COST EFFECTIVENESS OF SOME REMEDIAL MEASURES TO CONTROL SUMMER TIME TEMPERATURES IN AN OFFICE BUILDING

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ABSTRACT

This paper presents a summary of calculations on the total cost effects of the remedial measures to reduce high summer time room temperatures in a hypothetical building. In the base case the room air temperature is too high during the summer, and causes a considerable reduction in the productivity. The following economical items are included in the study: first cost of the remedial measure, the effect of the measure in operating cost, particularly on energy consumption, and the effect on productivity. The first cost of remedial measures was estimated based on a large Finnish database on the construction cost for refurbishment. The effect on energy consumption has been calculated with a new simulation program IDA Indoor Climate and Energy. The effect of temperature on productivity has been estimated to be 2% per °C above 25 °C. The measures included in the study were: longer operation hours of ventilation, higher supply air flow rate and mechanical cooling. The results show that in all cases the annual savings due to increased productivity were higher than the sum of operating cost and the annualized the first cost.

KEYWORDS: ventilation, air conditioning, productivity, solar radiation, operational costs, temperature

INTRODUCTION

High indoor air temperature is often a problem in office buildings. All buildings are not air conditioned or protected with other means against high temperatures either due to the solar radiation or high outdoor temperatures. It is well known that the problem is not limited to warm climate but is also a problem in cold climate during summer and spring periods. The solar radiation brings into a room a high heat load also in northern latitudes due to low altitude of the sun. It has been recognized for a long time that temperature has an influence on typical tasks performed in office environments. An excellent summary of these studies is given in a recent book [1]. Several investigations in office buildings have also shown that the thermal environment is not optimal, particularly in the summer time. For the building owner and employers it is important that the indoor climate in buildings meets the requirements of the occupants, and gives optimal conditions for productive work.

Building occupants and building owners do not always realize how important the thermal conditions are for productive work. The control of the high summertime temperatures are also often considered to be expensive and energy consuming.

New buildings are often in better designed and controlled in respect of the thermal environment, and the high room temperatures are experienced particularly in old buildings. The focus of this paper is on cost effectiveness of remedial measures for existing buildings to reduce high summer time indoor temperatures. The cost items, which are included in the analyses, are: capital cost of the remedial measure, cost of the used energy (heat and electricity), and the cost of deteriorated productivity due to high temperatures.

METHODS

A typical Finnish office building was selected for the analyses. It is a concrete structure with narrow bays and private offices located in the exterior zone of building (no open plan offices). The data describing the building has been used in several earlier analyses, and described in detail by Lassila [2]. A small office was selected in the detailed analysis. The main features of the room are described in the Table 1.

Table 1. Main features of the office room used in the analysis.

Floor area	9.7 m²	Construction	Heavy
Room volume	18.2 m³	Windows	3 panes, clear glass
Outdoor wall area (excl. windows)	5.3 m²	Glass area of the windows	2.5 m²
Lighting load	15 W/m²	Lights on	8 am to 4 pm
Heat load from office equipment	100 W	Load on	8 am to 4 pm

The basic case used as a reference had already solar protection of windows, and heavy construction to decrease the daily high temperatures with the thermal capacity. Thus the other means to reduce high temperatures are limited to those related to ventilation. The options to reduce high room are: increase the outdoor air low rate, increase the operation time of ventilation and mechanical cooling. The base case A, and the cases (B-F) describing in detail the remedial measures are summarized in the Table 2

Table 2. The description of base case A and remedial measures used in calculations

Case	Description
A(base)	Solar protection with the light venetian blinds between the window panes.
B	Mechanical cooling with cooling capacity of 20 W/m^2 of floor area in the air handling unit
C	Increased operation time of the ventilation and air conditioning system from 10 to 24 h/d
D	Increased flow rate of supply air from 2 to 4 L/sm^2 , and increased operation time from 10 to 24 h/d
E	Increased operation time from 10 to 24 h/d and mechanical cooling of 20 W/m^2 of floor area in the air handling unit
F	Increased flow rate of supply air from 2 to 4 L/sm^2, increased operation time from 10 to 24 h/d, and mechanical cooling of 20 W/m^2

The investment costs of the remedial measures are given in the Table 3. The investment costs are based on a large Finnish database on refurbishment costs [3]. The first costs have been calculated assuming 50 similar rooms to be repaired under the same contract. The total cost has been divided by 50 to get the cost per room. The first cost has been converted to annual cost using the annuity factor of 0.1 which corresponds the life cycle of 15 years and interest rate of 7%.

