PROGRESS AND TRENDS IN AIR INFILTRATION
AND VENTILATION RESEARCH

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Poster 9

ENERGY USE FOR TRANSPORT OF VENTILATION AIR

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1. SYNOPSIS

In the "Stockholm Project", different blocks of multi-family buildings have been extensively monitored for about three years. Temperatures, airflows and electricity use have been registrated each hour. As an additional base to this examination, ten fan units in the buildings have been intensively studied.

The results show that the specific use of power for transportation of ventilation air varies between approximately 1 and 4 kW per m^3 and second.

The results from the measurements indicate a notably low level of installation efficiency. The total efficiency of the ten units varies between 15 and 57 percent and has a mean value of 32 percent. The loads of the units have been comparatively low and consequently they have had an influence on the power factor. The operative conditions related to the loads also tends to have a disadvantageous influence on the efficiency.

The regained energy from heat recovery plants in two of the installations, compared to the total electric energy for operating the fans in the system, gives an approximate relation of 2 to 1. Regained energy compared to transformed energy specifically related to drops of pressure in the heat exchanger gives the relation 6 to 1.

Because of heat losses from ducts and inability to utilize the extracted energy from the exhaust air, the mean value for the useful recovered heat has been considerably below the efficiency of the plant.

The cause of the variaton in specific use of power for the examined units, mainly depends on the total pressure drops and the dimensioning of the fan motors. The power demand for the electric motors has in general been overestimated. 90 percent of the examined motors have an output power exceeding the requirement of power for the fan. The loads vary between 38 and 97 percent, with an average of about 64 percent.

One of the main reasons why the power of the motors exceeds the normal requirement, is the design of regulating extra needs of airflow on limited occasions, such as cooking hours. During normal operation the air flow is reduced by a damper. This gives an extra pressure drop for the main part of the running hours, which causes essential losses of energy.

The combination of high pressure drops and low efficiency in ventilation plants create unnecessary use of electric energy.

With a careful design of the system, well insulated ducts and an efficient regulation of air flow, the possibilities to improve the mode of application of the recovery system and decrease the use of electricity seem to be substantial.

2. BACKGROUND

In Sweden today, the uncertainty of the future situation of using and producing energy is noticeable. In this matter the questions of production and environmental effects have been dominating. The use of energy in buildings is considerable. Therefore, the potential of improving the efficiency of plants and building technology is of great interest.

The Swedish Council for Building Research encourages the development of new energy-effective techniques and systems for new and existing buildings. The "Stockholm Project" is the first larger joint experimental project for the evaluation of low energy consumption in multi-family buildings. The purpose of the project was to test new buildings that will lead to a lower requirement of purchased energy.

The technical evaluation of the project has been carried out by the Energy Conservation in Buildings Group - EHUB, a department of the Royal Institute of Technology - KTH, in Stockholm.

One of the results from the "Stockholm Project" is that advanced technique in multi family-buildings tends to increase the use of electricity, although the total level of purchased energy is comparatively low. The aspects of how different technical systems coordinate are of great interest and have been one of the main purposes of this evaluation.

In this paper the relation of use of heating and electricity for ventilation has been studied in six of the buildings of the project. Power to fans and state of pressure in ducts have been measured in ten different fan units. In two of the buildings the use of electric energy to the fans has been related to the energy balance of the ventilation system. The sacrifice of electric energy to regain heat from exhaust air has been calculated.

3. BRIEF DESCRIPTION OF BUILDINGS AND ENERGY SYSTEMS

Building A and B

The intention was to demonstrate the possibility of reducing the energy consumption by using conventional building methods. The buildings have been constructed with application of stringent air-tightness and insulation requirements.

Operating costs of the buildings in use have been tried to be kept low by concentration on quality during the building process. Improved construction documents, training of and information to the building workers and the provision of operating and maintenance instructions for users, have been important elements.

The heating system is a two-pipe, low-temperature system, operating at a maximum supply temperature of 55 °C and supplying not only radiators, but also the ventilation air heaters. Domestic hotwater, which is metered separately for each apartment, is supplied at a temeperature of 45 °C. The heated floor area of the two buildings together is 4282 m^2.

