# Implementing the Results of Ventilation Research
# 16th AIVC Conference, Palm Springs, USA
# 19-22 September, 1995

## Indoor Climate and User Interaction in Modern Swedish One-Family Houses - Results Using a Questionnaire

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## Synopsis

Disadvantages and advantages with different heating and ventilation systems in modern housing have been discussed during many years in Sweden. The discussion has intensified for modern low energy houses, where the use of forced air heating has increased during the last fifteen years, mostly in one-family houses. In many articles and the general debate diverging opinions have been presented concerning the thermal comfort, the air quality, the ventilation and the energy use in modern one-family houses with forced air heating. All modern Swedish one-family houses are very well insulated, fairly airtight and are equipped with mechanical ventilation.

The indoor climate (thermal comfort and ventilation), the energy use and the user interaction were examined using questionnaires in 236 houses built after 1988, 144 houses with exhaust fan ventilation and radiator heating and 92 houses with balanced ventilation and forced air heating. In 50 of the 236 houses measurements have been carried out, one-time tests of mechanical air flows, air tightness, status of heating system, indoor temperature, particles and long-term tests of outdoor air ventilation, humidity, carbon dioxide and indoor temperature during a winter month.

This report presents and discusses the quality of the indoor climate and the user interaction in modern Swedish one-family houses. Improvements to future houses are proposed e.g. reduce sound from the outside in "exhaust" houses, reduce draught from outdoor air vents in "exhaust" houses, reduce sound from the ventilation system in "balanced" houses, make more readable operating and maintenance instructions for the heating and ventilating systems, provide better air temperature control of individual rooms, reduce the ventilation rate?, supply all outdoor air to the bedrooms?

The investigated houses show appr. the same level of complaints concerning the indoor climate as in a study of the Swedish building stock i e there are no serious problems. There are some differences between houses with the two types of heating and ventilating systems.

## 1. INTRODUCTION

Disadvantages and advantages with different heating and ventilation systems in modern housing have been discussed during many years in Sweden. The discussion has intensified for modern low energy houses, where the use of forced air heating has increased during the eighties and nineties, mostly in one-family houses. In many articles and the general debate diverging opinions have been presented concerning the thermal comfort, the air quality, the ventilation and the energy use in modern one-family houses with forced air heating.

A nordic seminar concerning "Functional requirements on ventilation systems and their use for space heating and improvement in indoor air quality" took place in September 1992. The 35 participants agreed upon a number of disadvantages and advantages with forced air heating (Andersson 1993).

This project was initiated by the Swedish National Testing and Research Institute and was funded by the Swedish Council for Building Research, The Development Fund of the

Swedish Building Branch and Swedish National Board of Housing. During the project fruitful discussions took place with a reference group. The overall aim has been to evaluate modern housing and to evaluate disadvantages and advantages of forced air heating compared with radiator heating. This with respect to thermal comfort, ventilation, air quality and energy use (Blomsterberg 1995).

Indoor climate questionnaires were mailed during 1993 to 449 one-family houses built after 1988. Answers were received from 53 % of the houses. Of the houses 172 were equipped with forced air heating, 255 with exhaust ventilation and radiator heating, and 22 with exhaust-supply ventilation and radiator heating. Measurements of indoor climate were carried out as a case study during the winter of 1993-4 in 50 of the houses, where the occupants experienced problems with the indoor climate.

## 2. THE HOUSES TESTED

The houses which were examined in this project are representative of modern Swedish one-family houses. The houses with exhaust fan ventilation have exhaust air terminal devices in rooms such as bathrooms, kitchens and laundryrooms and outdoor air supply to the other rooms through outdoor air vents near windows. Space heating in most of the houses is provided for by radiators located below windows. More than 50 % of the houses have an exhaust air heat pump and thereby also a prefilter in the exhaust air duct.

All of the houses with forced air heating have exhaust and supply ventilation, and circulated air. Air is exhausted from rooms such as bathrooms, kitchens and laundryrooms and air is mainly blown into bedrooms and living-rooms. Most of the houses have a prefilter in the outdoor air and the circulated air ducts. There is usually no filters in the exhaust air duct. All of the houses are equipped with some kind of heat recovery.

The houses were chosen randomly. Important criteria were however; the houses should have been built after 1988, occupied for at least one year, located in the southern or middle part of Sweden, the number of houses with different brands of heating and ventilation systems should agree with their share of the market, different manufacturers of houses should be represented.

