Potential economical benefits of balancing airflows in an office building

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ABSTRACT

Earlier studies have shown that airflows are not well balanced in office buildings. This may lead to too low ventilation rates in some rooms and too high ventilation rates in others. Several studies have shown that low ventilation rates may lead to a higher prevalence of SBS symptoms. The reduction of these symptoms may be achieved with improved ventilation.

The purpose of this study was to evaluate the benefits of balancing the airflows of the air distribution system of an office building in Helsinki. The ventilation rates were measured in all the office rooms in the building before and after balancing. The results showed that the large variation in ventilation rates per person was considerably reduced and ventilation rates per person were significantly higher after balancing. The benefits of adjusting and balancing the air distribution system may exceed the costs if the risk of SBS symptoms is reduced.

INDEX TERMS

Air distribution; Costs; Productivity; SBS; Ventilation system

INTRODUCTION

The ventilation system consists of a large number of dampers and terminal units which have been installed to ensure design quantities of airflow to the various spaces within a building. During the operation of the ventilation system, the airflows within the air distribution system gradually change. The positions of the dampers and terminal units may alter due to disturbance by the volume of air passing by over time or by adjustments to terminal devices made by the maintenance personnel in the building. Ventilation systems should be tested and balanced regularly to accommodate for such changes.

Only a few studies have investigated the distribution of airflows within the ventilation systems of large office buildings. Measurements of supply and exhaust airflow rates in every office room of a building are scarce. The studies that have assessed the magnitude and balance of mechanical ventilation in office buildings show that the average airflow rates vary widely from building to building and, more importantly, vary on a broad scale within a building. Sundell *et al.* (1994) reported that the standard deviation of the outdoor airflow within an office building is on average about 80% of the mean airflow rate. Teijonsalo *et al.* (1996) investigated 33 office buildings in the Helsinki area and found that the standard deviation of the airflows per person were more than 50% of the average value in 17 buildings.

Airflow rates have been associated with health outcomes. The increase of SBS symptoms is significantly pronounced when the airflow rate per person falls below 10 l/s (Seppänen *et al.*, 1999). Some studies indicate a dose–response relationship. Jaakkola and Miettinen (1995) found that occupants' symptoms decrease up to 25 l/s/person but when airflow rates exceed

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this value, the symptoms tend to increase again. Sundell *et al.* (1994) reported a steady decrease of symptoms, even at airflow rates above 40 l/s/person.

The objective of this study was to assess the airflow distribution of the ventilation system of a large governmental office building in the centre of Helsinki. The building owner had commissioned one-half of the building's ventilation system to undergo the process of balancing. The supply and exhaust airflow rates of the office rooms were measured before the balancing of the air distribution system, and after the process the airflow rates were measured again in the section of the building where the balancing had taken place. In Finland, the minimum design outdoor airflow rate for offices has been 10 l/s/person or 1.0 l/s/m^2 for many years. The new Finnish Classification of Indoor Climate 2000 recommends an outdoor airflow rate of 12 l/s/person in the highest indoor climate category S1 (FiSIAQ, 2001).

METHODS

The HVAC system of the office building under study consisted of mechanical supply and exhaust ventilation with air recirculation when outdoor temperature falls below 5°C. The building consisted of about 340 office rooms designed for one or two persons, meeting rooms, publications offices and other public spaces. Only the ventilation rates of the office rooms were assessed for this study. The supply airflows to the office rooms are distributed by two air handling units. The air distribution system of one of the air handling units was commissioned to be measured and balanced by adjusting the dampers and fan speed and by renewing the terminal units of the supply air system. The objective of the process was to meet the design airflow rates of each office room, which are presented according to the floor area of the office rooms in Table 1.

Table 1 Design airflow rates of office rooms

Floor area (m^2) of office room	Design airflow rate (l/s)
10.5–11.5	21
16.8–23.8	42
>30.0	50–97
10.5[a]	28

[a]Twelve rooms on the fourth and fifth floors.

Before the balancing process, the supply and exhaust airflow rates in each office room were measured through the supply and exhaust air outlets using an electronic hand held rotating vane anemometer. A rectangular hood was clipped onto the vane for supply airflow measurements and a circular hood for exhaust airflow measurements. After the balancing, the supply airflow rates were calculated from the pressure difference over the new supply air terminal units. The exhaust airflow rates were measured with the rotating vane anemometer as prior to balancing.

