GOOD INDOOR CLIMATE AND AIR QUALITY IN ENERGY-EFFICIENT HOUSES

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ABSTRACT

Two energy-efficient single-family houses (known as ESPI houses) with competitive overall costs were set up during the study in Finland. The consumption of energy for room heating in ESPI houses was reduced to a half at the construction stage, by employing simple solutions which can be used by every builder. The level of thermal insulation of the houses was improved remarkably. The houses were equipped with a controlled ventilation system and an efficient exhaust air heat recovery unit. One of the houses was oil heated and the other was electrically heated. In ESPI houses the indoor air quality and thermal climate were good. Against common opinion there was no conflict between low energy consumption and good indoor air quality. Most important thing was adequate and energy-efficient ventilation. The consumption of energy for room heating in ESPI houses was 60 kWh/m² per year. The total heating bill of the ESPI houses was only EUR 27 - 38 per month. Due to the reduced heating demand the heating system can be simplified, and as a result the building costs do not increase significantly.

INTRODUCTION

The goal of the ESPI energy-efficient houses was to implement solution models for houses on the practical level which are reasonable in overall costs, have a good indoor climate, low energy consumption and are environmentally friendly [1]. The criteria were to use simple energy-efficient solutions suited to every home. Solutions were known to work through experience gained in earlier demonstration projects.

If the energy saving technology used in ESPI energy-efficient houses is applied in all new construction, it will be possible to reduce the consumption of heating energy in the total housing stock in Finland by 15 % by the year 2020. Emissions from energy production will also diminish by 15 %, even though total housing capacity will simultaneously grow by more than 20 %. The annual saving of heating energy for buildings will be 7 TWh, equivalent to the total electrical energy produced by one nuclear power station.

DESCRIPTION OF THE HOUSES

The ESPI energy efficient houses are located in Espoo, southern Finland. ESPI 1 was oil heated one-storey house and ESPI 2 was electrical heated two-storey house. Both houses had timber frame and facade. Gross floor area of ESPI 1 house was 147 m² and gross volume was 470 m³. Net floor area was 128 m² and net volume was 315 m³. Gross floor area of ESPI 2 house was 198 m² and gross volume was 535 m³. Net floor area was 145 m² and net volume was 360 m³. The energy-efficient solutions did not in any way restrict the layout solutions or other designs. On the contrary, the absence of radiators and the possibility to use large window surfaces, for example, increased the scope for design. An energy-efficient building consumes less than half the heating energy a conventional building does. In spite of this, indoor air quality and living comfort improve. The energy saving can be accomplished by building the house so that it is heated with a small amount of energy (Table 1). At the same time the heating effect will reduce remarkable.

Table 1. Simple means that are adapted to the building of a new energy-efficient building.

CONTROLLED VENTILATION AND EFFICIENT HEAT RECOVERY
- silent and draughtless supply and exhaust air ventilation
- demand controlled ventilation (manual 4-stage fan speed control and damper in cooking hood to increase the air flow)
- temperature efficiency of the heat recovery is 60 - 80 %, freeze protection
A BETTER LEVEL OF THERMAL INSULATION
- in walls, 250 - 300 mm rock wool insulation (U-value is 0.13 W/m²K)
- in the lower floor, 200 - 300 mm EPS insulation (U-value is 0.15 W/m²K)
- in the ceiling, 400 - 500 mm of rock wool insulation (U-value is 0.08 W/m²K)
- energy efficient windows (U-value is 0.6 - 1.0 W/m²K)
CAREFUL CONSTRUCTION
- safe structural solutions and building materials
- avoidance of uncontrolled air and heat leakage (also good sound insulation)
USING STRUCTURES AS A HEAT STORAGE UNIT
- heat-storing structures are used for 24-hour storage of heat