## 3. METHODS

### 3.1 Questionnaires

A survey of standardized questionnaires which are being used to investigate the perception of the indoor climate by the occupants, shows that there are mainly two more worked through questionnaires. One was developed by the hospital in Örebro. The Örebro-questionnaire deals mainly with the individual persons and their health. The other questionnaire has mainly been used to examine buildings which have had or are suspected to have problems with the indoor climate. In the ELIB-study the Örebro-questionnaire has been used in order to determine the indoor climate in the Swedish housing stock (Norlén 1993).

The second questionnaire "SABO" has been developed by the office of investigation and statistics in Stockholm. The questionnaire was recently used in a survey of the perceived indoor climate in the housing stock of Stockholm (Engvall 1992). The questionnaire uses as a starting point the dwelling, its use and indoor environment with regard to thermal comfort, air quality, sound and light level and the estimation by the occupants of problems. The questions concerning the indoor environment are supposed to be detailed enough and enough directed towards measures so that the answers can lead to measures.

As one purpose of this project was to be able to use the ELIB-study as a reference the Örebro-questionnaire was employed. As the purpose also was to be able to make a more detailed determination and thereby facilitate a comparison between air-heated houses and radiator-heated houses, with regard to thermal comfort, air quality, sound and light level and an estimation by the occupants of possible problems, the SABO-questionnaire was used.

### 3.2 Measurements

The measurements were started with an inspection and diagnostic testing of the 50 houses during the winter of 1994. The purpose was to document the status of the heating and ventilation system. If the performance deviated from the design values then the intention was to carry out an adjustment. An evaluation would otherwise not make sense. In reality it turned out that no system was in such a bad condition that an adjustment was really necessary.

The following inspections and diagnostic tests were performed:
- The total air flows, the air flows at the air terminal devices and the filters in the ventilation systems were measured.
- The insulation of the ductwork in the air-heated houses was inspected.
- The airtightness of the building envelope was measured and the main leakage paths were located.
- The fouling at the air terminal devices were inspected
- The function of the heating system was checked.
- The surface temperature of the floor and the indoor air temperature (absolute level and gradients) were measured in all rooms.
- The air velocity was measured in all rooms.
- The sound level was measured in all rooms.
- The number of particles outside, in one bedroom, in the supply air and in the circulated air were measured.

The following long-term measurements were carried out in the houses:
- The relative humidity was measured as monthly average in the middle of the house and in one bedroom. A diffusion tube with an absorption material was used.
- The indoor air temperature was measured as monthly average in the middle of the house and in one bedroom. The measurements were performed using electronic temperature meters, where the temperature is converted into pulses.
- The ventilation was measured as a monthly average in the whole house and in one bedroom. A passive tracer gas technique with two different tracer gases was employed.
- The carbondioxide concentration was measured during one night. A Drägertube was used.
The relative humidity, the indoor air temperature and the ventilation were measured using the same equipment as in the ELIB-study.

# 4. RESULTS

## 4.1 Indoor climate

The Örebro-questionnaire presents the perception of the indoor climate by the occupants as profiles of complaints and profiles of symptoms. The questionnaire has been used in order to be able to make a comparison with the Swedish one-family housing stock, as presented in the ELIB-study. A complaint or symptom must occur often to be regarded as a complaint or a symptom.

The frequencies of complaints in general are low for the examined one-family houses (see figure 1). The highest values were obtained for dry air and varying indoor temperature. Appr. 6 % regard the indoor temperature as often (every week) varying and appr 5 % that the air is often (every week) too dry. For two questions, draught and unpleasant smell, there is a statistically guarenteed difference between radiator-heated houses and air-heated houses and for both cases the complaints are higher for the radiator-heated houses. There is no statistically guarenteed difference between this study and the Swedish one-family housing stock, according to the ELIB-study (see figure 2).