The inaccuracy of the airflow measurements for both methods is in the range of ±5%, which amounts to 2 l/s at an airflow rate of 40 l/s.

RESULTS

The cumulative exhaust airflow rates per person before the balancing of the air distribution system are presented in Figure 1. The average exhaust airflow was 20.7 l/s/person with a standard deviation of 11.0 l/s/person. The average supply airflow was 19.4 l/s/person with a standard deviation of 9.7 l/s/person. The cumulative curve of the supply airflow rates was very similar to the curve of the exhaust airflow rates.

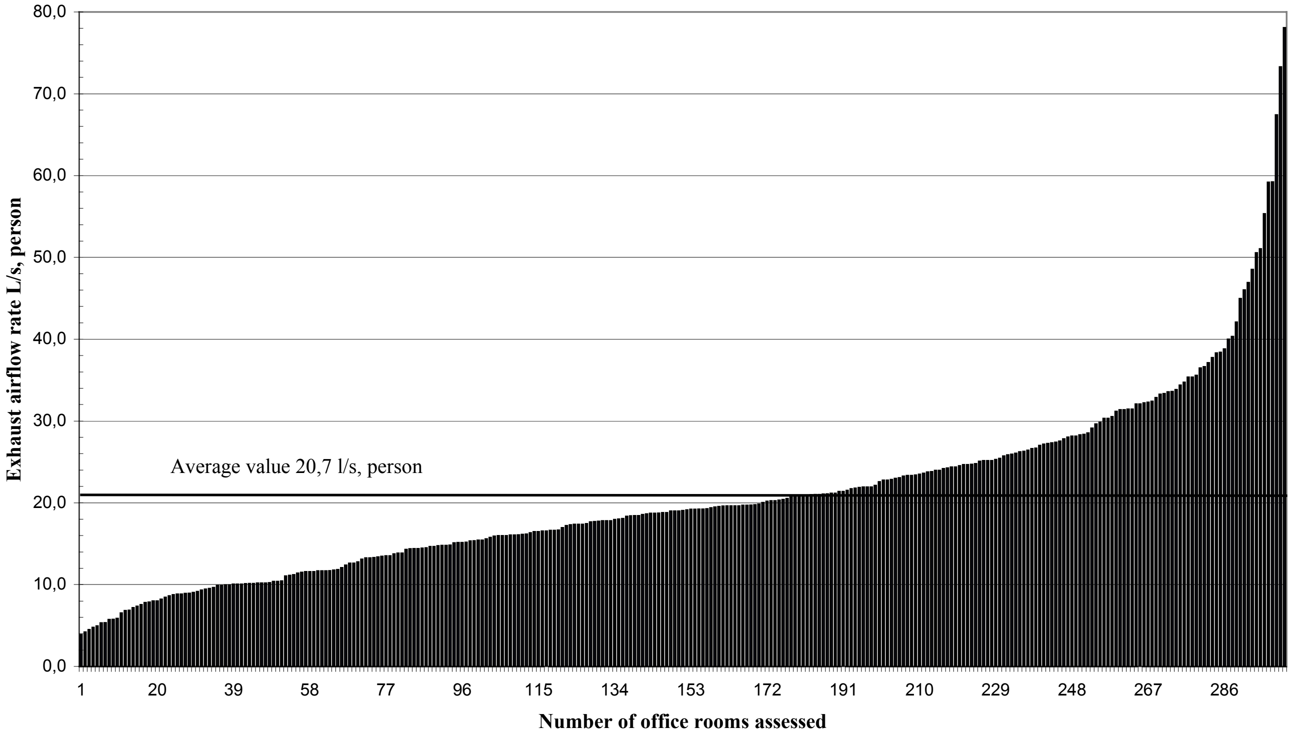

Figure 1 Cumulative exhaust airflow rates l/s/person by office rooms assessed in the whole of the building.

