ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING ACCEPTABLE INDOOR AIR QUALITY

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PAPER C

VENTILATION HEAT LOSS IN A DETACHED ONE FAMILY HOUSE

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SUMMARY

For optimum building design it is of importance to investigate the comfort and the energy conservation obtained with different types of ventilation systems and levels of airtightness of buildings. This could be achieved by aid of computer models based on full-scale and model measurements.

In order to obtain experimental data as input data to such a computer model, an experimental, detached one-family house has been built near to Gothenburg on the Swedish west coast. The house is inhabited and has built-in facilities to change the air tightness level and distribution by specially designed leaking panels. It is also possible to alter the flow rates, using one of three possibilities regarding ventilation; natural ventilation, mechanical exhaust ventilation and mechanical supply and exhaust ventilation with heat recovery.

The house, moreover, is equipped with a pressure scanner and plastic tubes connected to some 250 pressure taps, distributed around the perimeter and in wall and roof cavities. Data from the pressure scanner are fed into a computer system together with continuous data concerning wind speed, wind direction, temperature and tracer gas concentration.

This paper outlines the research program and describes the instrumentation and some features of the house.

1. INTRODUCTION

In order to minimize the ventilation heat loss but retain an acceptable indoor air quality, the Swedish Building Code of 1975 contains strict rules governing the various kinds of ventilation systems and the levels of air-tightness of buildings. There exists, however, very little basic data to justify the rules about air-tightness and the levels are not related to the types of ventilation systems chosen.

The code has had a very rapid impact on building practice. Clearly a future revision of the code as regards ventilation and air-tightness should be based on a careful study of cost effectiveness, durability and the inhabitants' comfort and health. Such a study could be based on computer models of infiltration, verified by model and full-scale measurements.

The interaction between the climate, the building and its services and the occupants is very complex. In full-scale measurements the number of parameters is large, some are difficult and expensive to monitor and many are difficult to control.

It was judged to be most expedient to divide our work on air infiltration into two different projects as follows.

1) Investigations of a few,recently built, detached, one-family houses. Measurements of climate parameters, wind pressures, ventilation and air infiltration with a limited number (≈100) of removable sensors and over a limited time (1 - 3 months).
2) Investigation of a single experimental house with built-in facilities for changing the air-tightness level, leakage distribution, type of ventilation system and flow rates. Measurements as in 1) but with a greater number (≈300) of built-in sensors and over a longer time (≈1 year).

Here we shall discuss the second project. As no measurement data are yet available, the paper will be restricted to a discussion about the purpose and planning of the project and a brief description of the experimental house and its instrumentation.

2. THE PURPOSE AND PLANNING OF THE PROJECT

The main purpose of the project is to investigate how the total ventilation rate and the ventilation heat loss in one-family houses depend on certain important parameters. The investigation is restricted to one experimental house, in which some house parameters can be altered. These include :

- type of ventilation system, i.e. natural ventilation, mechanical ventilation, or mechanical exhaust and supply ventilation with heat recovery,
- mechanical ventilation flows,
- air-tightness and leakage distribution.

Local climatic data for one year will form the basis of the investigation. By means of a computerized data aquisition system, hourly values of wind speed, wind direction and temperature will be collected. A change in the house parameters is equivalent to the creation of a different house set-up. Spread over the year, under different weather conditions, a certain house set-up will be measured intensively during periods of a couple of hours. These measurements will include measurements of wind pressure around the house perimeter and in wall and roof cavities, thermal stack effect, ventilation duct flow and total infiltration rate.

The corresponding ventilation heat loss will be computed for each measuring period as a function of the house set-up and the weather conditions. For each house set-up the total ventilation heat loss during one year is estimated by taking the individual heat loss values and weighting them by a time coefficient, corresponding to the total yearly duration of the pertinent weather conditions. In addition to average values of heat loss, variance of the ventilation rate will also be calculated. These values will be able to be compared and conclusions drawn concerning the merits of different house set-ups with respect to energy conservation, economy, and comfort.

Each measuring period will provide several thousand primary values. A large number of such measuring periods will be needed in order to accomplish the previously described analysis. A very large amount of data will thus become available for testing mathematical models of air infiltration.