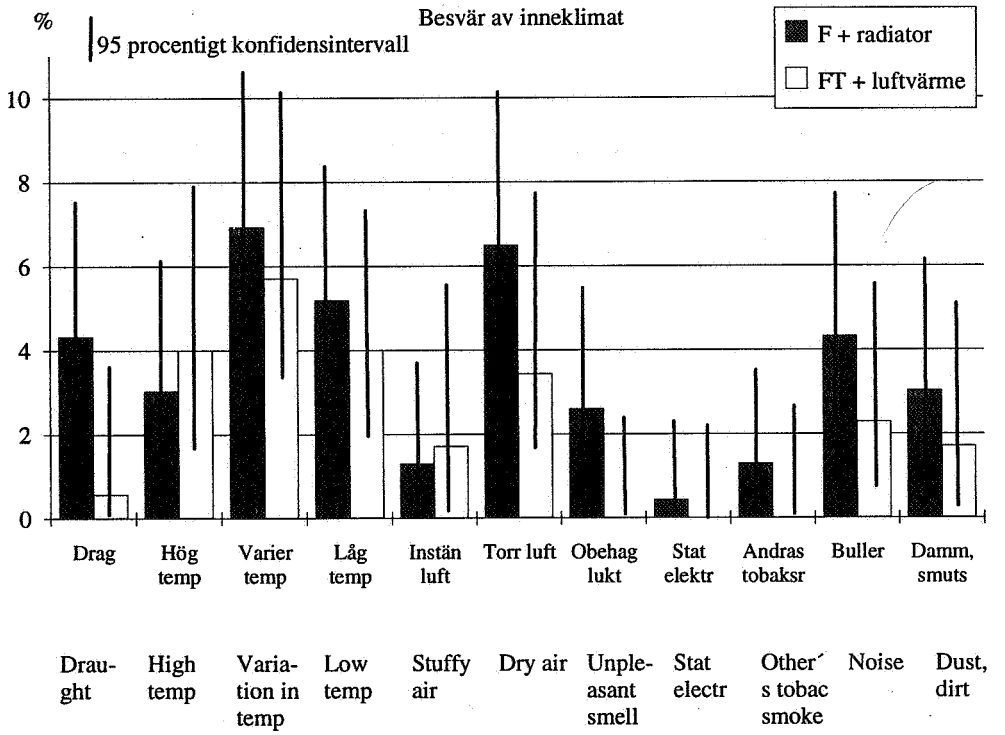


Figure 1. Frequencies of complaint ("often") in the examined houses. F + radiator = exhaust ventilation and radiator heating, FT + luftvärme = balanced ventilation and air heating.

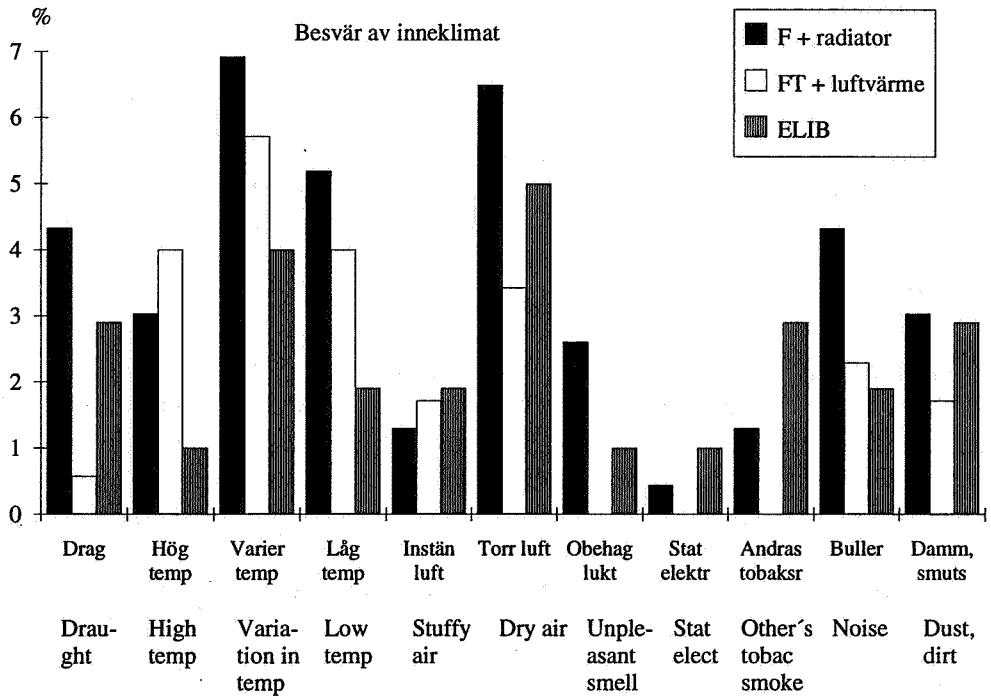


Figure 2. Frequencies of complaint ("often") in the examined houses. Comparison with the Swedish one-family housing stock according to the ELIB-study. F + radiator = exhaust ventilation and radiator heating, FT + luftvärme = balanced ventilation and air heating.