The cumulative supply airflow rates per person before and after the balancing of the air distribution system are compared in Figure 2. The airflow data before and after balancing have been treated independently and, therefore, the rooms in the two situations do not match. Because the air distribution system was balanced in only one-half of the office building, the number of office rooms in Figure 2 is considerably less than in Figure 1. The average supply airflow rates of the office rooms with improved ventilation were 22.0 l/s/person (SD 9.9) before balancing and 28.2 l/s/person (SD 12.5) after the balancing process. The average exhaust airflow rates of these rooms were 18.0 l/s/person (SD 10.8) before and 29.3 l/s/person (SD 13.6) after balancing.

Figure 2 shows that the airflow per occupant was much higher after balancing. Prior to the adjustments 15 office rooms had a supply airflow rate below 10 l/s/person. After balancing the smallest airflow rates were between 10 and 15 l/s/person in 13 office rooms. Fifty office rooms had a supply airflow rate close to 20 l/s/person and 42 rooms close to 40 l/s/person after balancing, out of a total of 172 office rooms.

To evaluate the improvements to the room airflow rates see Figure 3 showing the supply airflow in each assessed office room before balancing (columns) and after balancing (squares). All but one of the office rooms with an airflow rate above 68 l/s have two to six occupants.

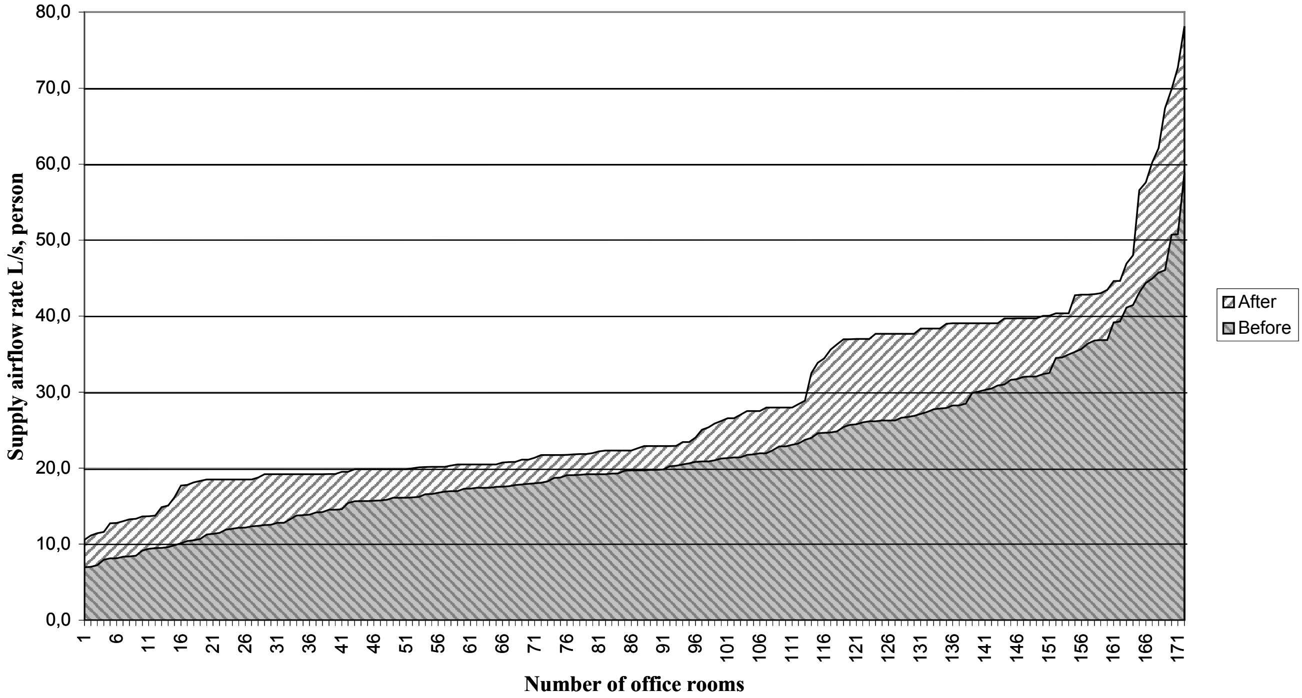

Figure 2 The cumulative supply airflow rates l/s/person by office rooms before and after the balancing of the air distribution system.