The buildings have a balanced ventilation system with mechanical supply and exhaust. The system also has heat exchanger of the air to air recuperative type.

Building C

Building C is a conventional Swedish apartment building. Each floor level contains two apartments consisting of five rooms plus kitchen. The total heated area is 1943 m^2. The structure is of cellular type with outer walls of 40 cm thick light-weight concrete blocks. The windows are triple-glazed.

The purpose was to reach a low requirement of purchased energy through utilization of solar energy gained by solar collectors integrated with the roof structure. The heating will be provided by means of a forced air heating system.

The building has a mechanically balanced ventilation system. Air is supplied to the building through an air/air heat exchanger in which the incoming air is preheated by the exhaust air. When the air through the solar collector reaches a sufficiently high temperature to be able to warm up the incoming air, the air is passed through the collector. Each apartment also has its own separate heating unit supplied by district heating.

Building D and E

Buildings D and E have a total heated floor area of 5336 m^2 and consist of 57 apartments. The buildings have been costructed of prefabricated sandwich type elements of concrete. The construction of balconies is carried out especially to reduce thermal bridges.

The concept with the energy system is to preheat the incoming air by passing the air through the external walls. The air inlets are designed as ducts in the concrete elements. During summertime the incomimg air passes through a separate outdoor air inlet. To reduce the peak power demand for heating, the structure is heavier than in conventional Swedich buildings.

The ventilation system uses mechanical exhaust air with the supply air system as described. The heating is provided by a heat pump and district heating. The heat pump recoveres energy from the exhaust air and supplies heat to the domestic hot water and the radiator systems.

Building F

Building F has a total heated floor area of 7265 m^2 and consists of 71 apartments. The object, which contains a glazed atrium, has been built with an in-situ-cast main concrete structure, with light- weight prefabricated external wall elements. Ducts for the heating and ventilating system have been built into the floor/ceiling slabs.

The building incorporates a forced air heating and ventilation system. Each apartment has an airheating unit in a wardrobe in the entrance hall. The heat is supplied by the domestic hotwater circuit, which therefore serves two purposes.

The ventilating is mechanically balanced with fans for exhaust and supply air. The incoming air is passed through two air-to-air heat exchangers, installed parallelly.

4. METHODS AND INSTRUMENTS OF MEASUREMENTS

The measurements have been carried out by the Energy Conservation in Buildings Group - EHUB, in cooperation with the consulting company AIB Anläggningsteknik AB, in Stockholm. The measurements include air flows, pressures in ducts and electric power to fan motors in the ten ventilation plants described in section three.

The air flows in the ducted systems have been determined by using a pitot static tube and a micro manometer. A traverse measuring has been carried out at a plane in a section of the duct. The traverse has been done in two diameters with nine points on each line. The method used is based on the recommendations of the NVG[5] (Nordiska Ventilations Gruppen).

The velocity profile has been plotted on the basis of the velocity pressure and the average velocity in the duct has been calculated. Corrections for errors in instruments and readings have been considered.

Total and static pressures have been measured by connecting the applicable tapping at the tail of the Pitot tube to the appropriate connection at the manometer. The connection used to measure the velocity pressure has then been left open to the atmosphere. Differences in static pressure across components in the system such as dampers, filters, heat exchangers and fans have been measured.

The manometer used is manufactured by FURNESS CONTROLS LTD.,s/n FM 2513 and was calibrated in connection with the measurements to an accuracy of 2.5 %.

A clip-on power instrument, EB 1286 MICROVIP MK1, has been used to measure power to the fan motors. The instrument indicates active power, current, voltage, frequency and power factor. The instrument was calibrated in connection with the measurements to an accuracy of 2 % measuring active power at the range 0 to 36 A.

The instrument can be used for measuring loads of one and three phase power. When measuring three phase power each phase has been measured separately to ensure that the load has been symmetric and if not, considered in the determinations.

Long term monitoring of the examined heat recovery plants in two of the buildings has been carried out by the Monitoring Center of Energy Research - MCE, a department of KTH.

The monitoring system is operated by a desk computer of the type Hewlett&Packard 85 or 86. The sensors in the system are connected to the computer through instruments of high standards of accuracy.