Table 3. First cost of some remedial measure to control high room temperatures

Remedial measure	Description	Total cost, €	Cost per room, €
Increase of ventilation 2 L/s per m^2	Air handling unit and ducts, 1 m^3/s	16 333	327
Mechanical cooling	Compressor, condenser, cooling coil and controls, 1 m^3/s air flow, 12 kW	3 666	73

The effect of the remedial measures on room temperature, productivity and energy consumption was calculated with a new modular computer program IDA Indoor Climate and Energy described also in the conference proceedings of Healthy Buildings 2000 conference [4]. The energy consumption was calculated using Helsinki weather data for reference year [5], which is summarized in the Table 4.

Table 4. Some data describing Helsinki reference year weather.

Annual average temperature	4.2°C
Maximum outdoor temperature	28.5°C
Minimum outdoor temperature	-30.0°C
Heating degree days	5693°Cd
Total annual solar radiation on horizontal surface	936 kWh/m^2

The energy costs used in the calculations reflect the average energy cost in Finland, for heating 0.03 € /kWh was used and 0.1 € /kWh for electricity. The calculated electrical energy in the Table 5 includes all electricity used per room: lighting, office equipment, fans, and mechanical cooling (COP=3). Heating energy includes only the energy used for heating of the outdoor air. Heat recovery from ventilation air with temperature efficiency of 50% is used in calculations.

The estimated loss of productivity is based on the data developed by [6]. He has calculated the mean performance of four typical tests used to evaluate the performance in the office work (mental tasks, performance of routine office work, performance of skilled manual work and speed of individual finger movements). The average performance decreases about 10% when the temperature is 5°C above the neutral temperature. In this analysis the losses in productivity were estimated from the calculated operative temperature. A loss was assumed to be 2% per each degree of Celsius above 25°C up to 30°C, and 10% with the temperatures at or above 30°C. The value of annual production of each employee was assumed to € 50 000. The operative temperature of assumed working location in the room was calculated for each timestep and the loss of productivity summarized over the whole year.

In the total cost calculations the case A in the Table 5 was been taken as a reference case and the other cases compared with it. Three cost items ware included: investment cost, operation cost (mainly energy), and the changes in productivity. Investment cost is the total investment of the remedial measure per room. In the final analysis the changes in productivity is calculated using as the reference the base case A. In all other cases the losses in productivity are smaller then in the base case, and the difference is a positive gain. The cost of this gain is investment and penalty in the increased use of energy. The increase in energy consumption has been calculated using the case A as a reference.

RESULTS

The results of the calculations are shown in Table 5. The total consumption of electricity and heat are presented for all 50 rooms. The costs of heat and electricity are in all cases of same order of magnitude. The cost of heat increases considerably with the increase of outdoor air flow rate and operation time which can be expected. It is interesting to notice that the increase in electricity consumption is higher if the outdoor air flow rate is doubled (case D vs. C) than if the mechanical cooling is used with lower flow rate (case E vs. C).

The maximum room temperature in the base case is 32.7°C, and corresponding degree hours above 25 °C are 330°Ch. The maximum temperature can be lowered to 29.8°C and degree hours to 164°Ch by increasing the operation time and air flow rate of ventilation, but to 27.1°C and 17°Ch with mechanical cooling. The investment cost and energy costs are considerably higher in the case of increased ventilation than with mechanical cooling.

In respect of over all economy the both alternatives with mechanical cooling are best e.g. give the highest annual savings.

The share of the first cost is small compared to other costs in all cases. The annual cost of the energy and savings in increased productivity are in order of same magnitude.