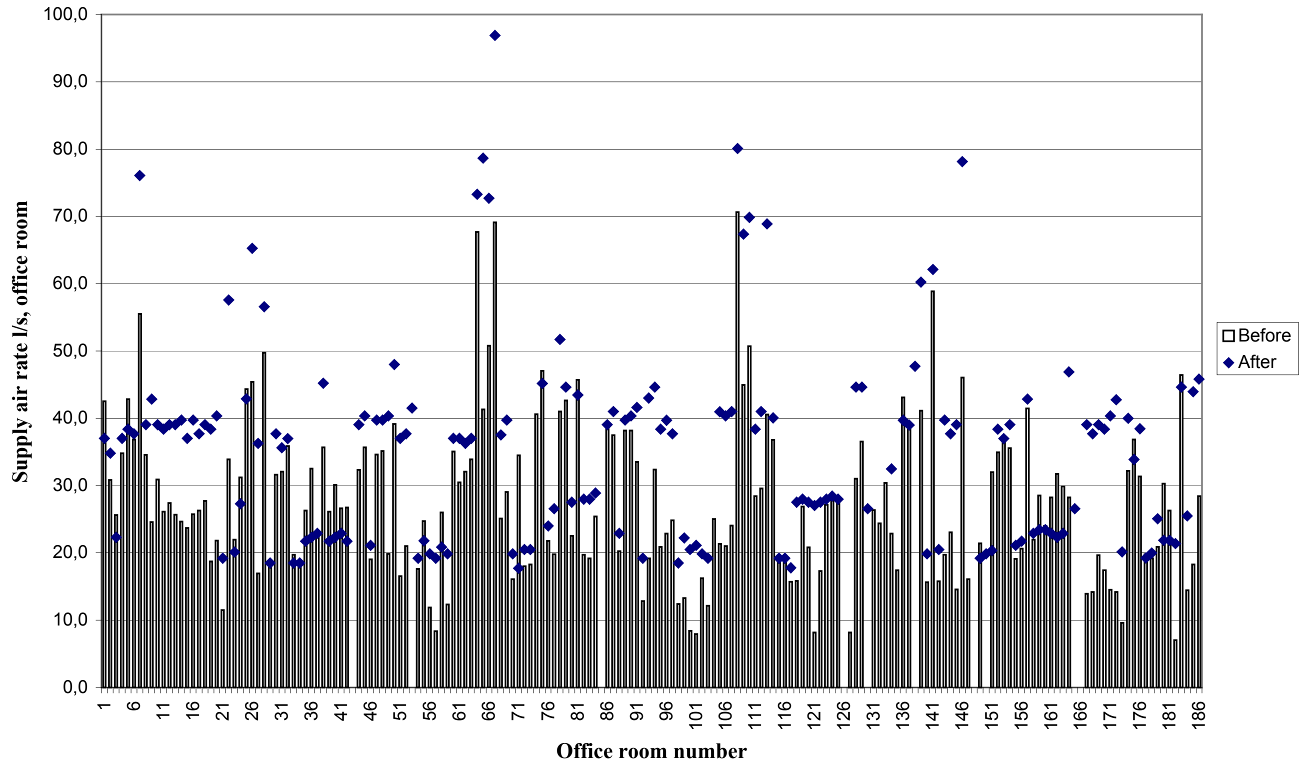

Figure 3 The supply airflow to each office room before and after the balancing of the air distribution system.

DISCUSSION

Almost 80% of the office rooms in the half of the building which underwent balancing were overpressurized relative to the corridors before the adjustments made to the air distribution system. In a cold climate, buildings should rather be underpressurized to reduce moisture problems (Seppänen *et al.*, 1999). After balancing, the supply and exhaust airflows of each office room were fairly equal.

It is possible to compare the cumulative supply airflow rates in Figure 2 with the design airflow rates in Table 1 because most of the office rooms had either one or two occupants. The design airflows were adequately achieved by adjusting the dampers of the air distribution system and increasing the fan speed (see also Figure 3). The rooms with a supply airflow around 20 l/s/person in Figure 2 are small rooms with one occupant or larger rooms (16.8–23.8 m^2) with two occupants. The small rooms on the fourth and fifth floors of the office building with higher design airflows (26.5–28.5 l/s) can be clearly seen in Figure 2. The considerable number of rooms with airflow rates around 40 l/s/person and over indicates that many of the office rooms were originally designed for more than one occupant. The airflow rates are less than 18.5 l/s/person in 19 office rooms. All these rooms have more than one occupant; the smaller sized two and the larger three or four occupants.