Signals from the sensors are registrated every 5:th or 12:th minute and stored as mean values or sums every hour. The accuracy of temperature meuserements is stated to be less than 0.1 Kelvin and measuring of energies in air to an accuracy of 10 %.

5. RESULTS

The results from the measurements of the ten fan - installations are illustrated in Table 5.1. All fan motors are of the type three phase non-synchronous. The fans are V-belt driven and of radial type with the blades bent forward.

Column one in the table shows the different buildings and the associated type of installations with a submerged index, the index $_i$ for units transporting incoming air and $_e$ for exhaust air.

L indicates the load, defined as the relation between measured and rated power of the fan-motor:

$$L = \frac{P_m}{P_r}$$

where P_r stands for the rated power of the motors, and P_m stands for the measured power.

PF_m shows the measured relation between useful power and apparent power, the power factor. Q_m shows the measured airflow in m^3/s and p_t the total drop of pressure in Pascal (N/m^2).

The total efficiency of the installations = n_t, is defined as the relation between the measured air flow, Q_m (m^3/s) multiplied by the total pressure drop, p_t (N/m^2) in the installation divided by the measured power to the fan motor, P_m (Nm/s).

$$n_t = \frac{Q_m * p_t}{P_m}$$

Table 5.1. The results from the measurements of ten installations of fans.

Fan-Unit	P_m (W) Measur. Power	L (%) Load	PF_m Power factor	Q_m (m^3/s) Airflow	P (N/m^2) Pressure	n_t Efficien
A_i	1000	70	0.62	0.67	500	34
A_e	1670	57	0.54	0.65	640	29
B_i	1040	69	0.61	0.68	640	42
B_e	1980	66	0.62	0.86	590	26
C_i	700	64	0.57	0.68	330	32
C_e	1560	*104	0.58	0.73	578	27
D_e	2130	97	0.57	0.83	1450	57
E_e	1140	38	0.42	0.50	333	15
F_e	5100	46	0.51	1.98	540	21
F_i	7110	65	0.68	1.84	1268	33

* Variable speed of C_e is controlled by a frequency converter, why the load can exceed the rated load.

The mean value of the total efficiency of the installations of fans has been approximately 32 percent, and varies between 15 and 57 percent. The difference of total drops of pressure for different installations has been about 1100 Pascal.

The low levels of loads of the motors is noticeable. The mean value is 64 percent. The load has an influence on the power factor which decreases with a decreased load.

One way of comparing the efficiency of transporting air, is by studying the power to transport a specific volume of air as a function of the total drop of pressure in the system. The results show that the specific use of power varies between approximately 1 and 4 kW per m^3 and second.