The frequencies of symptoms are generally low for the examined houses (see figure 3). The highest values are obtained for tiredness. Appr. 8 % feel tiredness often (every week). For peeling/itching in scalp/ears there is a statistically guarenteed higher frequency of symptoms for radiator-heated houses than for air-heated houses, the levels are however low. There is no statistically guarenteed difference between this study and the Swedish one-family housing stock, according to the ELIB-study (see figure 4).

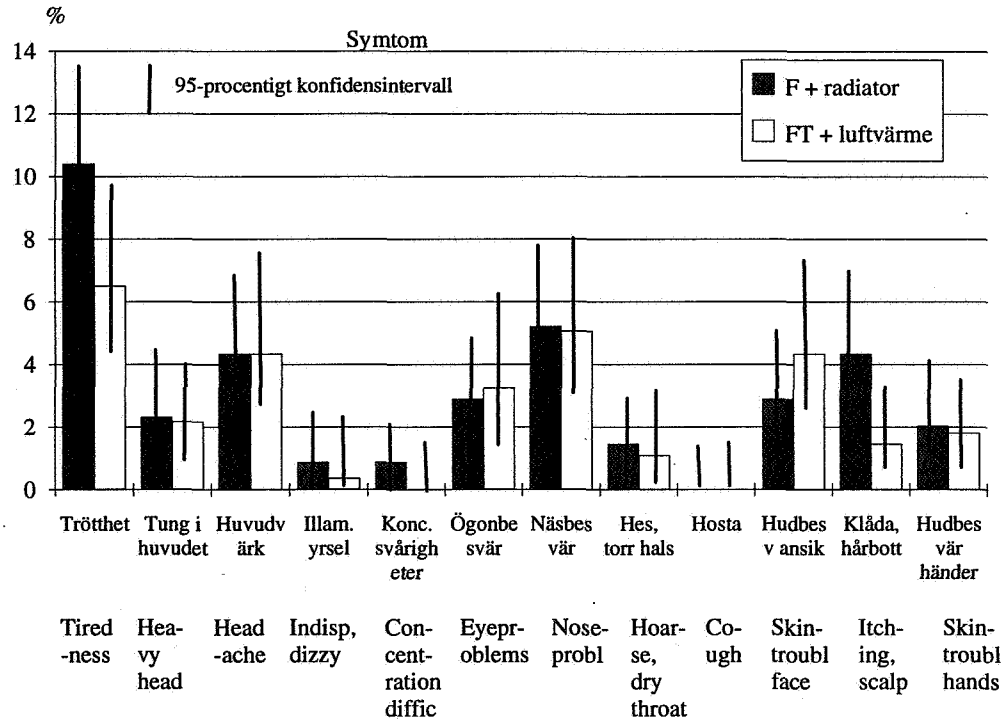


Figure 3. Frequencies of symptoms in the examined houses. F + radiator = exhaust ventilation and radiator heating, FT + luftvärme = balanced ventilation and air heating.