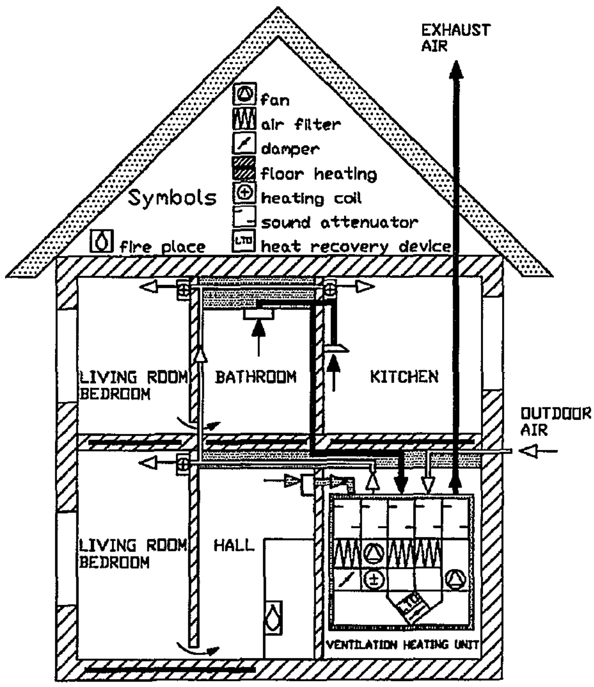

Figure 1. Ventilation heating system in the ESPI-houses.

In Finland the majority of new single-family houses are built with a controlled supply and exhaust air ventilation system. By combining this with room heating that has a supply air heating device, we obtain a simple, low-cost and efficiently controllable heating system, ventilation heating system (Figure 1). It is indeed well suited to energy-efficient buildings because their heating requirement is so small as to make the need for a separate heat distribution system questionable. For example, the heat generated by two people suffices to heat a bedroom even when the mercury falls a couple of degrees below zero. Heat distribution system in ESPI 1 house was water pipe floor heating with room based temperature control and ventilation heating system with 2-zone temperature control. In ESPI 2 house an electrical accumulating floor heating in first floor and ventilation heating system in all rooms was installed. Both floor temperatures and room temperatures were controlled by centralized control system. In both houses there were also energy efficient soapstone masonry fireplaces.

METHODS

The ESPI energy-efficient single-family houses was a project which was launched in 1994 and comprises the design, construction and monitoring of two product-package, energy-efficient houses for a two-year period during 1995 to 1997. In this paper results of the energy monitoring and indoor air quality measurements are presented. The energy consumption, the technical systems and indoor temperatures were monitored continuously. Indoor air quality and thermal conditions were studied by one day single measurements.

RESULTS

Energy consumption has been reduced significantly in the new energy-efficient houses of the 1990s compared with houses of the 1980s. Measurements indicated that about 60 kWh/m^2 per year was spent on heating the spaces in both ESPI houses (Table 2). It was only half of what is consumed in a conventional single-family house. Wood heating accounted for 27 - 44 % of heating. The total energy costs were EUR 950 per year in the oil-heated house and EUR 820 per year in the electrically-heated house. The higher costs in the oil-heated house resulted from the larger consumption of energy by the building services, more expensive electricity and a slightly lower level of wood burning.

Table 2. Annual energy consumption of the ESPI energy-efficient houses.

ESPI 1	Annual energy consumption		
	kWh/a	$kWh/m^2/a$	%
Heating oil (1 172 litres)	10 550	82	52 %
Electricity	7 718	60	38 %
Firewood	2 105	16	10 %
Total energy	20 372	158	100 %
Room heating 1)	7 866	61	39 %
Household electricity	7 718	60	38 %
Hot water	2 679	21	13 %
Internal heat losses 2)	2 110	16	10 %
ESPI 2	kWh/a	$kWh/m^2/a$	%
Daytime electricity	3 475	24	19 %
Night time electricity	11 744	81	64 %
Total electricity	15 219	105	82 %
Firewood	3 237	22	18 %
Total energy	18 456	127	100 %
Room heating 1)	8 395	58	45 %
Household electricity	6 097	42	33 %
Hot water	2 642	18	14 %
Internal heat losses 2)	1 322	9	7 %

1) Room heating energy (including firewood) was normalized by reference heating degree day value of Helsinki, Finland (S_{17} = 4 366 Kd)
2) Heat losses of heat storage and pipes inside of the houses.

According to the measurements (Table 3), the indoor air was pure and the concentrations of harmful impurities were below their limits. Concentrations were slightly higher in ESPI 2 than in ESPI 1. Indicated compounds were typical emissions from wood material and normal living. Main reason for the higher concentrations was the lower ventilation level in ESPI 2 than in ESPI 1. In ESPI 1 the average ventilation rate was over 2.5 times the ventilation rate in ESPI 2 in a six month period before the measurements (Figure 2). During the measurements the ventilation rate was the same (60 dm^3/s) in both houses. Houses were pre-fabricated by the same company from same materials. Emissions from the building materials could not explain the difference in the concentrations. Concentration of the microbes were as low as they can be in an occupied house. Low concentration of actinomycetes were found. They may be emissions from firewood stored in the living room. The particulate matter concentrations were a little bit higher than typical. They may be also emissions from firewood. Total number of indoor air particles was only half of that in outdoor air.