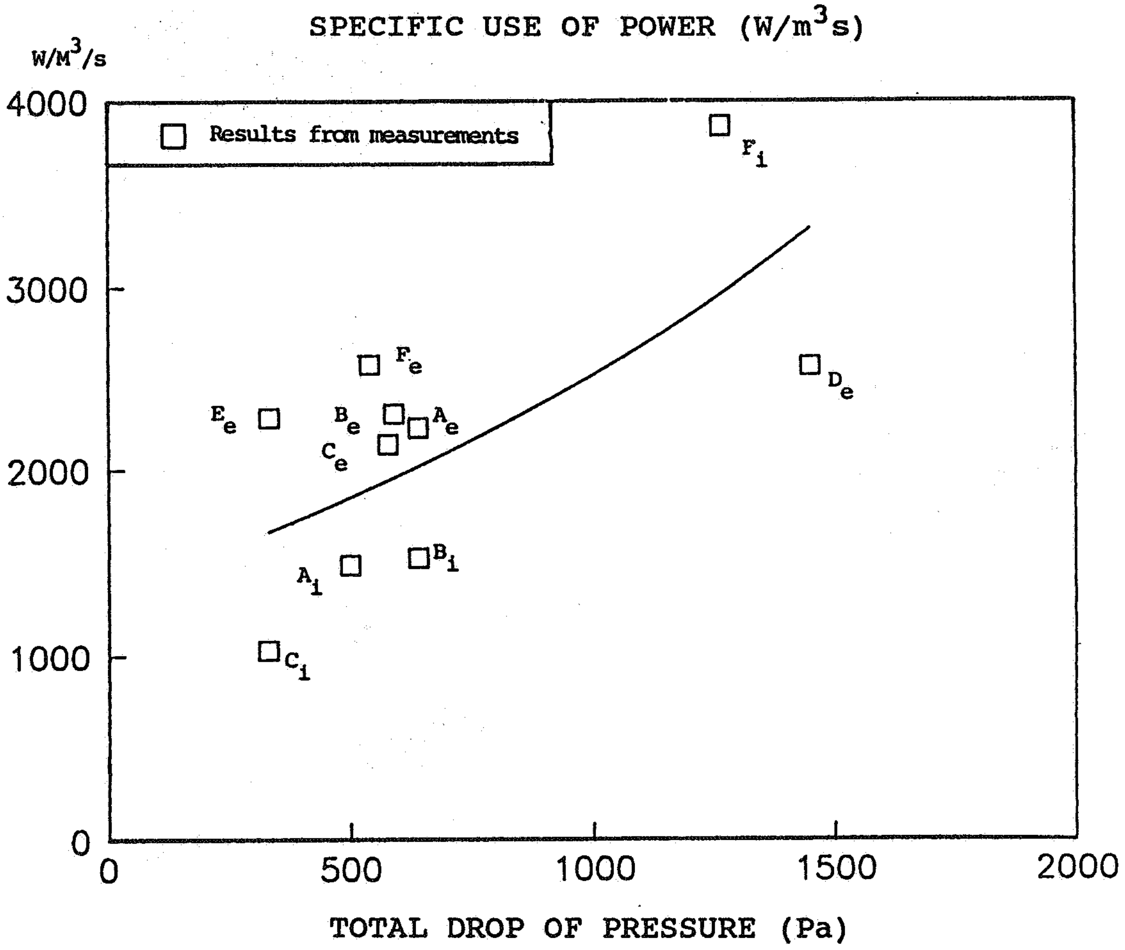

Figure 5.1. Specific power, defined as measured electric power to the fan motor at a certain airflow as a function of the total drop of pressure in the system.

It can be observed that the results from the calculations of specific power from the examined units are considerable scattered. Comparing the extremes the most significant digit is almost four times greater than the lowest.

The power demand to transport the same amount of air varies because of differences in drops of pressure and designs of systems. The main reasons for these variations are owing to the influence of adjustability and dimensioning of the electric motors.

The total electric energy to the fans over a year has been calculated by extrapolating test results from instantaneous measurements. The electric energy extensively related to the regaining system = P_{re}, has been calculated from drops of pressure across both sides of the exchanger including the filter for the exhaust air.

The values of pressure drops (N/m^2) have been multiplied with values of the air flows (m^3/s). The results have then been divided with the total efficiency of the fan unit, as:

$$P_{re} = \frac{Q_{mi} * P_{exi}}{n_{ti}} + \frac{Q_{me} * P_{exe}}{n_{te}}$$

Where Q_{mi} = Incoming airflow through the exchanger

P_{exi} = Drop of pressure across the exterior side of the exchanger

Q_{me} = Exhaust airflow through the exchanger

P_{exe} = Drop of pressure across the exhaust side of the exchanger including the filter.

n_{tx} = Total efficiency of the unit

Some of the energy that is transformed to heat by the drop of pressure can be used for heating. The transformed energy in the exhaust system has normally to be considered as losses.

The heat recovery units (consisting of air-to- air recuperative heat exchangers) and the fans in building A and B are placed in a plant room situated on the top floor. The ducts between the apartments and the units lead through unheated spaces. The ducts are insulated according to the Swedish Building Code.

The heat losses from the ducts depend on dimensions, insulation, length of ducts, difference in temperature outside and inside the ducts and the velocity of the transported air. The energy losses are proportional to drops of temperature.

In building A and B, mean values of the losses have been calculated to approximately five percent of the transported energy. These buildings were built under certain supervision to obtain greatest quality, why similar or worse conditions can be expected in the oridinary production of the same category.

DIFFERENCES IN AIR TEMPERATURES BETWEEN INDOORS AND THE RECOVERY PLANT °C.