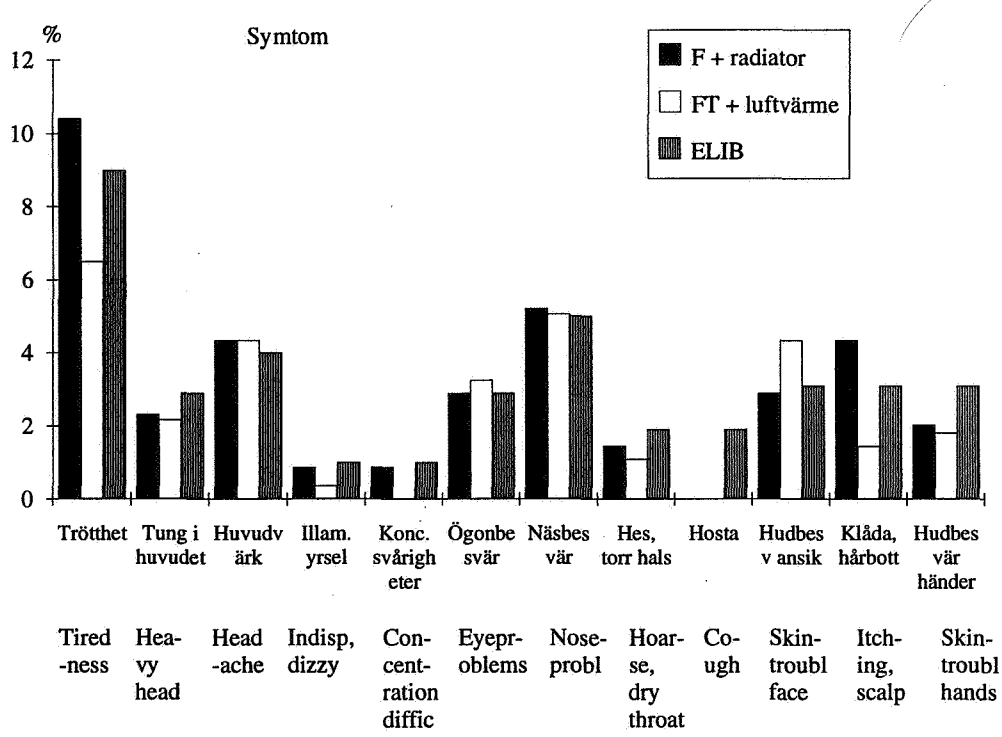


Figure 4. Frequencies of symptoms in the examined houses. Comparison with the Swedish one-family housing stock according to the ELIB-study. F + radiator = exhaust ventilation and radiator heating, FT + luftvärme = balanced ventilation and air heating..

The SABO-questionnaire has been used in order to be able to answer detailed questions and thereby also enable a comparison between radiator-heated houses and air-heated houses regarding the use and the indoor environment of the dwelling with respect to thermal comfort, air quality, sound and light level and an estimation of problems.

What concerns the field of heat appr 90 % of the occupants consider the thermal comfort during the winter season as good or acceptable (see figure 5). The occupants perceived most complaints concerning the indoor temperature during the winter season and cold floors. Appr 45 % claim that one or a couple of rooms are very cold or too cold. The frequency of complaints for cold floors is 50 %. A statistically guarenteed difference between radiator-heated houses (14 %) and air-heated houses (4 %) exist only for often varying indoor temperature due to changes in outdoor temperature.

What concerns the field of ventilation 99 % of the occupants answer that the indoor air quality is good or acceptable. The highest frequency of complaint concerns draught, appr 30 % are troubled by draught somewhere in their house. A significant difference exists between radiator-heated houses (42 %) and air-heated houses (23 %).

As to sound 25 % of the occupants in both types of houses consider the sound from the ventilation system as sometimes or often disturbing, a few more in air-heated houses than in radiator-heated houses. In radiator-heated houses however sound from the outside is perceived by more occupants as often or sometimes disturbing than in air-heated houses, 24 % resp. 6 %.

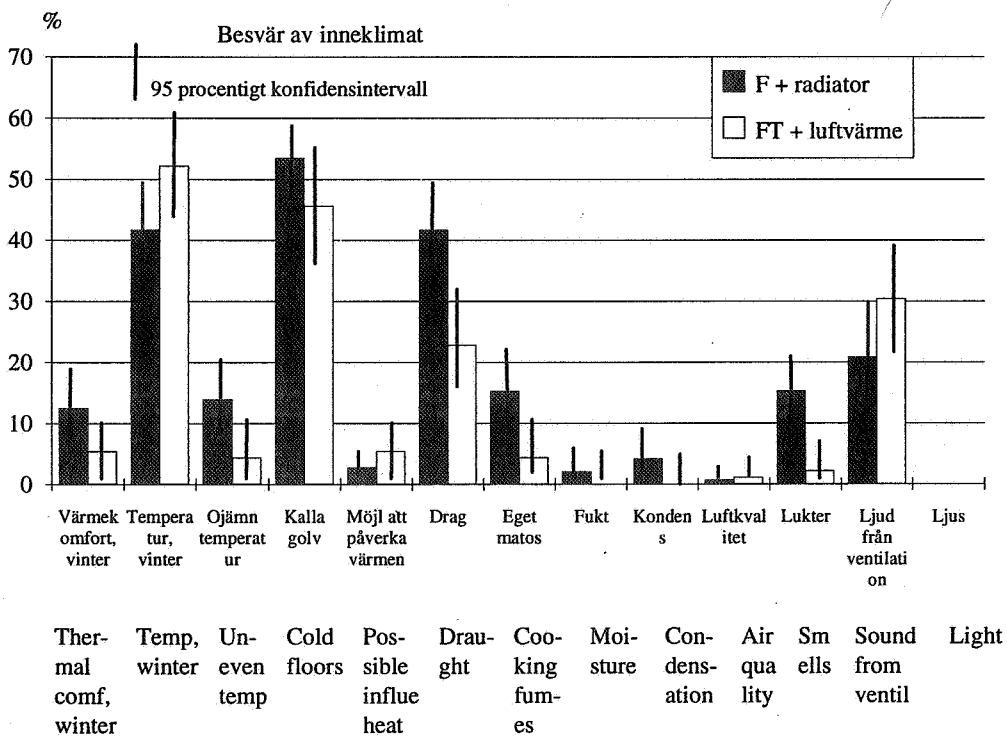


Figure 5. Frequencies of complaint (many alternatives include "sometimes" and "often") in the examined houses. F + radiator = exhaust ventilation and radiator heating, FT + luftvärme = balanced ventilation and air heating.

