As the results of this study are examined, one must take into consideration that only the mechanical exhaust air flows were measured. Because there are leaks through open doors and openings in fenestration, some actual exchange rates may be different, especially where the measured air flows were very low or no air outlet was in the room (in which case the exhaust air flow was recorded as zero). Also, the measured air flow does not take into account the ventilation effectiveness in the room, which may affect the indoor air quality.

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ENERGY CONSUMPTION AND COST AT HIGHER VENTILATION RATES IN AN OFFICE BUILDING IN MONTRÉAL

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ABSTRACT

This paper presents the impact of higher ventilation rates on the energy consumption and cost of a large office building in Montréal, which was evaluated by computer simulation. Four configurations of the VAV system were analyzed: (i) with heat recovery from the exhaust air and the condensers, (ii) with heat recovery only from the exhaust air, (iii) with heat recovery only from the condensers, and (iv) without heat recovery. The amount of outdoor air was either kept constant or was controlled by the mixing temperature. The ventilation rate was assumed to be increased from the actual value to that recommended by the ASHRAE Standard 62-1989 or even higher. On average, the energy consumption increases at a rate of about 2.3% and the cost by 2.7% for each increment of 2.5 L/s/person of the ventilation rate, when the system uses a fixed amount of outdoor air. When the outdoor air rate is controlled by the mixing temperature and the ventilation rate is smaller than 20 L/s/person, the increase of energy consumption and cost is negligible.

INTRODUCTION

ASHRAE Standard 62-1989 "Ventilation for Acceptable Indoor Air Quality" specifies two alternative procedures to design and operate a ventilation system for achieving acceptable indoor air quality: (i) Ventilation Rate Procedure, and (ii) Air Quality Procedure. The first procedure prescribes the minimum outdoor air ventilation rates to be delivered by HVAC systems in commercial and residential facilities. The minimum ventilation rate for office buildings was increased from 2.5 L/s/person, as required by the previous standard, to 10 L/s/person. However, soon after its publication, ASHRAE Standard 62-1989 was contested regarding the global approach as well as the recommended values for ventilation rates. For instance, some researchers recommended higher values for the ventilation rates in office buildings of 20 or even 50 L/s/person (1).

Although most building managers are very sensitive to factors such as market conditions, public image, quality of indoor air, and tenants satisfaction, they also look at the increase in energy cost. Moreover, they ask questions about the proofs of beneficial effects of higher ventilation rates on occupants health and productivity. Some answers to their questions regarding the energy cost can be retrieved in previous publications by Eto and Meyer (2), Eto (3), Pacific Northwest Laboratory (4), and Zmeureanu and Stylianou (5), which indicated based on computer simulation that the increase of ventilation rate from 2.5 L/s/person to 10 L/s/person is expected to increase the total energy cost by 1.8% up to 12.4%, depending on factors such as: size of building, type of HVAC system, and source of energy. The evaluation of physiological and psychological effects of higher ventilation rates on people is one important factor to be investigated. However, because of the limited information regarding this subject, this paper presents only the evaluation of the impact of higher ventilation rates on the energy consumption and cost of an existing office building in Montréal, as a contribution to this discussion.

COMPUTER SIMULATION

The office building, which was selected as a base case for this study, has 28 floors above ground and a total floor area of about 100,000 m^2. Some features with an important effect on the energy performance are the following:

- a fixed amount of outdoor air, of about 7.6 L/s/person, is brought into the building between 3:00 a.m. and 8:00 p.m.; at the time of construction, the outdoor air rate was higher than the recommended values of both ASHRAE Standards and by-laws of the City of Montréal,
- two Variable Air Volume (VAV) systems are used on each floor, with a total supply air flow rate of 11.4 L/s/m^2; during the heating season (October to May), the system for the perimeter zones only recirculates the return air, which is heated up to 37.8°C, before to be introduced underneath the windows; in summer, there is a mixing between the return air and a fixed amount of outdoor air, and the supply temperature is kept at 15.8°C; the second system supplies to the interior zone a mixed air (return and outdoor air) at 15.8°C in summer and winter,
- indoor set-point temperature is 22.5°C for the cooling and heating operation, between 5:00 a.m. and 8:00 p.m; the night set-back temperature is 16.0°C,
- heat eliminated by the condensers of two double-bundle chillers, with a total capacity of 6000 kW, is recovered between 6:00 a.m and 7:00 p.m during the heating system, and then used for reheating and humidification,
- during the cooling season, two centrifugal chillers with a total capacity of 8000 kW are used; the heat from condensers is evacuated through the cooling towers,
- heat recovered from the exhaust air is used to preheat the outside air.

The evaluation of energy consumption and cost of the office building was performed by computer simulation using the MICRO-DOE2 program (6), which is a PC-version of the DOE-2.1D program developed at the Lawrence Berkeley Laboratory (7). Since 1978, the DOE-2 program has been extensively validated by using analytical solutions, comparisons with other programs or metered data. Some examples of validation work are presented in references 8 and 9. To reduce the computing time, the model of office building was composed of four typical floors. Several thermal zones were defined on each floor: four perimeter zones, one interior zone and one ceiling plenum. A one-year simulation of the energy performance of this building takes about 400 s on a 486/50 MHz micro-processor. The calibration of the computer model, which was performed by comparing the predictions with the measured energy consumption and cost of the existing building, as obtained from the monthly utility bills, shows a good agreement. The annual energy consumption and cost for electricity and gas were predicted within 8% of the measured values. The pattern of monthly performance is adequately simulated. On the average, the monthly predictions are within 10% difference.

In order to evaluate the impact of heat recovery systems on the increase of energy consumption, four configurations were simulated: (i) with heat recovery from the exhaust air and the condensers, (ii) with heat recovery only from the exhaust air, (iii) with heat recovery only from the condensers, and (iv) without heat recovery. The amount of outdoor air was either kept constant or was controlled in terms of mixing temperature. For each configuration and control type, the ventilation rate was assumed to be increased from the actual situation (7.6 L/s/person) to 10, 20, 30 and 40 L/s/person.

RESULTS

In the case of this particular building, when the amount of outdoor air is controlled by the mixing temperature, the total energy consumption is expected to be greater than in the case of a system with a fixed amount (Figure 1).

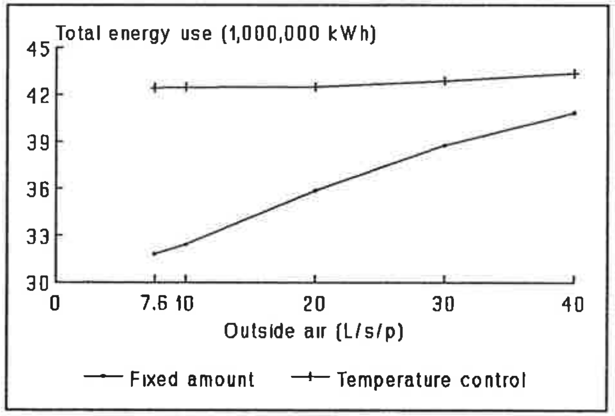

Figure 1. Increase of energy consumption at higher ventilation rates.

However, for an existing building it is more important to evaluate the increase of total energy consumption and cost with respect to the present situation. The energy use increases by 1.7-1.9% (Figure 2) and the cost by 2.2-2.4% (Figure 3), when the ventilation rate increases from the present situation of 7.6 L/s/person to 10 L/s/person, in a system with a fixed amount

