EKONO

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THE EKONO BUILDING
COST EFFECTIVE ENERGY DESIGN

J. Gabrielsson
H. Mäki
J. Sulku
L. Kuusela

EKONO Consulting Engineers, Helsinki, Finland

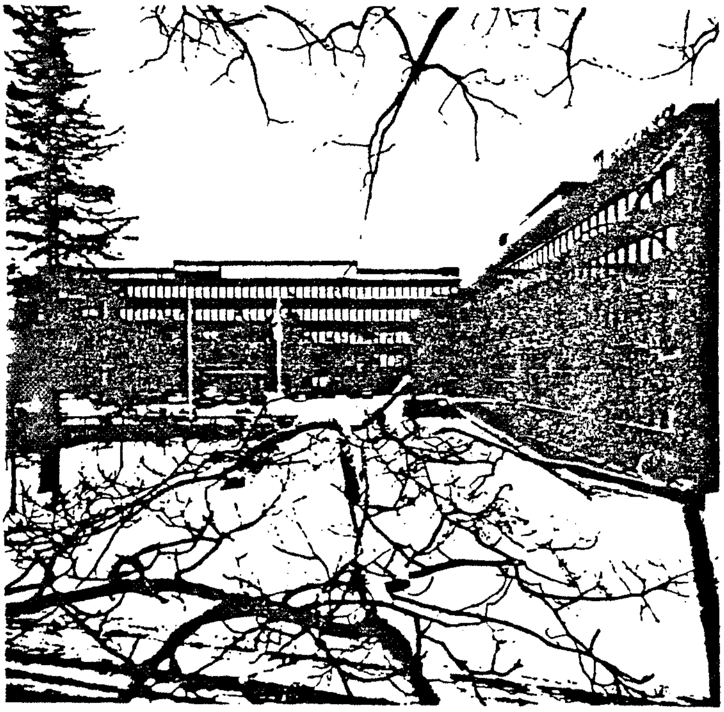


Fig. 1. The headquarters of EKONO Consulting Engineers.

INTRODUCTION

This paper concerns energy savings measures in the EKONO-building's second phase. The headquarters of EKONO Consulting Engineers is located 9 km west from Helsinki, the capital of Finland. (Weather data in Appendix 1.)

The EKONO office complex at Otaniemi was built in two phases. The first phase was completed in 1973, while the second was occupied at the end of 1979. Though the first phase was realized before the energy crisis, a major design consideration was energy efficiency of construction and operation. The measured energy consumption of the first phase for heating is 124 kWh/m^2·a and the annual electrical consumption is 70 kWh/m^2.

The operation of the first phase, including the performance of the Extract Air Window System, was monitored during the first two years. About 600 000 measurements were registered each year. This performance data was used as a basis for the design of the second phase building.

Because of the energy saving measures implemented the calculated heat consumption of the second phase building is 70 W/m^2·a, which is 30 % of the average energy consumption of office buildings in Finland for heating.

The total volume of the EKONO-building is 45 000 m^3 (phase one 30 000 m^3, phase two 15 000 m^3) and the floor area is 12 800 m^2 (phase one 8100 m^2 and phase two 4700 m^2) 4700 m^2).

ENERGY CONSERVATION MEASURES

Hollow slabs as intermediate floors

The goal of the design of phase two was to achieve the most effective use of space as possible without sacrificing human comfort. On this basis it was concluded to use hollow slabs in the construction of the intermediate floors.

By using the holes of the slabs as air ducts and routing for electric cables, no suspended ceilings were needed. So it was possible to realize a room height of 2,7 m even though the total floor to floor height is only 3,0 m. This reduces the area of the building envelope for a given total floor area, which will reduce the conductive heat losses and initial building costs.