A comparison with the one-family housing stock in Stockholm (Engvall 1992) show a couple of higher frequencies of complaints than for modern one-family houses (see figure 6). The Stockholm one- family housing stock consists of houses of different years of construction, 3/4 of them have passive stack ventilation. The frequencies are higher for temperature during the winter season (one or a couple of rooms are very cold or too cold), cold floors and draught.

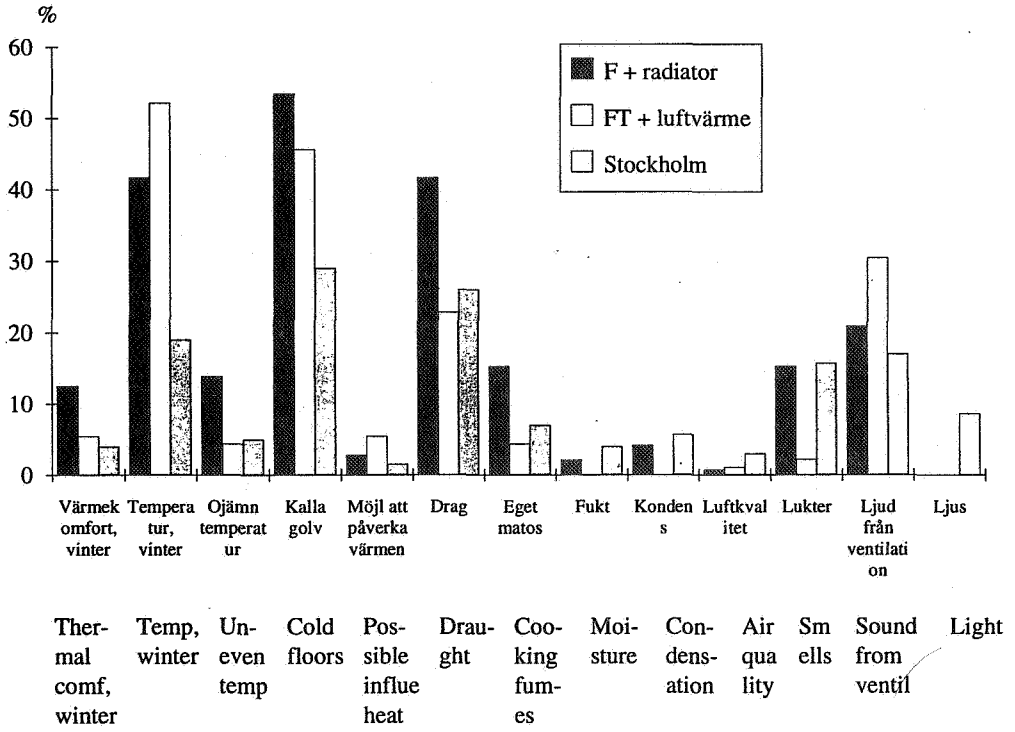


Figure 6. Frequencies of complaint (many alternatives include "sometimes" and "often") in the examined houses. Comparison with the one-family housing stock in Stockholm. F + radiator = exhaust ventilation and radiator heating, FT + luftvärme = balanced ventilation and air heating.

If thermal comfort, temperature, sound from ventilation, dry air and sound from the outside only include "often answers" then the frequencies of complaints are reduced by at least 2/3.

## 4.2 User interaction

An interesting question for modern houses is whether the occupants think that the heating and ventilation system gives any possibility to influence the indoor climate. Only 5 % of the households answer that there is no possibility to influence the heating of their dwelling i e the heating system gives according to the occupant of 5 % of the houses no means of influencing the indoor air temperature. The same percentage applies to the answer that there is no possibility to influence the ventilation of the dwelling i e the ventilation system gives according to the occupant of 5 % of the houses no means of influencing the air quality.

In every second to every fifth one-family house the operating and maintenance instructions for the heating and ventilaiton system are considered to be "not so easy to understand". The problem is more common in radiator-heated houses than in air-heated houses. 2/3 of the

radiator-heated houses have an exhaust air heat pump. In every tenth house the occupants do not know whom to contact if problems occur with the heating and ventilation system. In appr 90 % of the houses the occupants claim that they vacuum clean their house at least once a week. In 60 % of the air-heated houses and 10 % of the radiator-heated houses this is done using a central vacuum cleaner.