3. THE EXPERIMENTAL HOUSE

3.1 The Topography

The house is built on the Swedish west coast, 17 km south of Gothenburg centre and 3½ km from the coast. Except for vegetation the area is rather exposed, the prevalent wind direction being south-west. It is situated on a high plateau, 80 m above sea-level, figure 1. The vegetation is not cultivated and consists of a mixture of deciduous (mostly birches) and non-deciduous trees. The house stands isolated in a clearing and is several hundred meters from the nearest neighbour.

3.2 A general description of the house

The house is a 1½ storey timber framed house, erected above a concrete structural floor. This is a very usual and economical house type in Sweden. The house also has two common features, namely a dormer window and a gable balcony. The balcony is visible in figure 2. The walls are cladded with cover boardings and the roof with concrete tiles. A cellar and an adjoining garage are built into the ground, with a low slope towards the south. The cellar will be sealed from the house during the experiments.

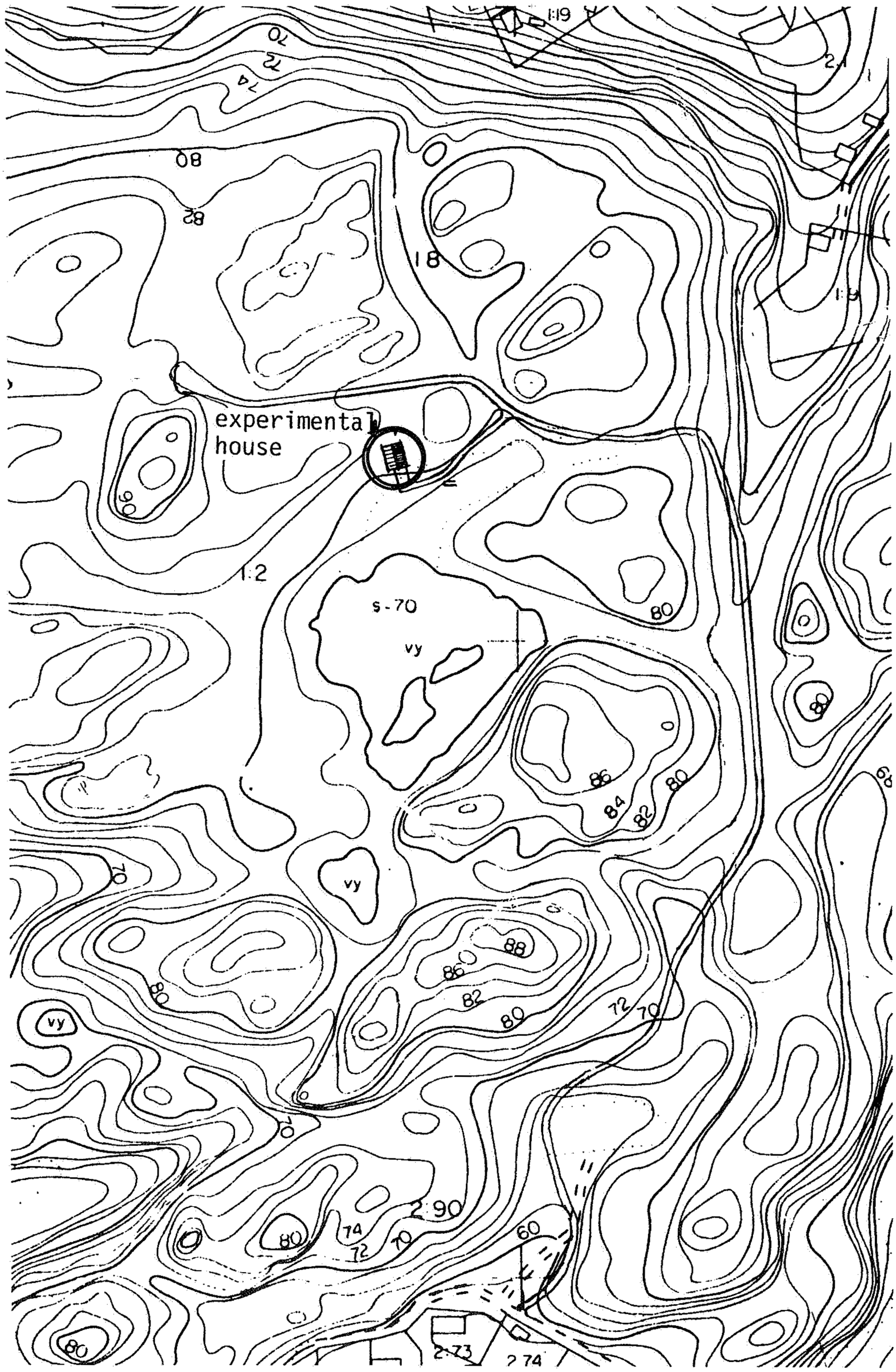


Figure 1. Topography. Map scale 1:4000 with 2 m contours.

Figure 2. The experimental house as seen from WSW.

The house has a high thermal insulation standard due to triple glazing and 265 mm of Rockwool in the walls and roof, cf. the cross-section in figure 3. The heating system consists of a heat pump with brine pipes in a small nearby lake. The heat pump provides all the domestic hot water and the space heating, the latter consisting of plastic pipes in the concrete cellar floor and in the false ceilings in the ground and upper storeys. The performance of the heating system is monitored as part of a separate project, which does share the data aquisition system and adds a further 100 sensors to it.

The house is privately owned and inhabited by the author and his family. Normal building costs are being met in the usual way through a bank and a building society. The additional costs for the experimental parts of the building are covered by a scheme administered by the National Swedish Council for Building Research. Under this Energy Experimental House Scheme, interest and repayment free loans are provided during the time the experiments are made. Thereafter part of the loan must be paid back by the house owner, in accordance with the true benefits gained from the investment made in experimental energy-saving equipment.

3.3 Air-tightness

Much effort has been made to make the house as air-tight as possible. The air-tightness is mainly ensured by a special long-life 0.2 mm thick plastic sheeting. It has been placed about 6 cm into the wall and roof, as seen in figure 3, thus leaving space for electrical wiring etc. The sheets are joined together with plastic tape. This was shown to be a mistake. We found no tape that could