Table 3. Indoor air quality of the ESPI energy-efficient houses. Indoor air quality measurements were done six months after people moved in.

ESPI 1		Pollutant concentration		
		Living room	Bed room	Target value
TVOC [1]	mg/m³	0.16	0.15	< 0.2 (S1)[4]
Ammonium [2]	mg/m³	0.015	0.017	< 0.02 (S1)
Formaldehyde [3]	mg/m³	0.012	0.009	< 0.03 (S1)
Radon	Bq/m³	100	90	< 200 (S1)
Fungal spore	cfu/m³	17	25	< 500
Bacteria	cfu/m³	480	500	< 4 500
Actinomycetes	cfu/m³	2	0	0
Particulate matter	mg/m³	56	-	< 60 (S1)
ESPI 2		Living room	Bed room	Target value
TVOC [1]	mg/m³	0.71	0.69	< 0.2 (S1)[4]
Ammonium [2]	mg/m³	0.022	0.047	< 0.02 (S1)
Formaldehyde [3]	mg/m³	0.035	0.043	< 0.03 (S1)
Radon	Bq/m³	130	110	< 200 (S1)
Fungal spore	cfu/m³	79	39	< 500
Bacteria	cfu/m³	340	210	< 4 500
Actinomycetes	cfu/m³	3	0	0
Particulate matter	mg/m³	64	16	< 60 (S1)

[1] TVOC is total concentration of volatile organic compounds calculated as toluene. Typical level of TVOC concentration is 0.05 - 0.4 mg/m³.
[2] Typical level of ammonium concentration is 0.010 - 0.025 mg/m³.
[3] Maximum concentration of formaldehyde is 0.15 mg/m³.
[4] S1 is the best indoor air quality class in three-stage Finnish category system. Category S3 is equivalent to minimum level required in Finnish building code.

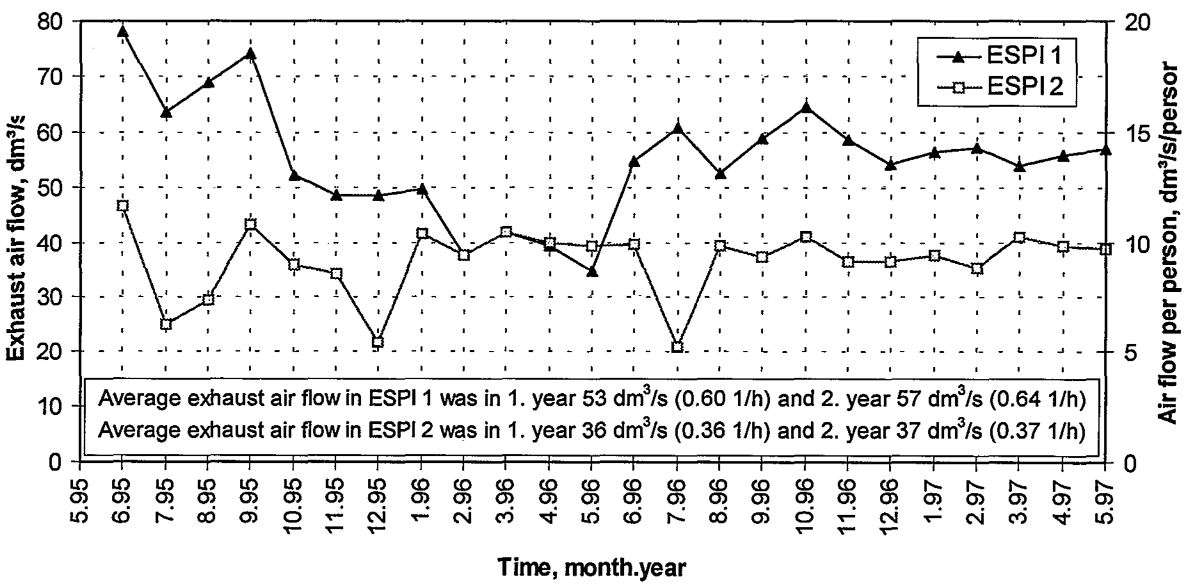

Figure 2. Average exhaust air flows in ESPI houses.