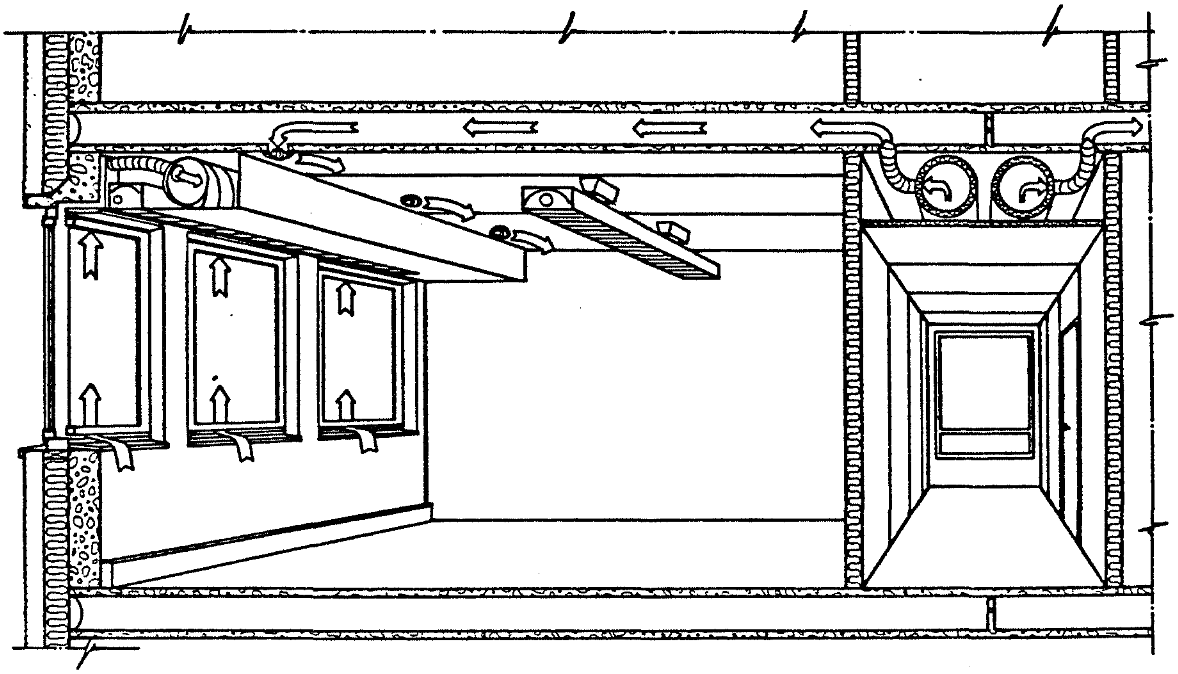


Fig. 2. Cross-section of a typical room. Using holes in the hollow slabs as air ducts, the room height was maintained though the floor to floor height is small.

The supporting structures of the building are the exterior walls and elevator and stair shafts, which are collected to the middle of the building as a stiffening core. Due to this solution it is possible to change the intermediate walls arbitrarily. The width of the building, 11.6 m, was chosen on the basis of the longest available hollow slab.

Tight structures; good insulation

When the conductive heat losses decrease, the relative amount of air leakage increases. Therefore special attention was paid to the tightness of the structure and to the quality of the thermal insulation.

The weakest point is often the gap between the window frame and the wall. This gap was observed thoroughly in the testing of several methods of window construction and the tightest selected for use.

High heat capacity of structures

In the construction of the phase two building the massive concrete is placed to the inside of the insulation and the surfaces of the hollow slabs are directly in touch with room air, while the supply air is conducted through the slabs. This arrangement allows a larger effective heat capacity of the building even though the mass of the structures is not increased.

Extract Air Window System

The ventilation in both phases is handled by an Extract Air Window System. In this system the exhaust air is extracted through the gap between the two inner window panes. The windows in phase one are three-paned and in phase two, four-paned.

Extract Air Windows can be used also as solar collectors. The collection efficiency of a window which is equipped with black venetian blinds can be as high as 60 %. On the sunny facade, warmed air can be transferred to the shady facade by using recirculation air.

Exhaust air from sanitary rooms however is not used as recirculation air but is blowed stright out. The heat from the exhaust air is recovered by a glycol coil recovery system. This heat is used to warm the fresh incoming air. (See reference 1 and 2.)

Low electrical load of illumination

During design the lighting was examined in a model room. Several luminares with different illumination geometries were tested. The wall surface materials were also varied to get the best illumination efficiency. An illumination level of 900 lux was achieved by an electricity load of 17 W/m^2.

Since in a typical office building the lights are normally on during the entire work-day (even though the influence of natural lighting can be significant) research to determine the positive effects of natural lighting is being undertaken. In the EKONO-building two automatic lighting control systems have been installed to regulate artificial illumination in response to daylight.