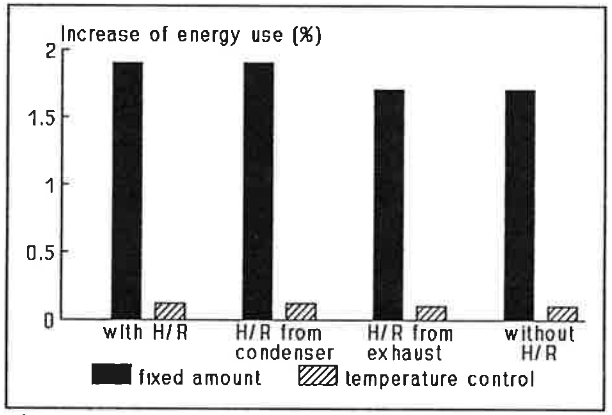

Figure 2. Increase of energy use due to the increase of ventilation rate from 7.6 L/s/person to 10.0 L/s/person.

of outdoor air, for all four configurations. When the ventilation rate is controlled by the mixing temperature, the increase of ventilation rate has a negligible impact on the energy consumption and cost. Therefore, a VAV system with a fixed amount of outdoor air is more sensitive to the increase of ventilation rate that a system controlled by the mixing temperature. The use of heat recovered from the exhaust air to preheat the outside air, and therefore to reduce the electricity used by the preheating coil, has a noticeable impact on the increase of energy use and cost, only when the ventilation rate is higher than 20 L/s/person. For instance, in a system with a fixed amount of outdoor air, the largest increase of energy use (Figure 4)

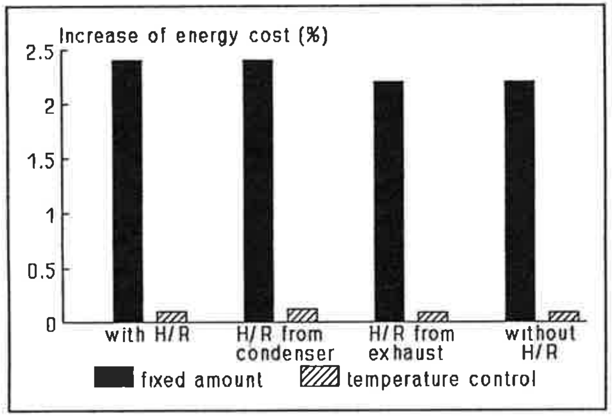

Figure 3. Increase of energy cost due to the increase of ventilation rate from 7.6 L/s/person to 10.0 L/s/person.

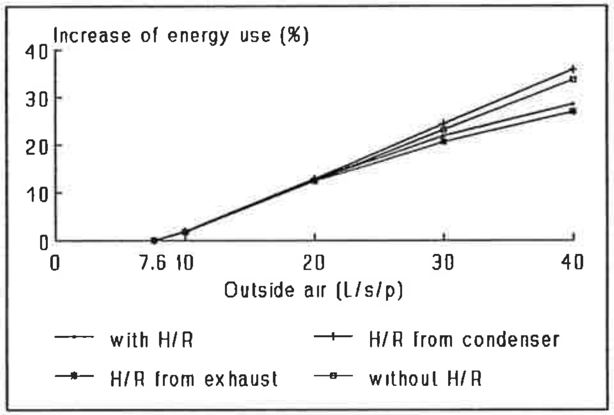

Figure 4. Increase of energy use in the case of a VAV system with a fixed amount of outdoor air.

and cost is obtained by using configurations without heat recovery from the exhaust air (iii and iv). The smallest increase is obtained by a system with heat recovery from the exhaust air, as well as by a system with heat recovery from the exhaust air and the condensers. In the case of a system controlled by the mixing temperature, there is an important increase of the energy consumption (Figure 5) and cost at ventilation rates greater than 20 L/s/person, when the heat recovery from the exhaust air is not used. On average, the energy consumption increases at a rate of about 2.3% and the cost by 2.7% for each increment of 2.5 L/s/person of the ventilation rate between 7.6 L/s/person and 40.0 L/s/person, when the system uses a fixed amount of outdoor air. When the outdoor air rate is controlled by the mixing temperature and the ventilation rate is smaller than 20 L/s/person, the increase of energy consumption and cost is negligible.