Average room temperatures were 1 - 2 °C higher in ESPI 1 than in ESPI 2 (Figure 3) due to occupants preferences. Average relative humidity of the room air was 5 - 10 % lower in ESPI 1 in ESPI 2 (Figure 4) due to higher temperature and ventilation air flows.

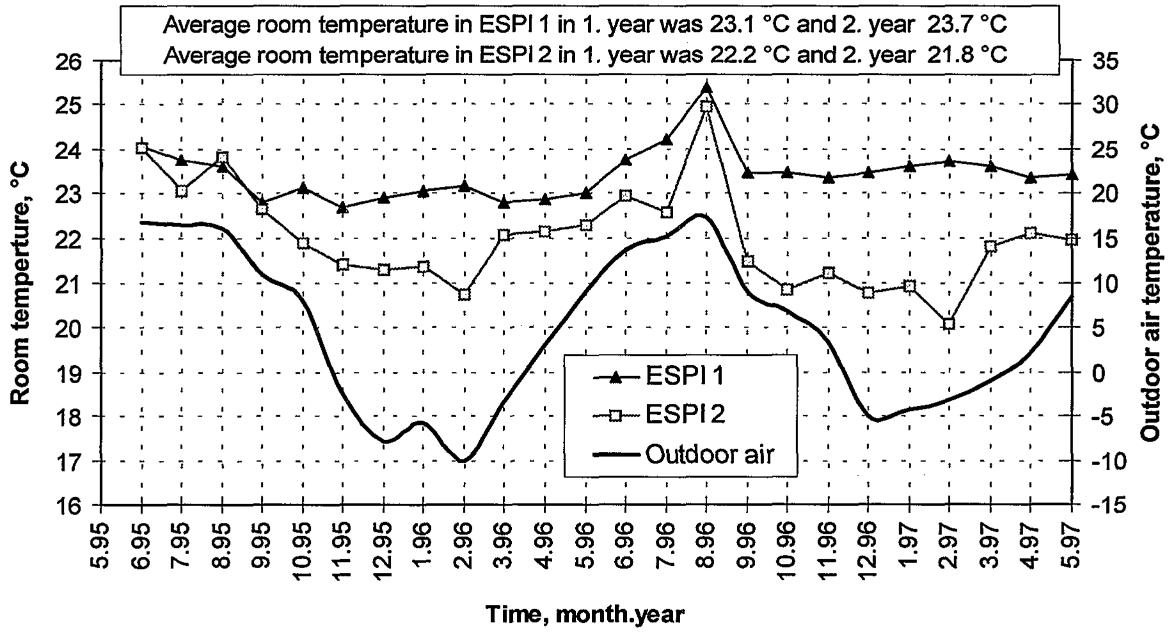

Figure 3. Average outdoor and room temperatures in ESPI houses.

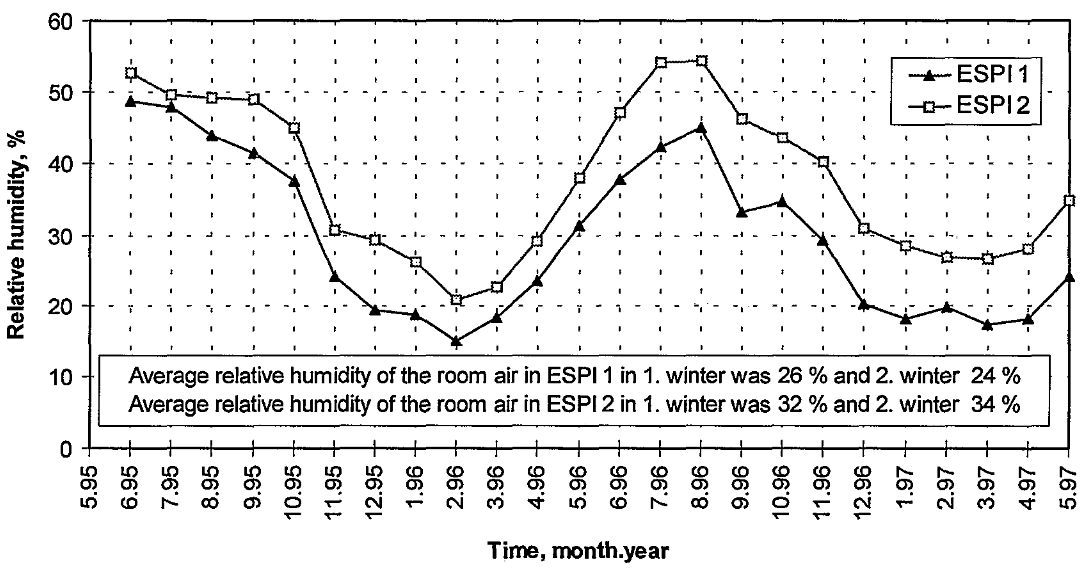

Figure 4. Average relative humidity of the room air in ESPI houses.

