Potential benefits of reduced summer time room temperatures in an office building

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ABSTRACT
The purpose of this study was to evaluate the potential economical benefits of reduced summer time temperatures in an office building. We selected for the study, a typical office building in downtown Helsinki. We measured the room temperatures during a summer representatively in the office rooms. In many rooms the maximum temperatures were well above 30°C in summer 2002. We used these measured data and calculated the potential savings due to improved thermal environment. A method for calculating the potential savings was introduced in paper by Seppänen *et al.* (2003). This study proposed a 2.0% decrement of productivity per °C when the room temperature is above 25°C. We carried out the analysis using different reduced maximum temperatures. We report the potential savings due to a better thermal environment depending on the maximum temperature, and evaluate the cost effectiveness of night-time ventilative cooling to reduce high summer time temperatures.

INDEX TERMS
Calculation; Cooling; Ventilation; Productivity; Office work

INTRODUCTION
Mechanical cooling systems are not used in older office buildings in Finland. Thus, indoor temperatures rise high during summer months due to high internal and external loads. According to several studies presented in other paper (Seppänen *et al.*, 2003) high indoor temperature decreases performance and thus reduces productivity of office work. The average reduction of productivity is 2% per degree ºC when the indoor temperature is above 25ºC. We used a federal office building built in 1974 as an example of use of night-time ventilative cooling.

METHODS
The federal office building is a typical Finnish seven-floor office building built in the 1970s. It has a concrete structure the total floor area being 6500 m^2 (69 970 sq. feet). The building has double-glazing and a mechanical ventilation system. The supply air is distributed to the corridors and is exhausted from the office rooms. We chose four typical office rooms all located on the fourth floor and on different faces of the building. We studied the indoor temperature in all four rooms with simulation software and compared the results with values measured in the office rooms during summer 2002.

The selected rooms are located on the fourth floor. The first is facing north-west (15.4 m^2, 166 sq. feet), second south-east (15.8 m^2, 170 sq. feet), third north-east (14.5 m^2, 156 sq. feet) and fourth south-west (15.0 m^2, 162 sq. feet). Due to their location they present different conditions within the building. The indoor temperature was measured in those rooms during 12 June and 16 August 2002. The employees either have a private office room or share a room with a colleague, 72 office workers occupy the selected floor. The floor area is 900 m^2 (9690 sq. feet). The layout of the building is presented in **Figure 1**.

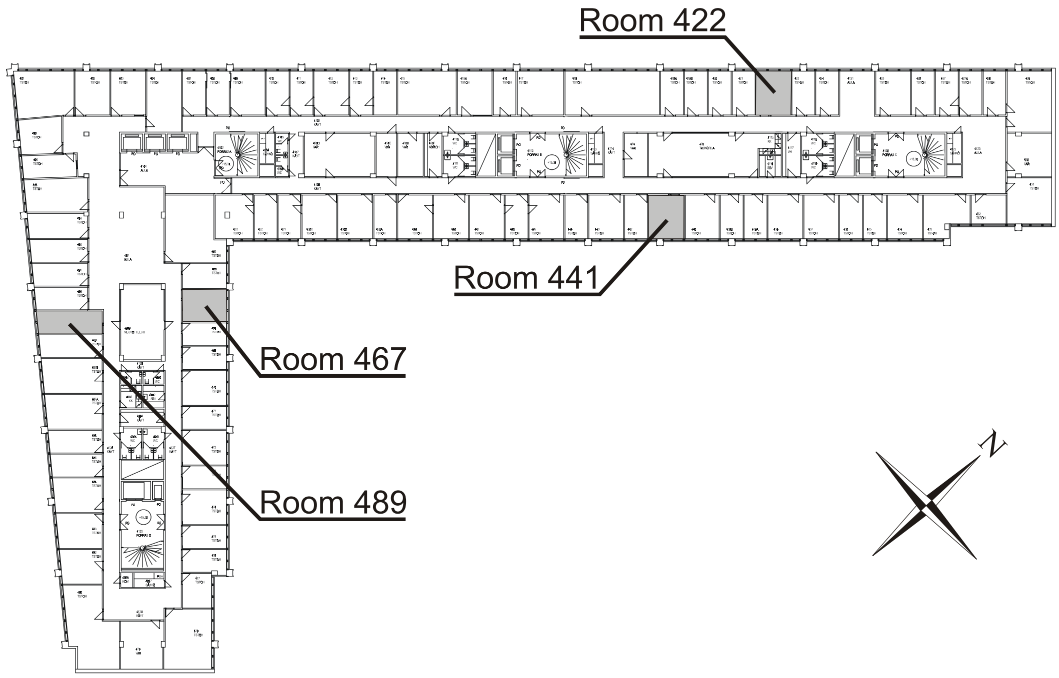

Figure 1 Location of the rooms in the fourth floor of the federal office building.