The filters are cleaned more often in air-heated houses than in exhaust-ventilated houses. In 85 % of the air-heated houses they are cleaned every month and in 35 % of the exhaust-ventilated houses according to the occupants. Most of the houses have a range hood with a grease filter. This filter is cleaned in almost 50 % of the houses every month. In a couple of % the houses it is done very seldom or never. Most of the houses are equiped with an air-to-air heat exhanger or an exhaust air heat pump. In 1/3 of the houses this component is cleaned every month. In 15 % of the exhaust-ventilated houses the exhaust air heat pump is cleaned very seldom or never.

Airing is more frequent in exhaust-ventilated houses than in air-heated houses during the heating season (September - April) (see figure 7). In exhaust-ventilated houses 60 % the occupants claim that they air daily or almost every day compared with 25 % in air-heated houses. It is quite common in air-heated houses that no airing takes place, 40 % of the houses. In exhaust-ventilated houses the number is 10 %. When airing the most common technique is to cross ventilate for a couple of minutes. This is in done in 50 % in both types of houses. Some 10 % of the houses air continuously for a day or a night using windows or airing panels.

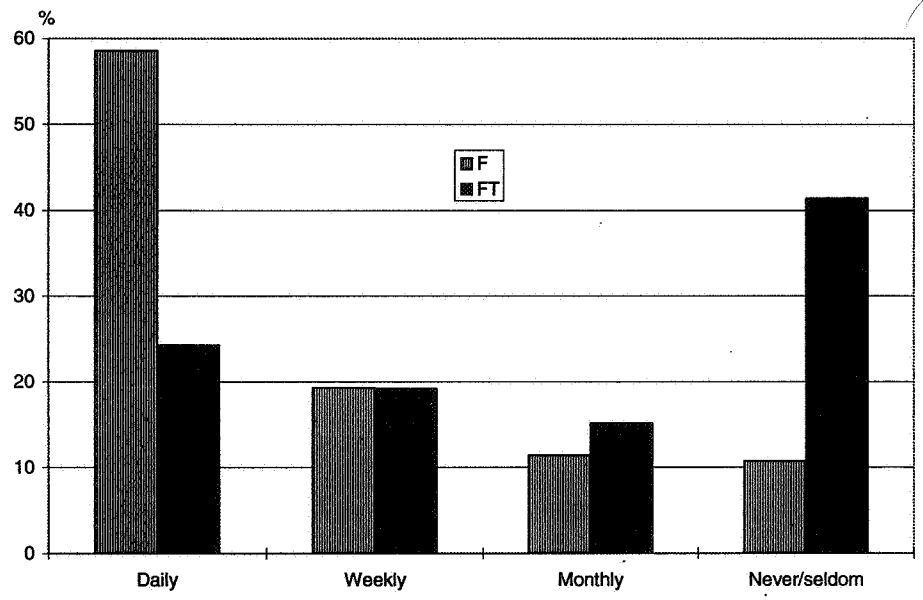


Figure 7. Airing habits in the examined houses. F = exhaust ventilation and radiator heating, FT = balanced ventilation and air heating.

## 4.3 Measurements

The inspection and diagnostic testing of 50 houses show that

- the air flows in the ventilation systems fullfill the requirement of an overall ventilation of 0.5 ach of outdoor air (Nybyggnadsregler 1989) apart from the exhaust-ventilated houses, where 50 % had a ventilation rate which was somewhat too low
- the sound from the ventilation system is considerably lower in the exhaust-ventilated houses than the houses with balanced ventilation, which in some cases do not fullfill the requirements of the Swedish building code of 1988 (Nybyggnadsregler 1989)
- the measured temperature difference between the warmest and coldest room is appr the same in all houses, appr 1 °C, during an ordinary Swedish winter day
- the requirement of a maximum vertical temperature gradient (between 0.1 and 1.1 m) of 3 °C is not fullfilled in ¼ of the houses, when the outdoor temperature is - 10 °C
- for several of the houses the requirement of a lowest surface temperature on the floor of 19 °C is not fullfilled during an ordinary Swedish winter day
- the air velocity does not exceed 0,15 m/s during an ordinary Swedish winter day
- most of the houses fullfill the requirement on airtightness of the Swedish building code
- it is not possible to see any difference in the content of particles in the air of exhaust-ventilated houses and air-heated houses.

