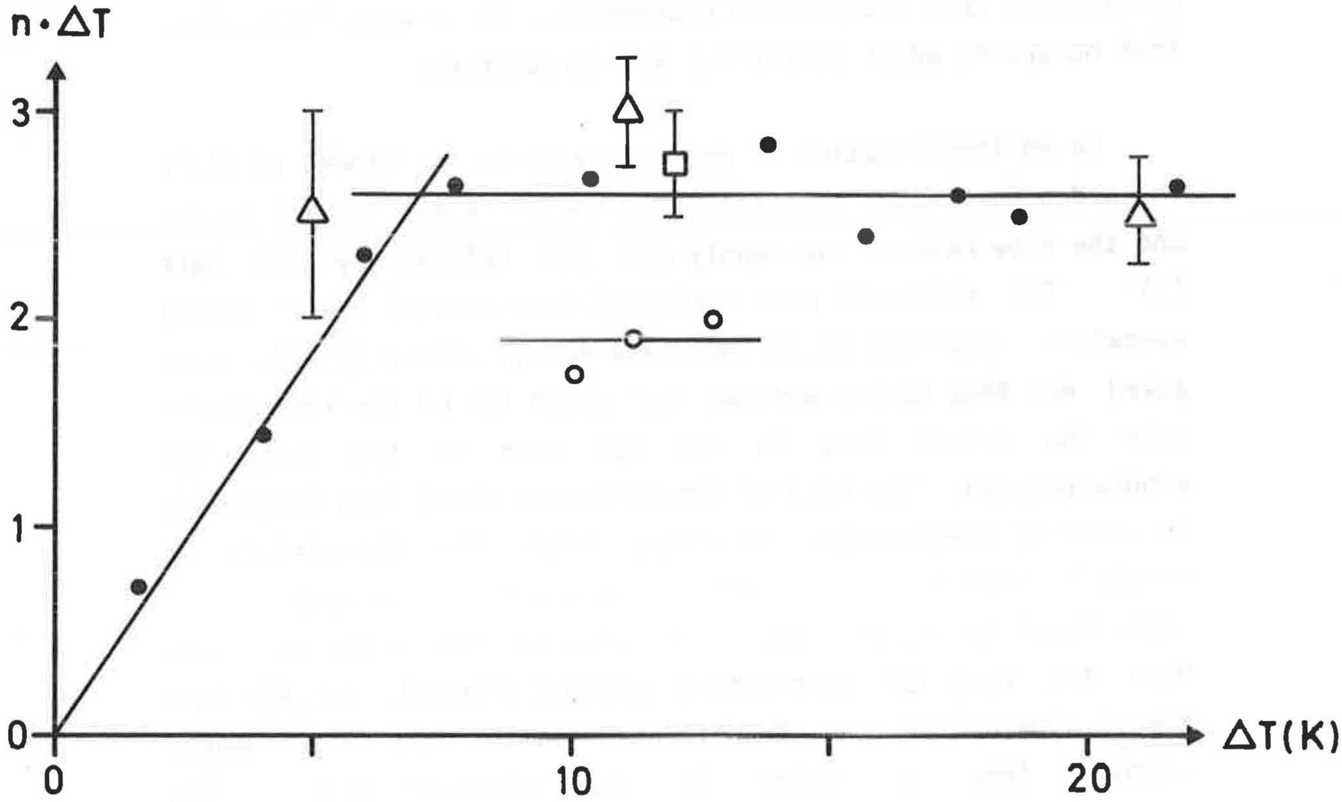

Fig 1 Fraction of rooms having open windows, n, times the indoor-outdoor temperature differences ΔT, versus ΔT.
o pilot study of ref 7
● observation ref 7
Δ interviews ref 7
□ interviews ref 8

THIS INVESTIGATION

In this investigation we have relied on observations for the determination of the frequency of airing. However, we have not wanted to study a few buildings in detail as in previous investigations, but have instead observed a large number of buildings at a limited number of occasions. In this way one gets a better idea about the average frequency of airing. However, the studied buildings have not been selected in any systematic way.

For observational reasons it has been necessary to restrict the observations to multi- family buildings with less than 5 storeys and to one- and two- storey row- houses. The observations have mainly been performed in a medium- sized Swedish town, but some have been made in Stockholm. The observed buildings have been erected between 1950 and 1975.