The operation hours of the ventilation system are from 7 a.m. to 5 p.m. on weekdays. The exhaust air rate was measured in all studied rooms and varies from 1.7 to 4.3 l/s/m^2. The average exhaust air rate measured on two floors and 125 rooms is 2.13 l/s/m^2. The average value is used in calculations but not in the simulation of the rooms where the corresponding exhaust air rate values were used. The values are presented in **Table 1**, which also presents the number of employees in the same zone as the selected room.

Table 1 Gross area and air exchange rate of the office rooms studied

	Room 422	Room 441	Room 467	Room 489
Gross area, m^2	15.4	15.8	14.5	15.0
Air exchange rate, l/s/m^2	1.9	1.7	4.3	1.8
# of employees in the zone	23	22	12	15
Floor area of the zone, m^2	290	230	120	260

The purpose for the simulations was to calculate hourly averages of indoor temperatures in all selected rooms. From the results we calculated hourly temperature differences when temperature rose above 25ºC. By summing those values we got degree hours for the selected rooms. The degree hour values represent decrement in performance, and can be used for calculating the value for lost productivity due high indoor temperature. We calculated the potential benefits of night-time ventilative cooling by comparing the degree hour values of different cases. Hence, the calculations are based on degree hour values derived from the simulation results and the following assumptions:

1. One room represents all rooms on the same face of the building on that same floor. Therefore we divided the floor into four zones.
2. We use average exhaust air rate for all rooms (2.13 l/s/m^2).

3. Average value of an hour of work is 30 €, total energy consumption of return, exhaust and supply fans is 2.5 kW/m^3/s of airflow (based on Finnish building code D2), and the price of electricity is 0.08 €/kWh.
4. There is 2% decrement in work performance per ºC when the temperature is above 25°C.
5. The benefits are calculated for a 35-day period, which contains 24 working days.
6. July has been omitted from the calculations, as it is the most common time for summer vacation in Finland.

Simulation Data

A simulation program IDA Indoor Climate and Energy was used for simulating indoor temperatures using the measured weather data of the year 2002. The summer time outdoor temperature in Helsinki is presented in **Figure 2**. The simulation period started from 12 June and ended 16 August. At first, the present situation was simulated using the initial data such as exhaust air rate, building structure materials and windows, number of personnel in a room and known internal heat loads such as lighting and personal computer. Unknown input factors such as use of shades and curtains, presence of the employee during office hours and opening hours of windows were estimated based on our engineering knowledge, and trial and error procedure. After several attempts in choosing input values the model was found to be accurate enough and the simulation results corresponded reasonable well the measured data. A comparison of simulated and measured indoor temperatures during office hours is presented in **Figure 3**.

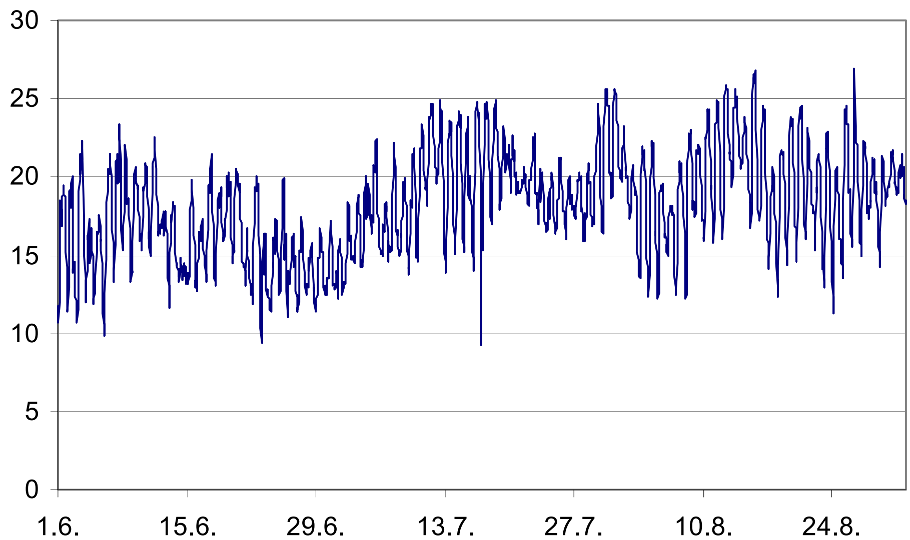

Figure 2 Outdoor temperature in downtown Helsinki measured between 1 June and 30 August 2002.