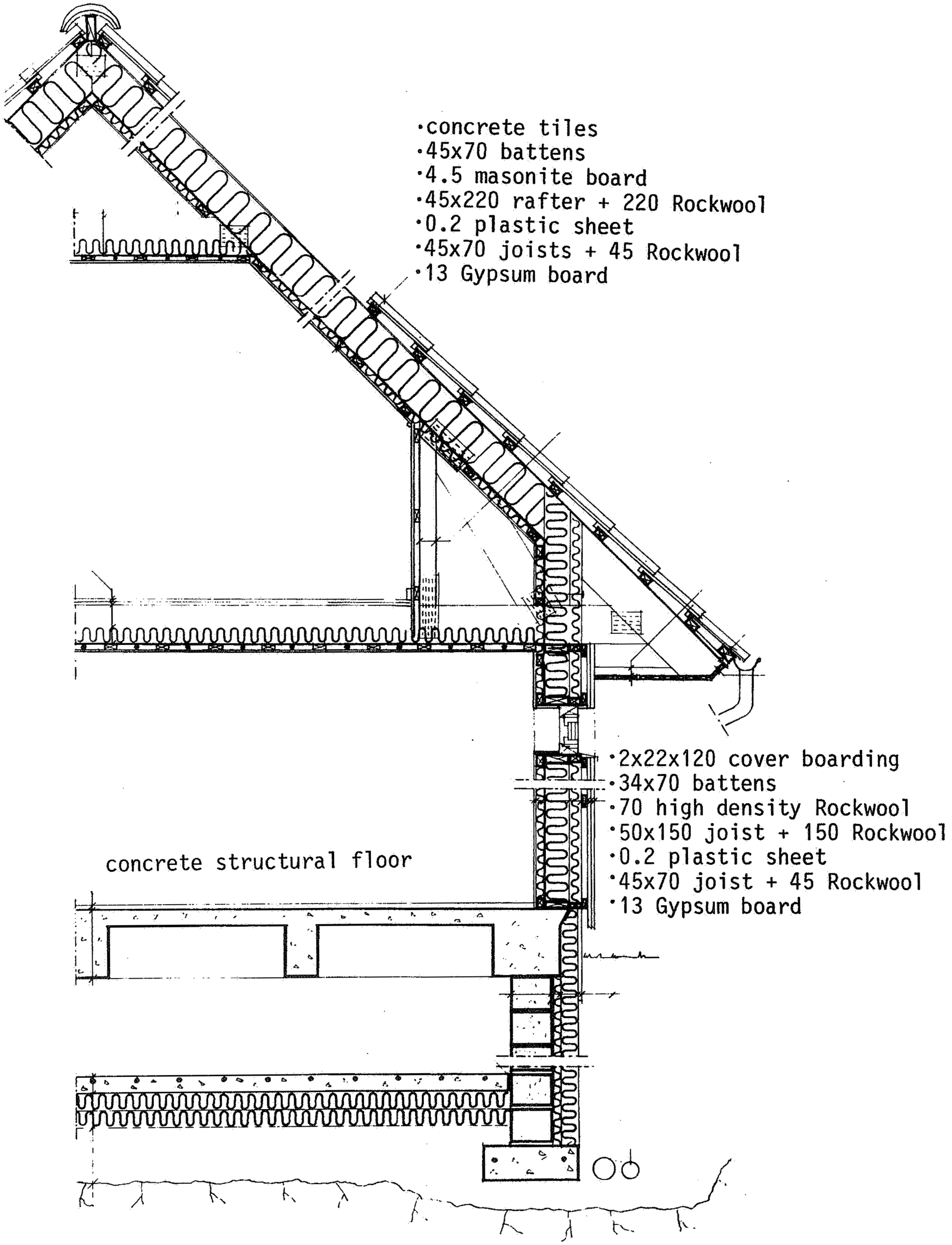


Figure 3. Cross section.

give satisfactory service when used by ordinary workmen. As the plastic sheets were left exposed for rather a long time during construction work, the tape could be seen to loosen, a process which seemed to be caused by stress introduced during mounting. Only by extreme care in avoiding this stress, could the tape be made to stay in position. A much more satisfactory performance was obtained by tape on a paper base, coated by melting glue. It was put in place between plastic sheets and protruding joists and timber frame in window openings, by means of an ordinary hot iron.

All doors,windows and airing panels are of good quality and were air-tightness tested in our laboratory prior to mounting. They all fulfilled the requirementsin the building code with an air-leakage well below 1.7 $m^3/h.m^2$ at 50 Pa. The space between these elements and the timber frame were foamed using I-component polyurethane foam.

The air-tightness level of the house and leakage distribution can be altered by means of the nine airing panels, which are situated on all sides of the building. Their normal, air-tight doors can easily be replaced by special leakage panels.

3.4 Ventilation systems

The mechanical ventilation is provided by an ordinary supply and exhaust ventilation system with heat recovery. The heat exchanger is of the regenerative type, working with alternating (1 minute) air flow directions in two duct elements filled with corrugated aluminium sheets. This system was chosen as it is claimed to give high thermal efficiency and no extra heat is needed for de-icing in winter time. The working principle makes the measurements more complicated, however. Duct flows can be altered by restrictions in the ventilation ducts and by regulating the fan speeds by means of variable transformers. By sealing the supply air duct, the system is changed to an ordinary mechanical exhaust air system.

The natural ventilation system consists of ducts separated from the mechanical ventilation system. It conforms to the regulations in the Swedish Building Code, with the exception that all ducts are brought together into one in the attic, where the flow rate is measured.

4. INSTRUMENTATION

4.1 Data aquisistion system

The data aquisition system is placed in a special room in the cellar and consists of the following main units :
·desk computer, Hewlett Packard 9835A with 49 kbytes memory,
·digital voltmeter, Solatron 7055,
·analogue scanner, Solatron, 200 channels

- pulse counter, Meteb, 100 channels
- solenoid valve scanner , purpose built, 276 channels, with Setra differential pressure transducer, ± 100 Pa range
- printer, Anadex.