One is an on/off system which turns the lamps beside the windows slowly off when daylight is sufficient.

The other is a continuous control system which dims the lamps to maintain a consistant illumination level in response to the amount daylighting available.

Free cooling

The inner heat generation of the building is slight due to the shading factor of the Extract Air Window (20 %) and a reduction in power for lighting. This low heat generation rate along with an outdoor temperature that rarely exceeds 28°C for a very short cooling season, allows the EKONO building to be without mechanical cooling equipment.

However, free cooling will be examined. Night air will be vented through the hollow slabs to cool the structure for the next hot day. Evaporative cooling will also be examined.

Computer control and floating room temperature

The heating and air-conditioning system of the EKONO-building is under on-line control of a microcomputer. The algorithms of all the control-loops have been programmed to take into account the total behaviour of the building.

Computer control has enabled effective use of heating and air-conditioning strategies to decrease the total energy consumption. This means extended use of heat-exchanging, night time set-backs and optimal start of re-heating.

To utilize the thermal mass of the building in short-time heat storage, detailed work was done to study the thermal behaviour of the building. An analogue model (Appendix 2) was developed and simulation runs done with typical internal loads (people, lighting, equipment). The model described the behaviour of the rooms as well as the effects of the hollow-slabs, which are integrated to the air-conditioning.

The most economic way of storing internal "free" heat is to use the mass of the building. This suggests that strict room temperature settings can be relaxed (thermal comfort studies show that high thermal acceptability can be maintained with moderate variations, say 21...24°C).

Keeping this in mind, two simulation runs were done. In the first run the room temperature was allowed to increase freely due to internal loads. In the second run the room temperature was kept constant.

In both cases the outside temperature was set to be 0°C, which is typical in Finland in spring and late autumn. The room temperature behaviour can be seen in Fig. 3.

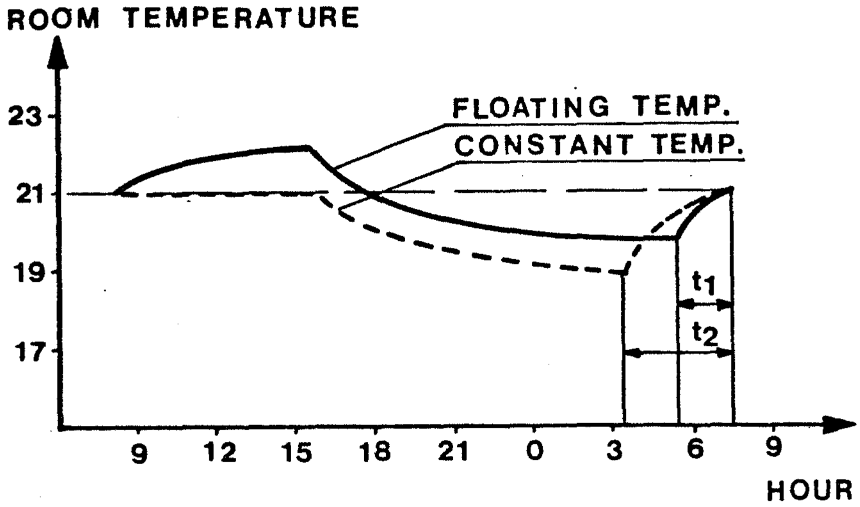


Fig. 3. Room temperature behaviour with floating and constant settings (simulation).

t_1 = preheating time with floating temperatures
t_2 = preheating time with constant office hour temperature

The dramatic reduction of preheating time is clearly seen. Estimations (degree-day weighting) suggest 20 % annual heating-energy savings.

The encouraging results led to actual control modifications in the EKONO-building. The floating temperature range was set between 21 °C and 23 °C by a dead-band in control, which allows the temperature to vary freely between the two limits. To avoid excessive room temperatures a special algorithm was programmed into the microprocessor. It continuously monitors the highest measured room temperature and if the upper margin (23 °C) is reached, it takes over the temperature control. To store most of the internal heat available, the temperature is still allowed to rise but is controlled to reach 24 °C at the end of the office hours.

The control actions are described in fig. 4. The computer notices the time t_L when 23 °C is reached and calculates a room temperature set-point line heading for 24 °C at the end of the office hours. Any tendency to exceed this line predicts too high room temperatures and more cool outdoor air will be used. Accordingly, if the room temperature cannot reach the calculated set-point line, then maximum recirculation will be used.