There are no indications that the habit of airing should vary much between buildings of different kind. The only observed exception is an old persons´ home, where the frequency of airing was about twice the average one.

The observations have been performed on days with an outdoor temperature ranging from -25 C to 17°C. Days with not very frequently occuring weather conditions like days with strong winds, and days with a very intense solar radiation, have been avoided. The time of the day for observations depends on the season as the length of the day varies. Most observations have been made between 9 a.m. and 6 p.m.

A total number of 50 000 rooms have been observed. The results are presented in Fig. 2. Each data point represents an observation of about 3000 rooms in one day. The data are presented in the same manner as in Fig. 1, i.e. the product of the fraction of rooms with an window open or ajar, n, and the temperature differece ΔT, is plotted versus ΔT. For row- houses the average value of $n*\Delta T$ is 2.2 and for multi- family residential buildigs 2.3. It has been assumed that the nocturnal airing habits are the same as those during the day.

This assumption is not supported by any strong evidence except by information collected from interviews with a rather small number of households (8).

Most data points represent days when it is not known in how many households there was someone at home. To compare with other experiments this information would be of value. On a few occasions it was possible to perform the observations on days for which such information was available, days when popular sport events were broadcasted on TV. According to an investigation performed by the Broadcasting Company, these events were watched by someone in more than 80 % of all households. The data points corresponding to observations performed on these days ca be found in Fig. 2.

As seen from Fig. 2, there are good reasons to believe that the fraction of rooms with windows open or ajar is inversely proportional to the temperature difference. In Fig. 3 we have collected data from the experiments described in the previous section and from this investigation. In Table 1 the average value of $n*\Delta T$ found in these experiments is given. All values lie in the range 1.8 - 2.6. This is rather remarkable as the variation of all other parameters vary between the experiments:

1) the heating system varies between the buildings

2) the average rate of air change varies from about 0.5 to over 2 ACH between the studied buildings

3) the average indoor temperature varies from 14°C to 22°C.

4) the studied buildings are from different countries and climatic regions, and the exposure to wind varies

5) the first investigation (4) was performed about 30 years before the last one (11)

As a first approximation one can therefore conclude that the average value of the fraction of open windows, n, is inversely proportional to the indoor- outdoor temperature difference, ΔT, with a proportionality constant equal to 2.2. Influence from other factors does not change this value by more than 0.4.

Some other observations have also been made in connection with this investigation:

1) If by an open window is meant that the width of the opening shall exceed a few cm, then open windows are very rare. Only a few per cent of all open windows have been open in this more restricted sense. From observations it is estimated that windows ajar have an opening with a width not exceeding 5 mm, in many cases it is probably as small as 2 mm.

2) Open windows in the above more restricted sense are in most cases represented by windows inside a balcony or by a balcony door, especially in the spring. To some extent kitchen windows may also be opened when the residents´ are preparing meals, but also in this case most windows are ajar.

3) It seems to be a rather common habit to leave bed room windows ajar when leaving for work in the morning. These windows then remain open for the rest of the day.

4) Windows are in most cases opened on the leeward side of the building.

TABLE 1

EXPERIMENTAL STUDIES OF AIRING HABITS

reference	building type and length of investigation	heating system	average temp indoor (°C)	range ΔT (K)	n*ΔT
4	8 detached 2-storey houses. Sheltered site One heating season	central heating water-heated ceiling panels	14	6-12	2.6
4	15 2-storey rowhouses. Exposed site. One heating season	various	14	5-11	1.9
6	25 2-storey highly insulated houses. One winter. v< 5 m/s	electric	16	3-20	2.2
7	10-storey MFD.200 flats. One year	water-heated radiators	22	1-24	2.6
7	3-storey MFD. 200 flats. One week	"	22	10-14	1.9
this inv.	3-5 storey MFD 1000 flats. 6 months	water heated radiators	22	5-45	2.2
"	2-storey row-houses 1000 houses. 6 months	water heated rad. and electric heating	22	5-45	2.4
11	16 flats of 4-storey residential building	water-heated radiators	20	9-23	1.8