The computer and the instruments communicate via the HP-IB bus. For ease of operation the system needs to be expanded to include extra computer memory and a disk drive. A plotter would provide means for real time analysis and checking.

4.2 Weather monitoring mast

A weather monitoring mast is placed on a low rock, 25m from the house, see figure 4. The mast consists of a 16m high steel flagpole. The following units are are mounted on the flagpole, with heights measured from the foot of the pole :

- cup anemometers, Vaisala , at heights of 3.5m (at the same height as the ridge of the house), 10m and 16m,
- wind vane, Thiess, height 16.5m,
- shielded temperature sensors, Pt100 + thermocouples, heights 2m and 15m,
- static pressure probe, double disk type, height 15.5m.

Thermocouples are placed along the plastic tube from the static probe to the valve scanner in order to provide information for stack effect compensation.

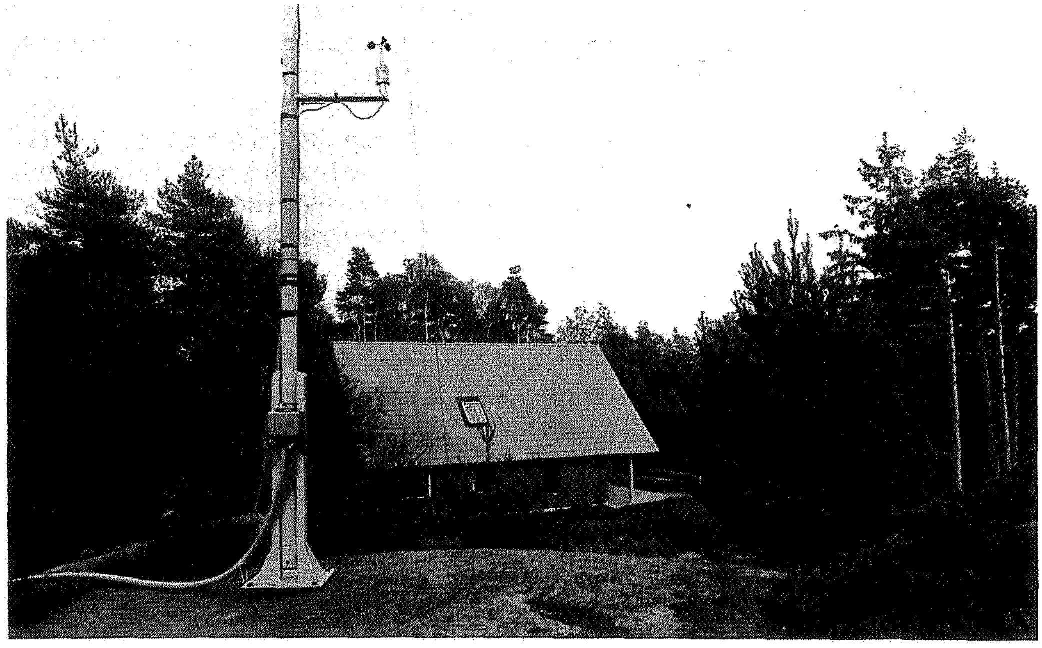


Figure 4. Weather mast and house as seen from WNW. The cup anemometer seen is at the same height as the house ridge.

4.3 Wind pressure distribution monitoring

Pressure taps are distributed around the house perimeter in such a way as to provide useful information about wind pressure distribution.There are also pressure taps in the wall and roof cavities, see figure 5. The cavities will moderate the wind pressures as a driving force for air infiltration. The investigation of this moderating effect is seen as a major feature of the project.

There is a total of more than 250 pressure taps connected to a solenoid valve scanner via plastic tubes with 5 mm inner diameter. All plastic tubes are 25 meters long (altogether ≈ 7000m !) and are hidden in the wall and roof cavities.