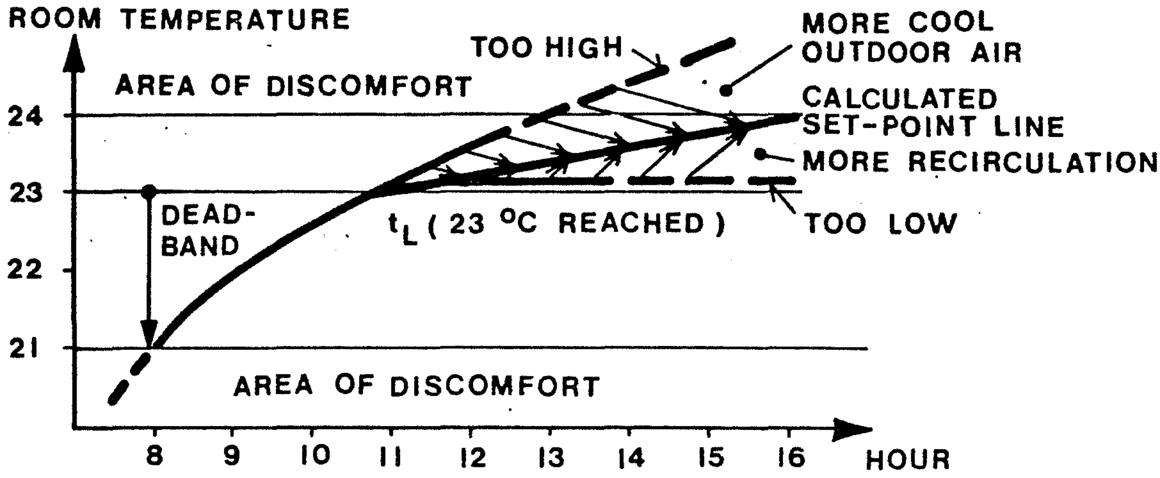


Fig. 4. Control of room temperature, if 23 °C is exceeded

The advantages of this special control are evident if compared to the case that only two exact limits, 21 °C and 24 °C were used. Because the cooling effect of outdoor air (at about 15 °C) is limited, maximum use of outdoor air, when the upper control limit is 24 °C, would not be sufficient to keep the temperature from reaching the discomfort area. With the additional 23 °C ... 24 °C control area excessive temperatures can be predicted beforehand, and more time is available for cooling. This is essential if cooling power is limited.

Ventilation control by air quality

The need of ventilation in office buildings is based mainly on odors and contaminants released from building materials and people. Because the required outdoor air rate during the heating period was designed for maximum occupancy, the ventilation rates during typical office hours are generally too high.

Smoke, odors and other air contaminant constituents can be correlated to the CO_2-content of the return air. In the second phase of the EKONO-building a CO_2-analyzer will be connected to the computer and the sampling air tube will be placed in the main return duct.