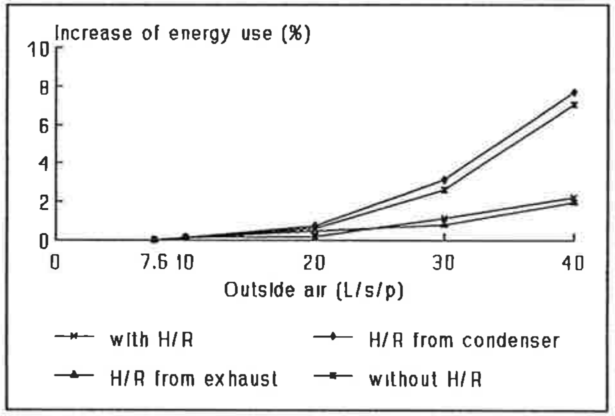

Figure 5. Increase of energy use in the case of a VAV system where the outdoor air controlled by the mixing temperature.

CONCLUSIONS

In the case of a system with a fixed amount of outdoor air, the increase of ventilation rate from 7.6 L/s/person to 10.0 L/s/person is expected to lead to an increase of energy consumption up to 1.9% and energy cost up to 2.4%. Since previous evaluations have considered the increase of ventilation rate from 2.5 L/s/person to 10.0 L/s/person, our results are extrapolated for that condition, and the results show an increase of energy use up to 5.9% and of energy cost up to 7.5%. This increase of the energy cost is higher than those obtained for Montréal by Eto and Meyer (1.8%) and Zmeureanu and Stylianou (3.2%). If the existing building operates with a fixed amount of outdoor air (7.6 L/s/person) and without heat recovery systems, then the increase of energy consumption is expected to be about 1.7% for an increase of the ventilation rate up to 10 L/s/person. However, if in addition a heat recovery system from the condensers is installed, then the energy consumption will be reduced by 7.2%.

In the case of an existing building, the increase of the ventilation rate might also require the replacement of fans and air ducts, if they are already at the maximum capacity, which involves additional costs for both equipment and labour. In the case of a new design, the additional cost for fans and air ducts corresponds only to the increment with respect to the present practice.

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COMPARISON OF VARIOUS AIR INLETS : AIR DIFFUSION AND COMFORT

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ABSTRACT

Fresh air intake in exhaust ventilation systems requires air inlets located in the building facade. This device is often blamed for draught problems. In this research, we tested several air inlets at various pressure and temperature differences. In order to identify the flow pattern and thermal diffusion, smoke flow visualizations using laser sheet and local temperature measurements were performed. It was shown that pressure and temperature differences had no sensitive influence in the occupied zone under French climatic conditions. Differences were only noted above the diffuser in the jet stream. With regard to these results, we analyze the standards under discussion and make some recommendations.

INTRODUCTION

Today, exhaust mechanical ventilation systems represent an increasing market share in moderate climates. National standards have focussed on the performance of exhaust components which are the driven forces. However, the overall system requires air intake components commonly called air inlets. Fresh air is supplied to bedrooms and living rooms; polluted air is exhausted from kitchens, bathrooms and toilets. Air inlet devices are often blamed for draught problems. In order to overcome this potential issue, some are closeable and limit draught risk in case of overpressure on the facade. Unfortunately, this answer can no longer assure a continuous minimum air change with a good distribution because the air inlets could stay closed over a long period if the occupants do not understand their essential role. Unfortunately, occupants are rarely aware of the function of each ventilation element.

Another way to limit the draught risk is to require self regulated air inlets. France has adopted this technical solution which offers a constant flowrate with a pressure difference between 20 and 100 Pa.

The aim of this research was to study air flow patterns and diffusion within the room at various pressure and temperature differences and to identify any discomfort problems generated by various self regulated air inlets in real conditions [1].

EXPERIMENTAL PROCEDURE

Methodology

The airflow patterns induced by various air inlets were investigated using two experimental techniques :