n=fraction of rooms having a window open or ajar   v=wind speed

ΔT=outdoor- indoor temperature difference

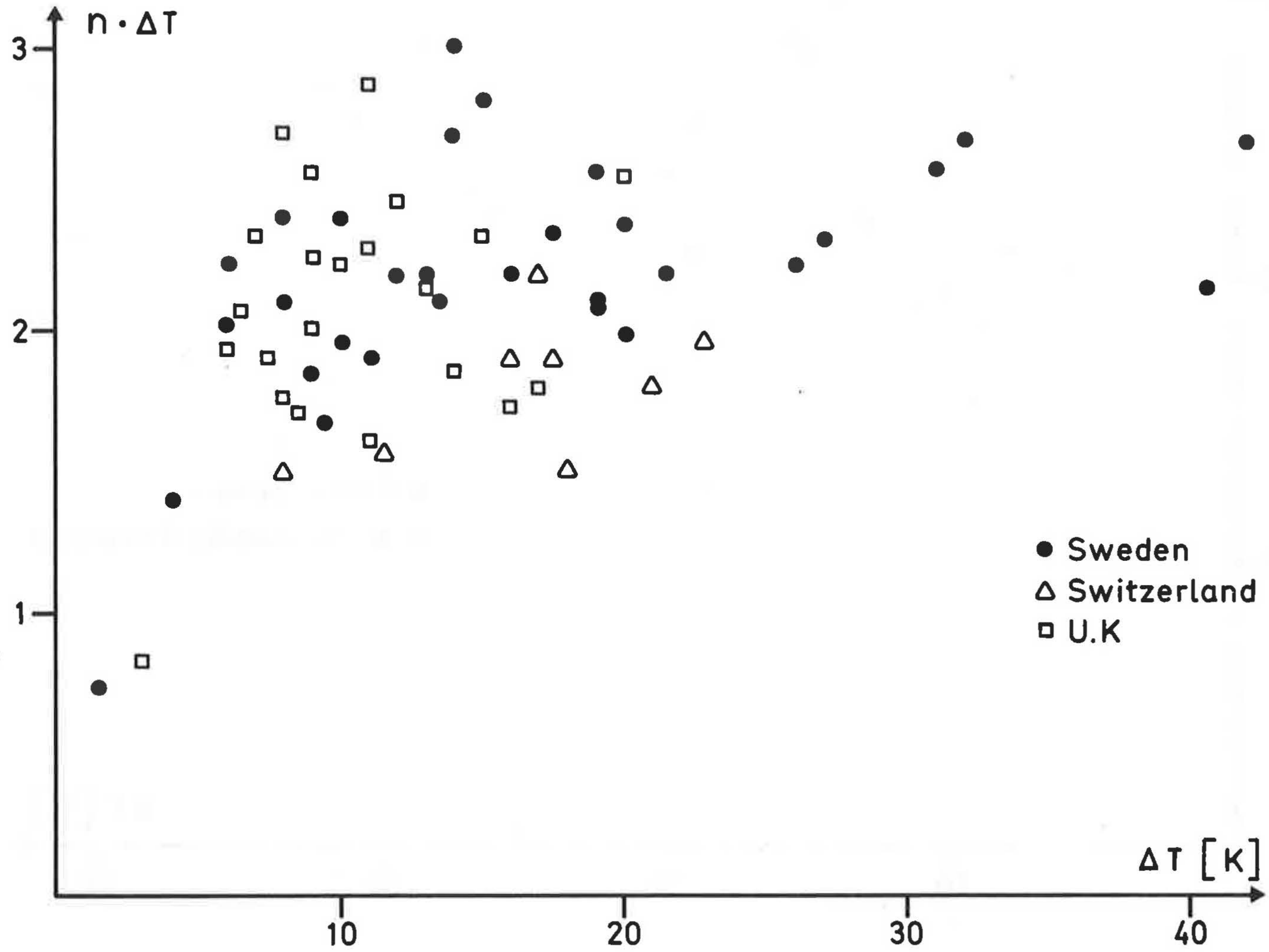

Fig 3 Fraction of rooms having open windows, n, times the indoor-outdoor temperature difference ΔT, versus ΔT. Data from eight studies (ref 4, 6, 7, 11 and this investigation) in Sweden, Switzerland and the UK.