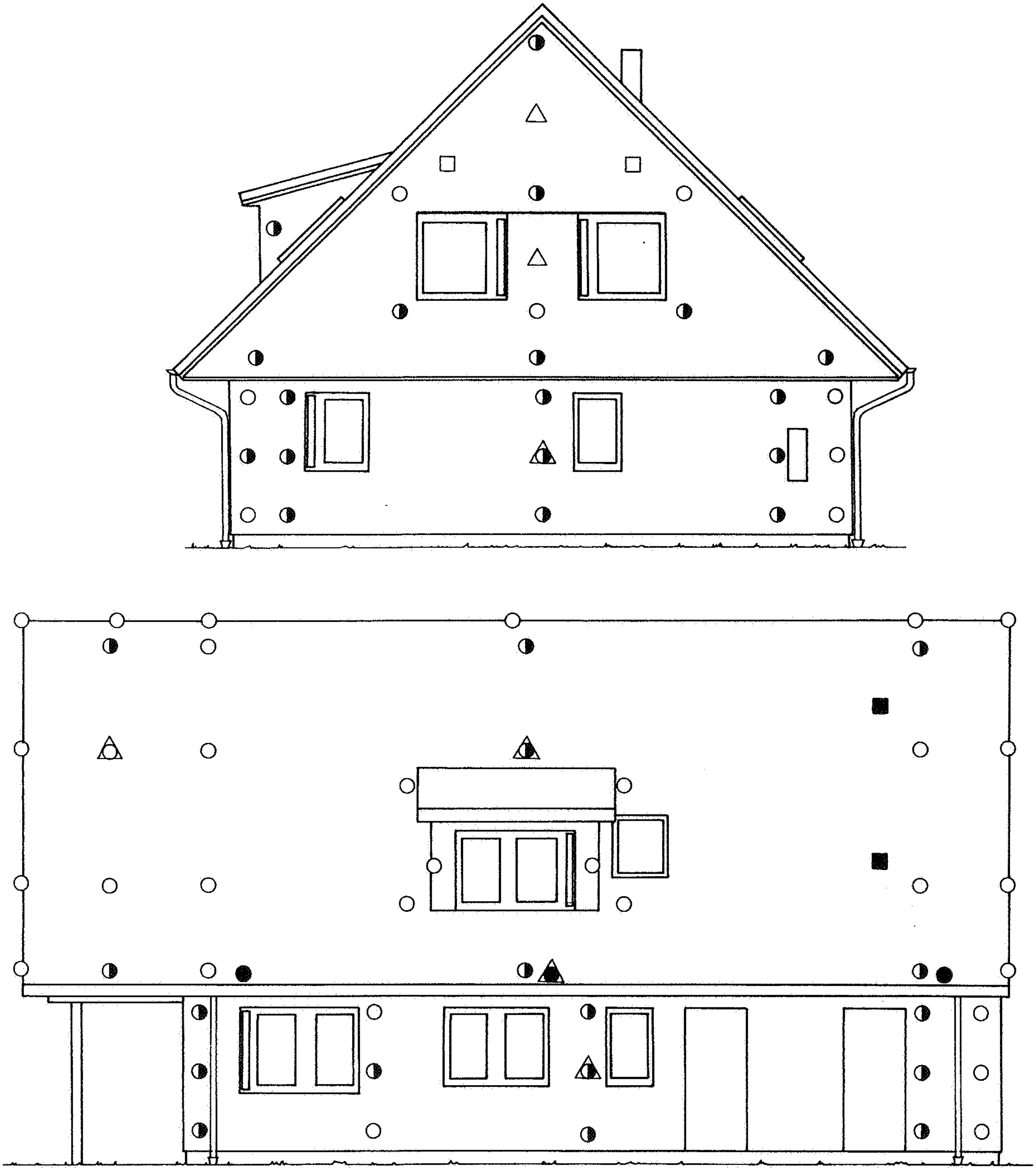
It is important to estimate the stack effect in all the tubes, since serious errors would otherwise occur due to the warming up of cavities by solar radiation on surfaces. The temperatures in the cavities, see figure 5, are measured by thermocouples placed in plastic tubes, both for protection and to get the same thermal inertia as in the pressure monitoring plastic tubes.

The solenoid valve scanner is interfaced to the computer via the analogue scanner and a special relay interface. The valve scanner connects the plastic tubes one at a time to a common, fast, differential manometer shown in figure 6. The reference pressure is that taken at the hall staircase. The time constant to get a 98% reading of the true value is ≈ 250 ms, which gives a useful sampling rate of 2 - 3 readings /s.