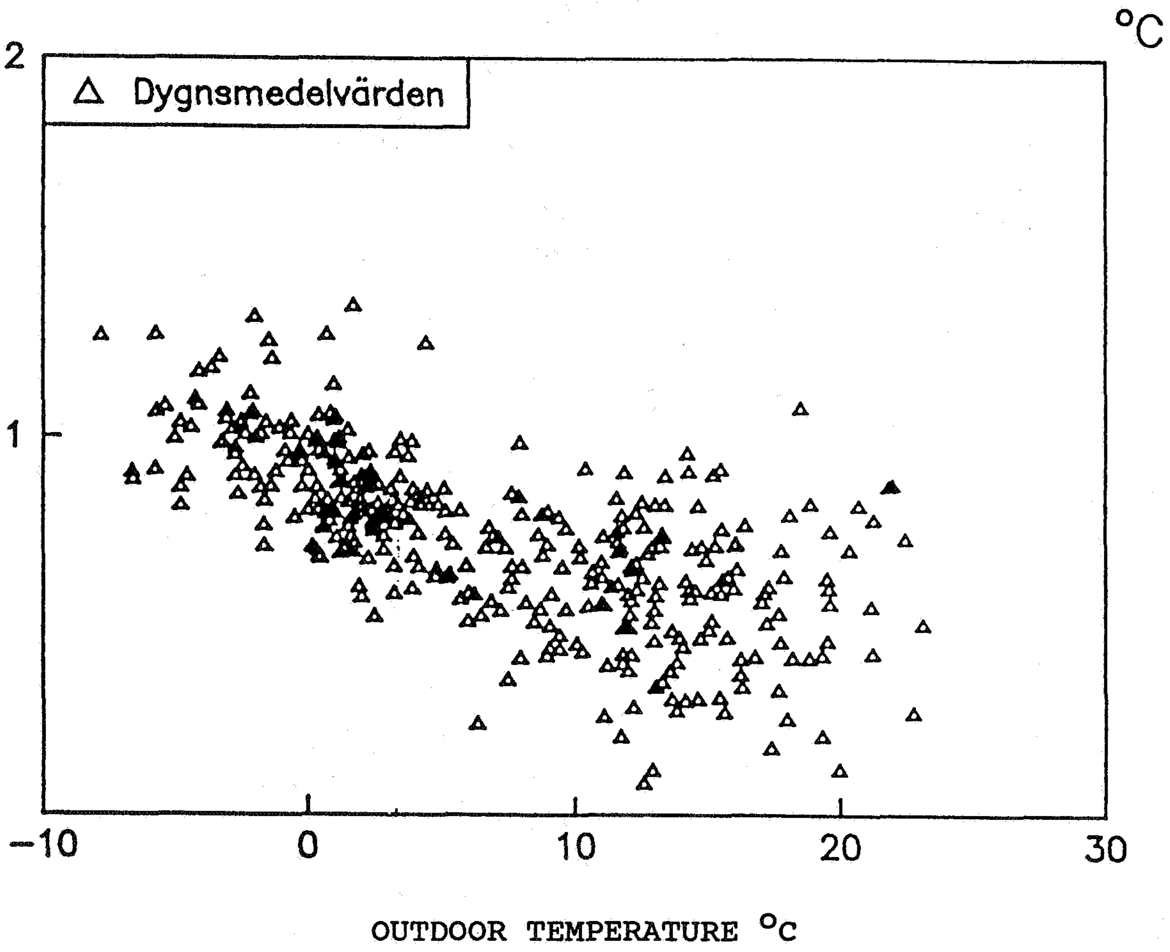

Figure 5.2. Differences between temperature in apartments and exhaust air passing the heat exchanger in building A, as a function of the outdoor temperature. The temperature difference is shown by daily averages for a year.

Some of the electric energy to the fans and heat losses from the ducts can be considered as sacrificed energy to provide the recovered energy. To study this relation, the influence of the internal heat-load on the possibilty to use the regained energy has to be calculated. This has been done by subtracting total regained energy over a year with the regained energy during the season without need of external heating, defined as the period between the 15:th of May and the 15:th of September.