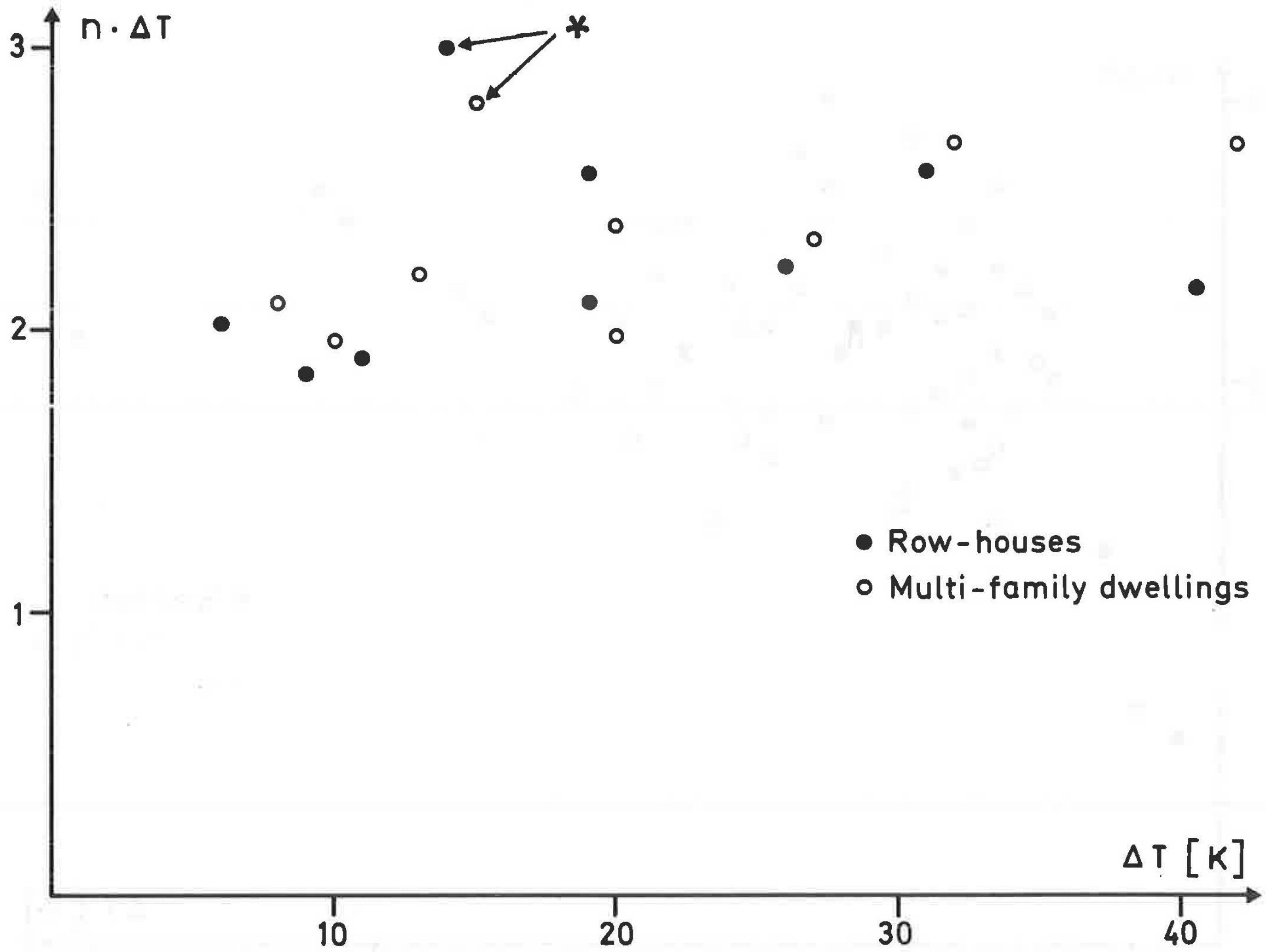

Fig 2 Fraction of rooms having open windows, n, times the indoor-outdoor temperature difference ΔT, versus ΔT. Data from observations of row-houses and multi-family buildings performed in this investigation. Data points indicated by an asterisk refer to days when there was someone at home in a large fraction of the households.