After simulating the known basic situation night-time ventilation was simulated. The new operation times for the air-handling units were 24 h per day for 7 days a week. However, the results presented in Figure 4 and Tables 2 and 3 contain only values of office hours on weekdays (8 a.m. to 4 p.m., Mon–Fri) because indoor temperature during night-time and weekends is irrelevant to this study. The comparison of indoor temperature in one room with and without night-time ventilative cooling is presented in **Figure 4**. As we can see the indoor temperature does not drop down to uncomfortably cold values during office hours. The average temperature difference of the two cases is 1.4ºC.

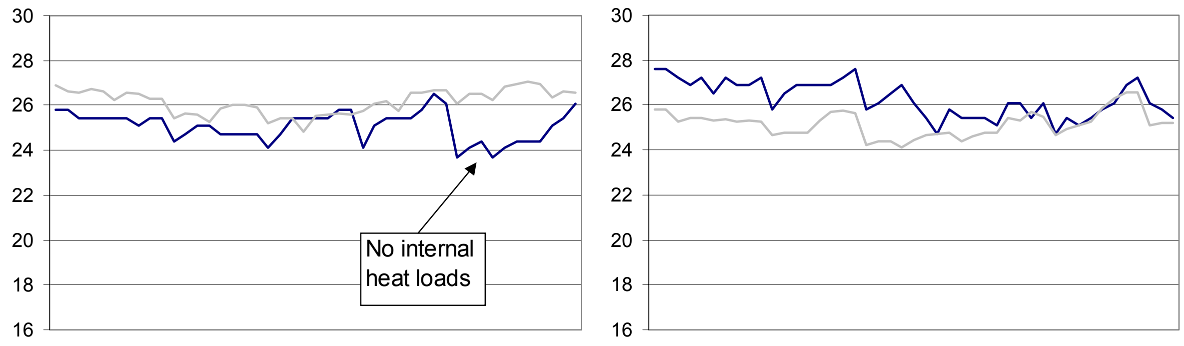

Figure 3 Measured and simulated indoor temperatures during 5–9 Aug 2002 in office rooms 422 on the left and 489 on the right. The measured values are presented in black and simulated values are presented in grey. Only values during 8 a.m. and 4 p.m. are presented in the graph.

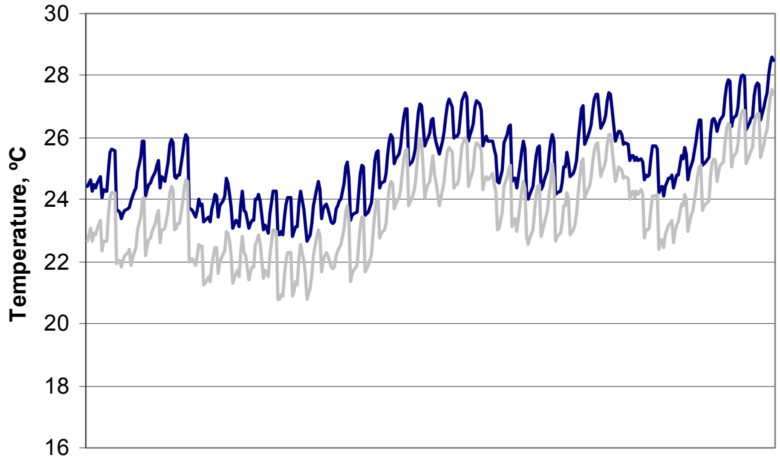

Figure 4 Simulated indoor temperatures with and without night-time ventilative cooling in room 489. The temperature in normal conditions is presented in black and the temperature during night-time ventilative cooling is presented in grey. Only values during 12 June and 16 August 2002, 8 a.m. and 4 p.m. on weekdays are included in the graph.

RESULTS

The simulation results were analysed and hourly averages were calculated. The degree hour values (°C h) for all rooms were calculated from those office hours when indoor temperature exceeded 25°C. The resulting degree hour values from both simulation cases and measured values are presented in **Table 2**. As we can see from **Table 2**, the average values for measured data and simulated data correspond even though values for individual rooms differ. This implies that the model simulates the behaviour of the office building in high indoor temperatures reasonably well on average. To illustrate the effectiveness of night-time ventilative cooling the duration curve of temperature for all three cases are presented in **Figure 5**.