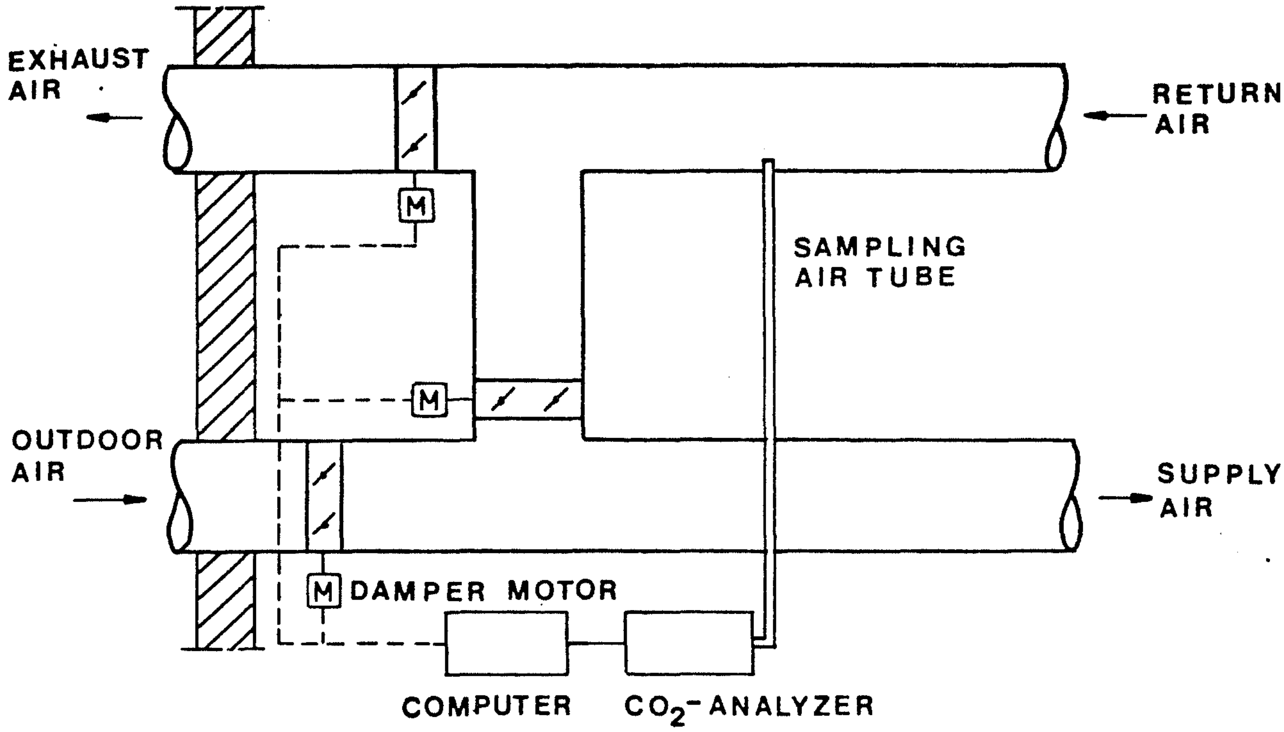


Fig. 5. The analyzer gives a message of the CO_2-content to the computer. The computer will adjust the recirculation air proportion in response to CO_2-concentration to maintain a level of 800 ppm to 1100 ppm.

The CO_2-based ventilation is estimated to give energy-savings up to 50 % compared to unregulated system, depending on whether the rate of tobacco smoke is significant or not.

Solar heat storage

In Finland solar radiation is most prevalent in the summer months (Appendix 1). To store heat from summer to winter, the EKONO-building will research a method of bedrock heat storage.

Solar panels (approximately 60 m^2) are used to heat water that is pumped through 10 m deep holes in bedrock under the building. During the cold season the heat from the bedrock storage is used to preheat the outdoor supply air.

EXPERIENCES

Heat consumption

Even though all the energy saving programs were not in use during the first half of the year 1980, the measured heat consumption in February was the same as the calculated value (16,1 Wh/m^2 per degree-day).

In March and April the heat consumption was only about 9 Wh/m^2 per degree-day.

Comparison between the heat consumption in February and April supports the efficiency of the Extract Air Windows as solar collectors. Even though the energy consumption for heating will increase conditionally during the mid-winter days, when solar radiation is low in Finland, the calculated consumption (70 $kWh/m^2 \cdot a$) should be achieved.

Infiltration rate

The air leakage rate was measured to determine the performance of the tightening measures.

This research was done by a tracer-gas technique. A N_2O-gas was used and gas concentrations were monitored by a 12-channel automatic infared analyzer (Wilks Miran II Multi-Point). The concentration levels used were about 100 ppm.

The measurements were carried out using 100 % recirculation air. Tracer-gas was released in the mixing box before the supply fan. Gas concentration was measured in the following locations: supply air, return air from separate facades, room air from separate floors, and outdoor air. With this method the infiltration rate could be measured in separate parts of the building. Air infiltration was also measured on the floors when the fans were not operating.