Table 5.2. Illustrates the relation between regained energy and electric energy to fans in MWh during one year .

	Building A	Building B
Energy in exhaust air	100	152
Regained in exchanger	58	79
Losses from ducts related to regain	-3	-4
Regained during summer	-10	-14
Utilized	**45**	**61**
Total electric energy to fans	23	26
Transport through exchanger, P_{re}	8	9

The degree of efficiency for two of the heat exchangers has been measured to 58 and 52 percent respectively. Owing to heat losses from ducts and inability to utilize the extracted energy from the exhaust air during the summerperiod, the mean value for a year has been calculated to 45 and 40 percent respectively.

The regained heat, compared to total electric energy for running the fans in the ventilation system, gives an approximate relation of 2 to 1. Regained heat compared to transformed energy related to drops of pressure in the heat exchanger is about 6 to 1.

6. DISCUSSION

The results show that the coordination of different technical systems must be observed. The efficiency of an energy recovery plant cannot be considered as a single factor connected to a specific unit, without looking at the entire system. This approach is necessary, especially as the complexibility of new techniques tends to increase.

The studies of the relation between regained heat from exhaust air and the electric energy to transport ventilation air through different parts of the system, show that the degree of efficiency can vary significantly. The way of designing the system is of vital importance for the efficiency.

Owing to the strong influence of the pressure drops on the power demand to transport ventilation air, the pressure drops should be minimized. This can for instance be achieved by choosing a larger dimension of recovery plant. The exceeding investments for a larger recovery unit must be related to the reduced costs of power and energy.

The design of systems where air flows are increased during short periods, must be considered. A common design is a damper that can be regulated. The drop of pressure across the damper during normal operation can be great and the losses of electric energy noticeable. These losses cannot normally contribute to the heating.

The only examined fan unit equipped with a frequency converter to control variable speed, has a noticeably low degree of efficiency. The operation of this motor has been disturbed, probably because of overload. The frequency converter makes it possible to exceed the rated load.

Beside the drops of pressure in the ventilation system the dimensioning of the fan motors has an essential effect on the use of energy for the transport of air.

The efficiency of the motors varies according to the load. Due to the size and type, the motors in the examination have an indicated efficiency of approximately 70 to 80 percent at rated power. The efficiency is almost stable at the upper range of the load. When the load decreases below 50 to 60 percent of the rated power, a drastic drop of efficiency is indicated.

The load of the ten fan motors in the test varies between 38 and 97 percent and the results of the examination indicate a strong relation between load and efficiency of the fan unit. The total efficiency of the ten units has been plotted as a function of load, and has a linear correlation of 0.91 (Figure 6.1).

To create the moving force in a non-synchronous electric motor a rotating electro-magnetic force has to be generated. This creates inductance with an angle of phase-difference between voltage and current. Inductance and current create reactive and apparent power. The Power Factor = PF, is defined as the quota of active and apparent power.

Electromagnetic force, bearings and cooling of the motor create almost non-variable losses, which in relation to the total losses increase at reduced load.

Beside the low efficiency of the motor caused by operating on low load, the reactive power creates losses from the eletricity supply network. Furthermore, the network cannot be used at its optimum because it has to be dimensioned for the apparent power.