ENERGY LOSSES

Even if the frequency of airing is approximately known, this is not the case for the resulting change of the ACH compared to when there are no windows open. The change of the ACH will also be determined by the properties of the building and the size of the opening. Measurements of the rate of air change with windows open and closed has only been performed in one of the experiments referred to in this Report (4). In this case the habits of airing increased the infiltration rate by a factor of two compared to what it would have been if no windows had been opened.

Lacking measurements of the ACH of the observed buildings, the change of the ACH has to be estimated. One must then make assumptions about the physical properties of the buildings and the size of the openings. Here we will treat the case of a two storey row- house and a flat in a multi- storey residential building. For the estimate we will use a model (3) that is expected to predict the ACH when windows are open with an accuracy of 20 or 30 %. The error introduced by using this model will be small compared to the uncertainty in some of the assumptions.

The following assumptions have been made:

1) The volume of the row- house is 330 m^3 and the volume of the flat is 180 m^3.

2) The height of the row- house is 5 m and the height of the flat is 2.5 m.

3) The length of the exposed facades is 9 m for both dwellings

4) The height of the window is 1.2 m.

5) The open window is situated at the leeward side of the building and in the row- house it is on the top floor.

6) The rowhouse is situated in a densely built suburban setting and the resulting average pressure coefficient across the building takes a value of 0.3. For the flat it is assumed that the average pressure coefficient across the building takes a value of 1.0.

7) The leakiness of the building is such that, with the assumptions made in 6) above, the infiltration rate, when no windows are open, is equal to 0.5 ACH for a wind speed of 4 m/s and a temperature difference of 20 K.

8) There is no internal resistance to the air flow inside the dwelling, e.g., all doors in the dwelling are open.

9) all wind directions are equally probable

Using these assumptions it is possible to estimate the change of the ACH, averaged over all wind directions, when a window is open compared to when it is closed. The result is given in Fig. 4. in terms of the percentual change of the ACH for every mm of effective opening width. The result is a change of about 2.5% for the row- house and about 4% for the flat. The change is rather independent of the wind speed and the temperature difference. This estimate is of course associted with an error. The assumptions 1) - 9) can be varied within certain limits. A sensitivity analysis, making other reasonable assumptions than those made above, reveals that the error of the above estimates, including the error introduced by the use of the model, does not exceed 50%.

To estimate the resulting energy losses it is necessary to know the frequency of airing and the width of the opening. For the frequency of airing we assume that the results obtained in the previous section are valid, i.e., we assume that $n * \Delta T = 2.2$. We also assume that the width of the opening is equal to 5 mm and that the discharge factor is equal to 0.4 (see the section "Experimental methods") which means an effective opening width of 2mm. Using the results of Fig. 4 one can then calculate the resulting energy loss due to airing.