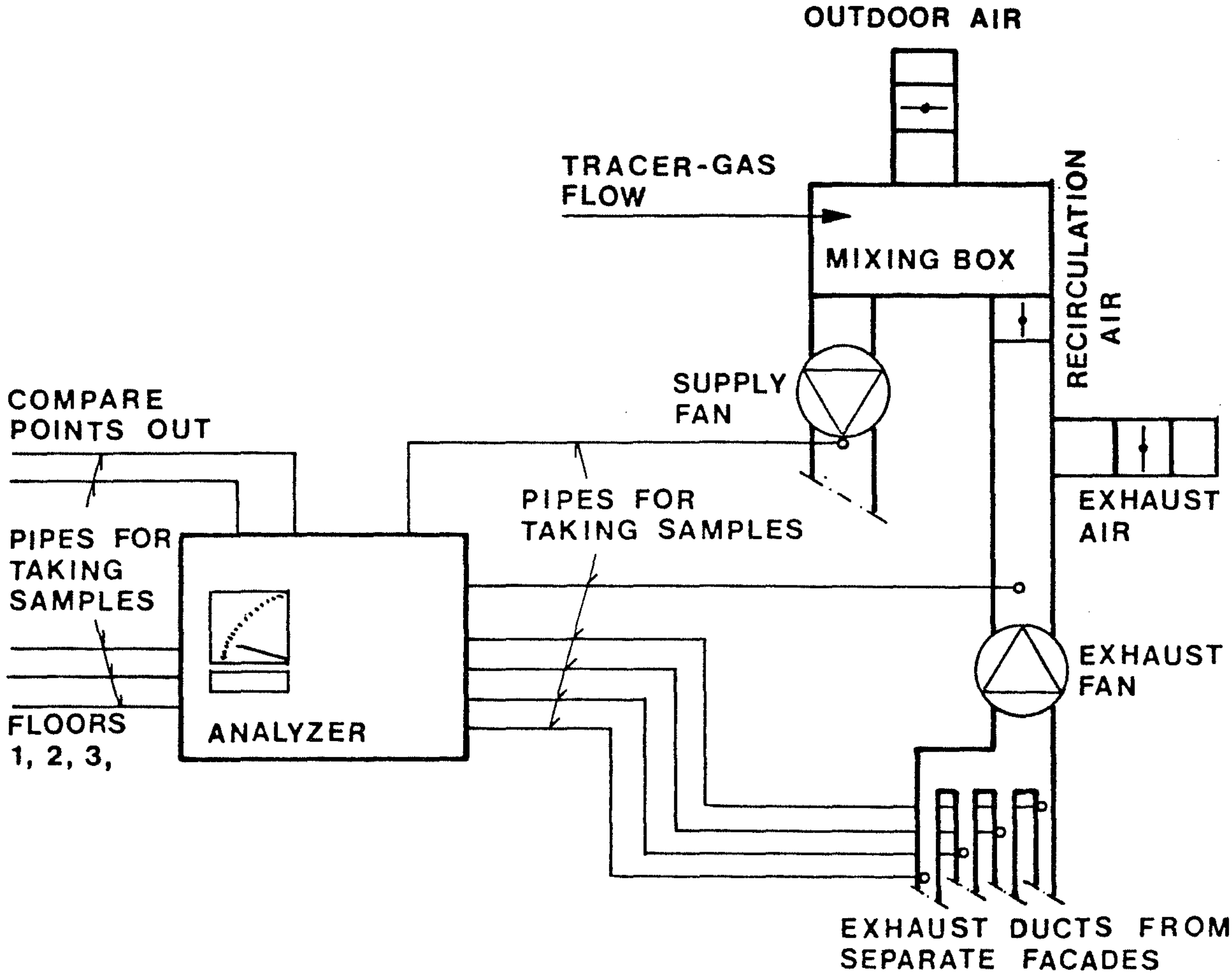


Fig. 6. Test arrangements for infiltration rate measurements.

Two different infiltration rate measurement methods were used:

1) Constant tracer-gas flow method
   - gas was released during the measurements
   - the infiltration rate was calculated from the formula

$$n = \frac{q}{VC_t}(1-e^{-nt}) + n\frac{C_o}{C_t}e^{-nt}$$

n = ventilation rate 1/h
V = volume of the building m^3
q = tracer-gas flow m^3/h
t = time h
C_o = tracer-gas concentration when $t=0$
C_t = tracer-gas concentration when time is t

2) The method of decreasing concentration
   - gas flow was shut down before the measurements
   - the infiltration rate was determined from the formula

$$n = \frac{1}{t} \cdot \ln\frac{C_o}{C_t}$$

The mean outdoor temperature during the measurements was -9.0°C and the average wind velocity was 0.7 m/s. The test situation corresponds to a normal winter weather in Helsinki.