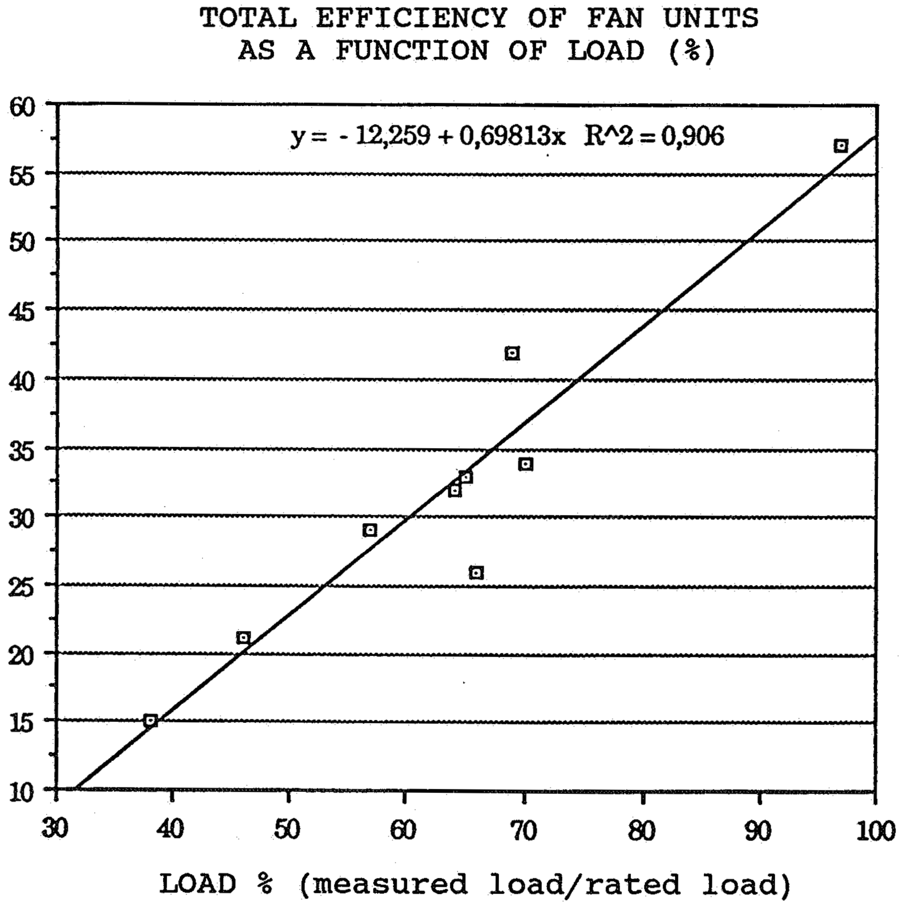

Figure 6.1. The figure illustrates the relation between the total efficiency of the fan units and the load. The influence of the load on the degree of efficiency indicates to be strong. The relation has a linear correlation of 0.91.

It is therefore of great importance that the motor is operating at the upper range of the load to achieve its rated efficiency. This demands accuracy in designing and operating the system.

The fan and the electric motor must be adjusted to the actual state of pressure in the system. To achieve an accurate adjustment the plant probably has to be in operation before final adjustment can be carried out.

The adjustment and the design of the fan units consequently have a great effect on the possibility to recover energy in an efficient way. The efficiency of the recovery plant must be compared to the energy related to its operation.

Besides electric energy for transporting air, the heat losses from the ducts transporting preheated air from the heat exchanger have to be calculated. The demands on insulation of ducts in the Swedish Building Code are not as strong as on the building envelope.

The total need of heating, influenced by climate, building technology and internal heat load, which strongly effect the possibility of utilizing the recovery plant on a yearly basis, must also be considered.

Owing to heat losses from ducts and inability to utilize the extracted energy from the exhaust air, the mean value for used energy from the heat exchanger has been considerably below the efficiency of the recovery unit. The values for two of the plants have been calculated to 45 and 40 percent respectively for a year compared to the efficiency of the heat exchanger unit which has been 58 and 52 percent respectively for the same period.

7. CONCLUSIONS

Adjustability and needs of increased air flows should not be designed with dampers. The losses of energy due to drops of pressure across the dampers during the main part of operating hours can be essential. If the dampers are installed in ducts for exhaust air, transformed energy from the drop of pressure cannot be used for heating.

Reducing the air flow with dampers during short periods of times creates operating conditions which are negative for the type of electric motors normally used in plants for ventilation. If the rated power of the electric motor exceeds the need for driving the fan, the influence on the use of energy for transport of air can be considerable.

Heat losses from ducts and inability to utilize the extracted energy from the exhaust air considerably decrease the efficiency of the plants. Therefore, the total need for heating effected by climate and internal heat in the building has to be considered when designing a recovery plant and making profitability analysis.

The examined systems were designed as recently as 1980, why similar or worse conditions can be expected in a large number of plants in operation.

With awareness of the importance of accuracy in designing systems and the co-ordination of techniques, there seems to be a considerable potential to improve the energy efficiency of plants for ventilation and heat recovery.

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