The long-term measurements of 50 houses show that
- the outdoor air flow to the rooms upstairs is lower in air-heated houses than in houses with balanced ventilation
- the outdoor air flow to bedrooms upstairs is often too low in exhaust-ventilated houses (Blomsterberg 1991)
- the purging air flow (Merkell 1993) to bedrooms is larger than the design outdoor air flow in all houses, which means that if the air quality of the transferred air is acceptable then the ventilation requirements (4 l/(s and bed)) of the Swedish building code is fullfilled
- the purging air flow to bedrooms is smaller in exhaust-ventilated houses than the other houses, which indicates that the ventilating air is being used more efficiently in the other houses as all houses have basically the same overall air change rate of outdoor air
- the exhaust-ventilated houses exceed 1000 ppm carbondioxid and have higher levels than the air-heated houses, which can be explained by the difference in the purging air flow
- the relative humidity indoors is somewhat lower than it should be during the winter season and there is no difference between the ventilation systems
- the indoor air temperature is 22 °C and no difference between the ventilation systems.

In the questionnaire the occupants were asked to write down their use of energy during 1992. Most of the houses seem to have a low and reasonable level of energy use.

## 5. CONCLUSIONS

According to the questionnaire survey there is no difference compared with the Swedish housing stock as to frequencies of complaints and symptoms concerning the indoor climate. The Swedish housing stock was examined in the ELIB-study and the conclusion from that study is that between 7 % and 11 % of the Swedish population is subject to an indoor climate in their homes which can influence the health and the comfort. The questionnaire survey and measurements in this project does not show any serious differences between houses with radiator and air heating as to indoor climate.

This project and a previous project (Johansson 1993) have shown that air heating and radiator heating can result in a thermal comfort of equal quality. In the previous project it was shown that both systems meet criteria for thermal comfort even at low outdoor temperatures.

This project has on a few points confirmed and other points not confirmed the disadvantages and advantages with air heating, which were presented at a nordic seminar.

| **Nordic seminar on warm air heating** | **According to SABO-questionnaire** | **According to diagnostic tests/long-term measurements** |
|---|---|---|
| **Advantages with warm air heating:** | | |
| - Possibilities of limiting noise from outside. | Confirmed i. e. in air-heated houses fewer occupants are disturbed by noise from the outside than in exhaust-ventilated houses. | No conclusions possible. |
| - Less risk of draught (compared with exhaust and naturally ventilated houses) | Confirmed for exhaust-ventilated houses: In air-heated houses fewer occupants are disturbed by draught in one or some rooms than in exhaust houses. | Not confirmed. |
| - Fast control of temperature in the whole house-/zone (compared with hydronic heating i e naturally, exhaust or balanced ventilated houses) | Partly confirmed: Fewer occupants of air-heated houses are often disturbed by varying temperatures due to changes in outdoor climate, than in radiator-heated houses. | Not tested. |
| - Guaranteed air flow to each room (compared with exhaust and naturally ventilated houses). | No conclusions possible. | Confirmed in the bedrooms: The purging and the outdoor air flow were lowest in the exhaust-ventilated houses. |
| **Disadvantages with warm air heating:** | | |
| - Less possibility of control of temperature of indivdual rooms (compared with exhaust and naturally ventilated radiator-heated houses) | Not confirmed: No difference between air and radiator-heated houses as to the perception of one or some rooms being too cold. | Not confirmed. |
| - Risk of annoying noise from ventilation system. | Confirmed: According to 30 % of the occupants in air-heated houses sound from the ventilation system is sometimes or often disturbing. The corresponding value for exhaust-ventilated houses is 23 %. | Confirmed: The highest sound level from ventilation was measured in balanced-ventilated houses, some were above the code requirement. |

According to the questionnaire the occupants air more in exhaust-ventilated houses than in balanced-ventilated houses. The reason could be that according to the measurements the ventilation rates, in particular in bedrooms, are lower and the carbondioxide concentration higher in bedrooms of exhaust-ventilated houses.

The following improvements should be made in the one-family houses of the future:
- improve upon the abatement of sound from the outside in exhaust houses
- reduce the draught from outdoor air vents
- improve upon the control of the indoor temperature i e the coupling to the outdoor climate
- develop quieter ventilation systems for air-heated and balanced-ventilated houses
- make the operating and maintenance instructions easier to understand for the occupants
- reduce the spread of cooking fumes within the dwelling
- investigate the possibility of reducing the outdoor air flow below 0,5 ach
- investigate the possibility of supplying all outdoor through the bedrooms

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