Results:

The mean infiltration rate for the whole building, as given by both test methods, was 0.15 1/h when the fans were on. No significant differences between the separate floors and facades were observed.

When the fans were switched off, the infiltration decreaced. The mean value was 0.10 1/h. The infiltration rate was 0.14 1/h on the first floor, 0.09 1/h on the second and 0.07 1/h on the third.

Conclusions:
In spite of cold winter weather the infiltration rate was low. The differences between the infiltration rates on different floors, when the fans are not operating, are due to thermal forces inside the building. However, the influence of thermal forces is not remarkable, because the infiltration rate at the third floor, when the fans are off, is smaller than that when the fans are on.

Altogether the tightening measures were considered successful.

FUTURE

The operation of the building will be monitored intensively during several years. Because of continuous development of the control algorithms, the energy consumption of the EKONO-building should be reduced from the present figures.

Note: Because of the value of these studies in energy economics, the Ministry of Trade and Industry in Finland is supporting this research.

References

/1/ Gabrielsson J. (1977) Extract-air Window, a Key to Better Heat Economy in Buildings.
Proceedings of 10th World Energy Conference 1977, Paper 2.2-5.

/2/ Seppänen O. (1980) Cost Effective Energy Conservation in an Office Building.
Proceedings of International Congress on Building Energy Management, 12...16 May 1980, Portugal.

EKONO BUILDING

Location 9 km west from Helsinki (24°50´East, 60°11´ North)

Phase one, long facades face the south and north.
Phase two, long facades face the west and east.

Weather (in Helsinki, average for 1931...-60, radiation for 1960...-71)

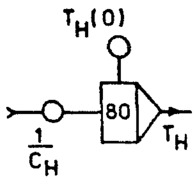
	Jan	Feb	March	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Mean temperature °C	-6.8	-7.4	-4.1	2.2	9.0	14.3	17.1	15.6	10.4	4.8	0.6	-3.4
Degree days (°Cd) 17°C based	738	683	658	444	183	-	-	-	154	378	492	626
Solar radiation horizontal surface (MJ/m²)	31.1	85.2	238.6	379.4	577.6	652.4	580.9	435.0	247.8	123.4	33.8	15.3

Mean temperature for the year, 4.4°C.
Degree days based on 17°C for the year, 4350°Cd.
Solar radiation on horizontal surface for the year, 3390 MJ/m².
Design temperature for heating system, -27°C.

SIMULATING MODEL FOR FLOATING ROOM TEMPERATURE

The simulation model is based on the assumption that the behaviour of a building can approximately be described with an electrical analogue model. This means that thermal masses are described with capacitances and heat transfer coefficients are described with resistances.

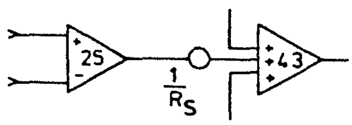
In the simulating program (IBM Continuous System Modeling Program) components are described with basic blocks. Using the basic blocks, complicated systems can be constructed. Thermal masses (capacitances) are functioned by integrators; e.g. block 80.



The output of the integrator represents the room-air temperature T_H.

The heat transfer coefficients (resistances) are represented by multiplying factor, e.g. between blocks 25 and 43:

Heat transfer coefficient, room-air and walls:



The multiplying factor, I/R_S, represents the heat transfer coefficient.

The model has been divided into four parts:

1. Room module
2. Extract air window
3. Hollow slab
4. Controller

1. Room module

T_H is room air temperature
T_S is wall temperature
T_U is outside temperature
T_K is internal load equivalent temperature

2. Extract air window

T_{IP} is exhaust air temperature after the window

3. Hollow slab

T_E is supply air temperature from the central air conditioning machine room

T_{HT} is supply air temperature when leaving the hollow slab core (to enter the room)

T_{PT} is hollow slab temperature (supply side)

T_{LP} is exhaust air temperature when leaving the hollow slab core (to return ducts)

T_{PP} is hollow slab temperature (exhaust side)

4. Controller

T_H (MAX.) is maximum of the room temperatures (seven zones)

The controller is basicly a P-controller with gain G (block 124), but it functions only in the area over 23 $^{\circ}$C (room temperature).

On the next page the complete model is drawn. The connecting lines between the four parts describe the path of the supplied and exhaust air.

SIMULATING MODEL FOR FLOATING ROOM TEMPERATURE