The large number of pressure taps means that the only economically possible alternative to a scanner would be a multitube, liquid manometer. The advantages of that instrument are its relatively low cost and that pressure readings from pictures taken can be correlated. The disadvantages are that it is difficult to interface to a real time computer system, it has low resolution and is generaly messy. For this project the disadvantages of the multitube, liquid manometer out-weighed its advantages.

4.4 Flows in ventilation systems

In the mechanical ventilation systems, duct flows are measured by orifice plates (Svenska Fläkt, EHBA). Flow measurements are much more complicated in natural ventilation systems. The flow is often highly irregular and an orificeplate would give low resolution and alter the properties of the system to an unacceptable extent. In this project we shall try to use pulsed ultrasonic transducers, a system which has been developed in collaboration with the School of Electrical Engineering as an M.Sc. project.



○ pressure tap on perimeter
● pressure tap in wall or roof cavity
◑ pressure taps on perimeter + in cavity
■ pressure tap in Rockwool insulation
△ temperature sensor in wall or roof cavity

Figure 5. Pressure taps and temperature measuring sensors on north gable wall and east wall and roof.

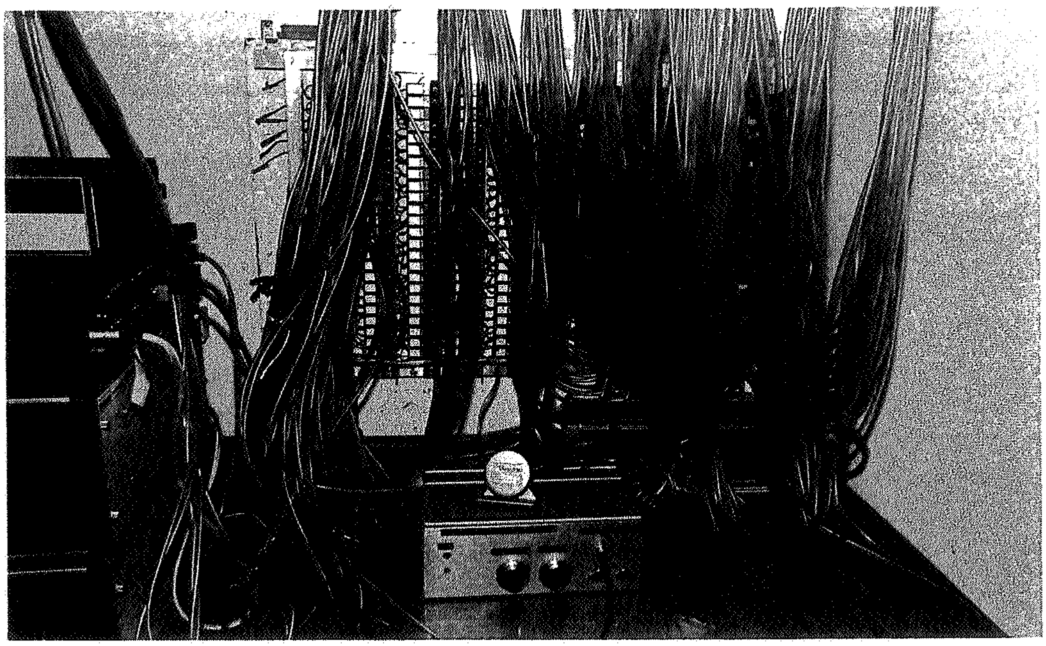


Figure 6. Solenoid valve scanner and Setra differential pressure transducer, with plastic tubes beeing connected.

4.5 Tracer gas measurements

Primarily the decay method has been adopted. The tracer gas analyser is a Miran 101, working with N_2O in the 100 ppm range. Mixing is accomplished by 3-speed table fans, with a free blowing capacity of 60 m^3/minute. The house has already been provided with piping for a constant concentration measuring system. If funds are available, such a system will be adopted giving better accuracy and speed and making it possible to use multi-cell analysis.

5. ACKNOWLEDGEMENTS

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