DISCUSSION

The results show clearly how important it is to control the room temperature in summertime in office buildings for good over all economy. Of course, the investment cost depends on the specific case, and may vary depending on the difficulties in actual installation considerably. This is specifically true if the increase of ventilation requires also new ductwork. The mechanical cooling is usually easier to install in the existing system. In this case also the existing air handling unit may set some restrictions as well. However, even the doubling of the first cost will not change the annual savings negative. The interest rate of 7% may be high at the moment but has only a minor effect on the annual, cost of the investment. The expected life cycle of the air handling system and air conditioning is 15 years. This can be considered typical and is taken from a reliable source [7].

The weakest part in the calculation is the effect of temperature on productivity. The data taken form scientific literature shows clearly the magnitude of the relation in typical task. More difficult is to judge, what is the effect of these tasks on the over all productivity in office work. However, everybody agrees that, for example, the time spend away from the actual working location increases during high temperature periods. Particularly, in Finland these periods are not so common, and people do not get adapted to high temperatures which may be the case in the warmer climates.

Table 5. The effects of the alternate measures for the temperature control of an office room on energy consumption and cost items. The case A is used as a reference, when incremental costs and savings are calculated.

Factor	Case					
	A	B	C	D	E	F
Supply air flow, L/sm^2	2	2	2	4	2	4
Solar protection	Yes	Yes	Yes	Yes	Yes	Yes
Operation time of air supply h/d	10	10	24	24	24	24
Mechanical cooling W/m^2	0	20	0	0	20	20
Electricity kWh/a	24 403	26 379	31 273	43 217	35 453	50 523
Heat kWh/a	38 636	38 448	65 007	109 719	65 209	110 326
Electricity € /a	5 740	5 929	6 170	7 115	6 528	7 731
Heat € /a	3 864	3 844	6 501	10 972	6 521	11 032
First cost of remedial measure, € /room	-	73	-	327	73	400
Degree hours above 25	890	390	367	164	51	17
Max room temperature during working hours, °C	32.7	29.5	30.8	29.8	27.3	27.1
Annual cost of lost productivity € per room (per person)	330	142	139	64	19	7
Value of improved productivity € per room	**0**	**188**	**191**	**266**	**311**	**323**
Annual **Investment cost per room € /a**	**0**	**7**	**0**	**33**	**40**	**40**
Annual energy cost per room € /a	192	195	253	361	260	375
Increase in energy cost, € per room	**0**	**3**	**58**	**169**	**68**	**183**
Total annual savings per room € /a	**0**	**178**	**133**	**64**	**203**	**100**

The most reliable part in the study is the calculation of energy consumption. The performance of the program used in the calculation is verified in several international projects both against other programs and against actual measured data. The calculated room temperature is reliable, too. The operative temperature which is used to calculate the reduction in productivity is calculated in actual working location in the room, and it takes thus into the account not only the air and surface temperatures but also the actual view factors to the surfaces. The calculations assume that the heat loads of each room are similar as the system does not have a temperature control system for each individual room. This assumption is valid in many cases if the rooms are located in the same façade of building without specific shadows cast by the adjacent buildings.

The calculations also assume that the windows are protected from solar radiation always when the radiation intensity would have been over 100 W/ m² through the unprotected window. This is a very optimistic assumption. The solar protection devices e.g. venetian blinds, can be controlled by the occupants, and windows may be unprotected particularly during the morning hours when the previous day has been cloudy. This will increase the room temperature considerably.

The room used in the calculation represents well the existing buildings. It was selected in mid 80´s to represent typical building production at that time. Presently the office buildings have often much larger windows than in case presented here. This leads easily to much higher room temperature than presented here.

The unit costs of energy used in calculations represent average Finnish energy prices, which may a little low in respect of electricity for the Middle Europe and a little high in comparison to the area where for example natural gas is available. The first cost of the remedial measures as well as the value of work may vary considerably by case to case, however, the marginal in the results is so large that a similar result can be expected in other climates and conditions as well.

CONCLUSION

The study showed clearly how important the effect of indoor temperature is on the total cost of an office space, and how overall economy can be improved by simple remedial measures focusing on the thermal. In the case used in this study all remedial measures caused a positive annual savings due to increase in productivity.

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