Draught-free conditions are ensured by way of efficient thermal insulation, good windows and an air-tight external envelope. Supply air devices that mix the air efficiently prevent vertical temperature differences (stratification). In figure 5 the measured thermal conditions in ESPI houses with different heating systems are depicted. There was no significant difference between the floor heating system and the ventilation heating system.

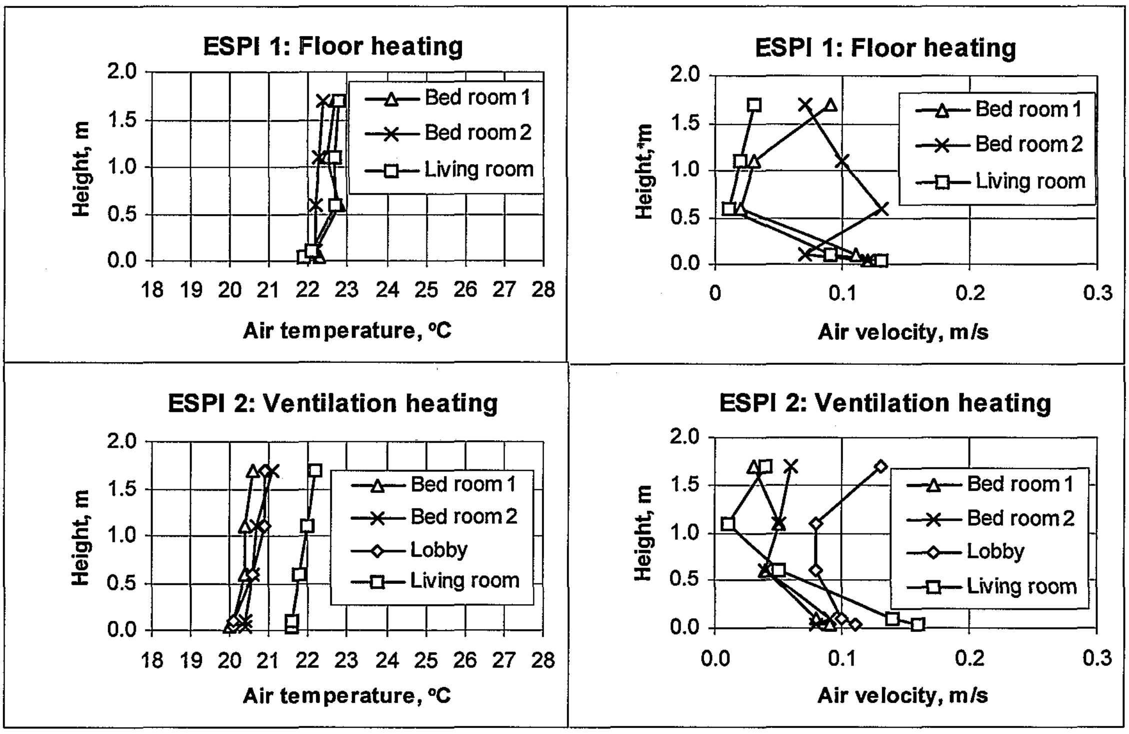

Figure. 5. Vertical temperature differences and air velocities in floor heated and ventilation heated rooms. In ESPI 2 there is ventilation heating in bed rooms and in lobby. In living room there is floor heating, fireplace and ventilation heating as adjusting heating.

DISCUSSION

According to the study, the residents were satisfied, the indoor air was clean, the simplified ventilation heating system functioned well and heating energy consumption was 50 % lower than in conventional houses. The measurements indicated that controlled and sufficiently efficient ventilation is an important factor when attempting to ensure good indoor air quality. The heating and ventilation systems that were studied worked well. In the study, it was noted that pleasant thermal conditions in energy-efficient houses can even be achieved by simple means of heat distribution, such as ventilation heating. This makes it possible to simplify the heat distribution system and thus to reduce costs.

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