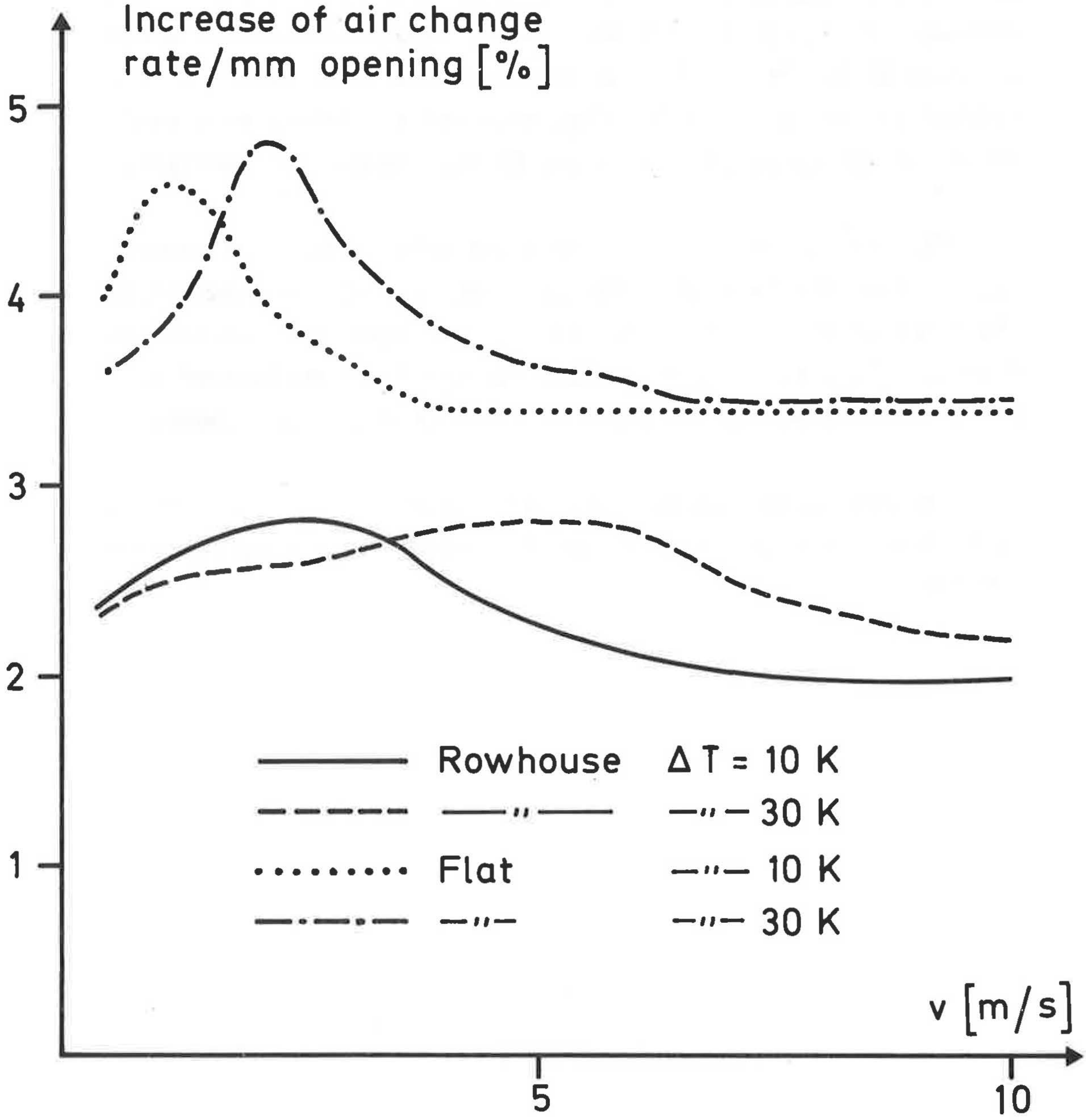

Fig 4 Increase in % of the rate of air change per mm effective opening width of the window, compared to the rate of air change when there are no open windows, versus the wind speed.

For a wind speed of 4 m/s and a temperature difference of 20 K one obtains an energy loss of 0.8 kWh/day for the row-house and an energy loss of 0.5 kWh/day for the flat. This estimate is then, as mentioned above, associated with an error of about 50 %. It should also be pointed out that this is the average energy loss for dwellings with average habits of airing. In individual cases the losses may be much larger (or smaller).

The crucial assumption in this estimate which, if wrong, may change the outcome of the estimate, is then the assumption about the width of the opening. Here more information is needed. If, e.g, the width of the opening is 10 mm instead of 5 mm, the resulting energy loss will be twice that given above.

The resulting energy loss may seem small, but it is sufficient to lower the room air temperature of the dwelling by 7 K/day.

CONCLUSIONS

1) The fraction of rooms with an open window, n, is inversely proportional to the indoor- outdoor temperature difference, ΔT, with an average proportionality constant equal to 2.2 K , or $n*\Delta T=2.2$. This constant may vary with about 0.4 depending on country, exposure to wind, indoor temperature, moisture content of the air, heating system, etc. This result is based on observations of the frequency of airing performed in three Western European countries.

2) The resulting energy loss due to airing probably varies much more than the frequency of airing if a correction is made for the temperature differences, depending on physical properties of the buildings and the size of the opening when airing. For Sweden it is estimated that the resulting energy losses are about 0.8 kWh/day for a row-house and 0.5 kWh/day for a flat if the wind speed is assumed to be 4 m/s and the indoor-outdoor air teerature difference is assumed to be 20 K. The uncertainty of these results are mainly associated with insufficient information about the width of the openings.

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