The results presented in **Table 3** show that the benefits range from 1 to 4 € per person per day, which is close to 200 €/day for the whole floor. We also calculated the benefits of night-time ventilative cooling compared to the measured data. The benefits were of same order of magnitude as presented in **Table 4.**

Table 2 Degree hours when the indoor temperature is above 25°C in June and August. Only values during 8 a.m. and 4 p.m. on weekdays are included

	Room 422	Room 441	Room 467	Room 489	Average
Simulated, without night-time ventilation, °C h	256	220	88	111	167
Measured, °C h	66	135	183	235	155
Simulated night-time ventilation, °C h	96	98	43	36	67

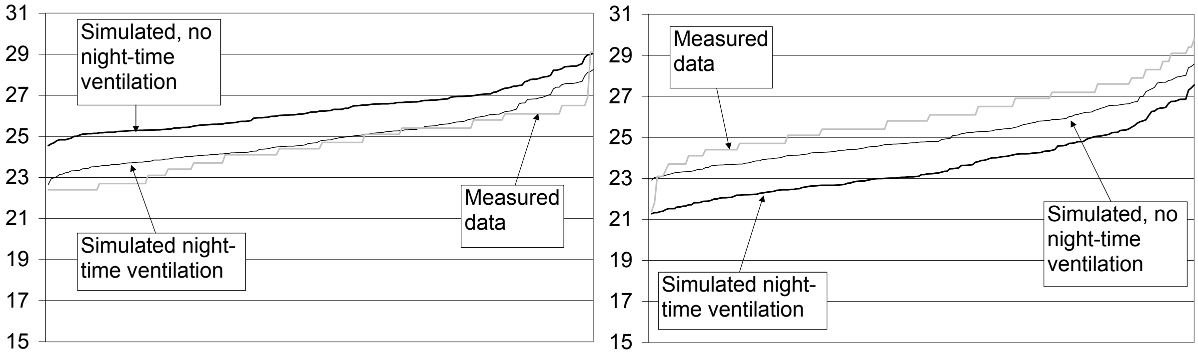

Figure 5 Duration curves of indoor temperature in office rooms 422 on the left and 489 on the right. The night-time ventilative cooling values are presented in grey, measured and simulated values are presented in black. Only values during 8 a.m. and 4 p.m. are presented in the graphs.

Table 3 Costs and benefits per employee per day and study period of 35 days when simulated basic data is compared to simulated night-time ventilative cooling

	Room 422 / Zone 1	Room 441 / Zone 2	Room 467 / Zone 3	Room 489 / Zone 4	Average
Costs / employee					
Cost of used electricity, €/day	0.11	0.09	0.05	0.10	0.09
Cost of used electricity 35-day period, €	2.63	2.09	1.09	2.36	2.04
Benefits / employee					
Increase in productivity, €/day	4.01	3.15	1.12	1.86	2.54
Increase in productivity, 35-day period, €	96.31	75.68	26.93	44.73	60.91
Net benefits / employee					
Benefits, €/day	3.90	3.06	1.07	1.76	2.45
Benefits, 35-day period, €	93.68	73.59	25.84	42.37	58.87
Total net benefits per zone					Sum
Benefits, 35-day period, €	2154.67	1619.14	310.03	635.57	4719.41

Table 4 Benefits per employee per study period of 35 days when measured data is compared to simulated night-time ventilative cooling. Costs are the same as in Table 3

	Zone 1	Zone 2	Zone 3	Zone 4	Average
Net benefits / employee, €	–2.63	22.63	82.93	117.23	55.04
					Sum
Total net benefits per zone, €	–60.53	497.92	995.20	1758.44	3191.03

DISCUSSION

In this study, we combined measured and simulated temperature data, and estimated the costs and potential benefits of night-time ventilative cooling using a generic relationship between high room temperatures and decrements in performance. This method makes several assumptions, and leaves uncertainty in the results. However, we feel that results show, even with a large error margin, the benefits of the control of high room temperatures in office work.

The simulation of the indoor temperature is dependent on the initial data. Accurate simulation requires precise data about internal loads and operation times, exact schedule when the person or persons are present in the room and even some information about the persons themselves as different sized people produce different amount of energy. However, we believe we have succeeded in estimating the input values and the simulation was as accurate as possible with the available information. The simulation gives satisfactory results if we compare the simulated average values to the measured average values, see Table 2. We assumed that one room represents all rooms on the same face of the building on that same floor which may cause some error in the calculations.

The results show that night-time ventilative cooling is very cost effective. The ratio of benefits to cost is 30 with simulated data and 28 with measured data. Night-time ventilative cooling should be quite easy to arrange in typical office buildings. One more positive effect from night-time ventilative cooling is better indoor air in the office building due to higher average ventilation rates.

CONCLUSIONS

According to calculations based on measured and simulated data, night-time ventilative cooling is profitable for the tenant. By reducing the high indoor temperature during summer time some loss of productivity can be avoided. The use of air handling units increases use of electricity and thus causes some costs. However, the increased costs are much smaller than the value of lost productivity if night-time ventilative cooling is not used.

ACNOWLEDGEMENTS

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