Sundell *et al.* (1994) and Jaakkola and Miettinen (1995) found that the risk to suffer weekly from work-related SBS symptoms when the ventilation rate of the office room is 20 l/s/person is approximately 1.5 compared to higher ventilation rates. Before the adjustments made to the air distribution system of the building under study, 57% of the employees worked in office rooms with a ventilation rate close to 20 l/s/person or under and had, therefore, a risk estimate of 1.5 or higher for weekly SBS symptoms due to the low ventilation rate. After the improvements made to the ventilation system, only 32% of the employees worked in office rooms with a ventilation rate close to 20 l/s/person or under. Thus, 25% of the employees in the balanced rooms had at least a 50% lower prevalence of SBS symptoms. The prevalence of SBS symptoms has in many studies been related to the performance of work. This in turn may lead to significant economic benefits. Fisk and Rosenfeld (1997) have estimated that the productivity decrease caused by SBS symptoms is approximately 2%. As 25% of the employees are assumed not to suffer from SBS symptoms in this building after ventilation improvements, the total productivity increase amounts to 0.5%.

Table 2 shows the total costs and benefits of improving the air distribution in the office building under study. The annual costs of investing in new supply and exhaust air terminal units and balancing the air distribution system has been calculated assuming an interest rate of 6% and an amortisation period of 10 years. The number of employees working in the balanced office rooms amounted to 241 persons. Because the improvements had a significant effect on the total airflow of the building, the energy consumption of the air distribution system is higher after balancing because more air has to be heated to the appropriate supply air temperature. The increase in the electricity consumption of the supply and exhaust fans must also be taken into account. Table 2 shows both the increase in heating energy costs and electricity costs per year due to the improvements.

To calculate the benefits of improved air distribution the labour costs per employee are multiplied by the assumed improvements in productivity. As the total labour costs per employee are 38160 €/a, and the estimated productivity increase 0.5%, the estimated benefits are 190.8 €/a per person annually. Thus, the ratio of the annual benefits (190.8 €/a per person) to the annual costs (44.6 €/a per person) is over 4.

Table 2 Annual costs and benefits of balancing the air distribution system

Balancing and changing terminal units	Balan-cing (€)	Supply air units (€)	Exhaust air units (€)	Sum (€)	Capital recovery factor	Total price (€/a)	Cost or benefit (€/a/ person)
	7365	42 206	7640	57 211	0.1359	7775.0	32.26
Supply air energy consumption	Before (MJ)	After (MJ)	Increase (MWh)	Heat rates summer (€/MWh)	Heat rates winter (€/MWh)		
	98 5175	1 241 627	71.24	17.08	33.1	1787.3	7.42
Electricity consumption of fans	Before (kW)	After (kW)	Increase (kW)	Operating time (h/a)	Electricity rate (€/kWh)		
Supply	7.40	9.33	1.93	2964	0.08	457.64	1.9
Exhaust	3.30	6.40	3.10	2964	0.08	735.07	3.05
Total costs of balancing and increased heat and electricity consumption						10755	*44.63*
Benefits of balancing the air distribution system (0.005 × 38160 €/a/person)							*190.80*

CONCLUSIONS AND IMPLICATIONS

The study supports the findings of Teijonsalo *et al.* (1996) that design airflow rates do not provide realistic values for estimating the ventilation rates of office rooms. Measurements of supply or exhaust airflow rates or both in every individual room must be performed. The air distribution system of office buildings should be tested and balanced always when the ductwork is cleaned to ensure that employees may work in rooms with adequate ventilation. The costs of improving the air distribution are less than the potential benefits to the employees assuming that decreasing the prevalence of SBS symptoms results in improved work performance.

ACKNOWLEDGEMENTS

This study is part of the Productive Office 2005 project funded by Tekes, the National Technology Agency of Finland and The Finnish Work Environment Fund.

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