Indoor Thermal Climate Criteria and the Effects on the Overall Environmental Performance of Air-Conditioning Systems

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ABSTRACT

The cooling loads of an office building vary with the desired indoor thermal climate. However, there is a lack of knowledge on how significantly the various indoor climate criteria affect the overall environmental performance of the air-conditioning systems. Here, we analyze the environmental consequences of the energy use, as well as the possible modifications of the system design and corresponding use of materials. The analysis is based on a theoretical case study of an air-conditioning system designed for a typical office building situated in Sweden. The environmental performance is evaluated by a life cycle assessment (LCA) method, taking into account the production, the user, and the disposal stages of the life cycle. For the same building, several scenarios of the user stage corresponding with the different requirements on the indoor thermal climate in the building are studied. We conclude that requirements on the indoor climate should be established at appropriate levels, taking into account the environmental performance of the air-conditioning system.

KEYWORDS

Indoor thermal climate, environmental assessment, life cycle assessment (LCA), air-conditioning system, comfort cooling system, office building.

INTRODUCTION

Modern office buildings have large cooling loads during a large part of the year even in the Nordic climate. These loads of a building are partly defined by the desired indoor thermal climate. Moderate requirements on the indoor climate can be fulfilled by systems of a relatively simple design and with a limited operating time, whereas a small range of allowed variations of air temperature, for example, requires more sophisticated systems with extended operating time. The increased energy use due to an extended operating time affects the environmental performance of the air-conditioning system negatively, since energy use most often is the main contributor to the overall environmental impacts of these systems (Heikkilä, 2003).

However, there is a lack of knowledge on how significantly the indoor climate criteria affect the overall environmental performance of the air-conditioning systems. In this paper, we analyze the environmental consequences of the various indoor thermal climate criteria; i.e. the environmental performance of the air-conditioning systems due to energy use, and due to necessary modifications of the system design and use of component materials.

METHOD

The analysis is based on a theoretical case study of an air-conditioning system designed for a typical office building situated in Sweden. For the same building, five scenarios of the user stage corresponding with different requirements on the indoor thermal climate are modelled. The environmental performance of the air-conditioning system is evaluated by a life cycle assessment (LCA) method, taking into account the whole life span of the system; i.e. the production, the user, and the disposal stages. The impact assessment is performed by the weighting methodology EPS 2000 default method (Steen, 1999), and the environmental impacts are expressed in environmental load unit (ELU).

CALCULATIONS

The Building and the Air-Conditioning System

The three-storeyed office building is situated in Göteborg, Sweden. The total net area of the building is 1920 m^2, which is divided into cell offices. The cooling energy for the air-conditioning system is supplied by a bore-hole heat pump system. The building is equipped with a variable air flow volume (VAV) system, the supply air temperature is 15^{o}C all during the year, and the system operates for 11 hours (7 am to 18 pm) each working day, 5 days a week. For a more detailed description of the building, and the bore-hole based air-conditioning system, see Heikkilä (2006).

The Indoor Thermal Criteria

The various criteria for indoor thermal climate used for the estimation of the annual energy use are given in Table 1 (the TQ is an abbreviation for thermal quality). The TQ1, TQ2, and TQ3 represent requirements that are frequently used criteria in Sweden. More extreme conditions of thermal climate are represented by TQmin (low requirements) and TQmax (high requirements) criteria. The supply air temperature remains 15^{o}C for all scenarios, while the design air flow volume differs for the criteria.

TABLE 1
Criteria for the thermal indoor climate used in the calculations

Criteria for the indoor thermal climate	t_{air}			Design air flow volume
	Min	Optimum	Maximum	
TQmax	20 ^{o}C	21 ^{o}C	22 ^{o}C	4.5 l/(s.m^2)
TQ1	23 ^{o}C	24.5 ^{o}C	25.5 ^{o}C	2.8 l/(s.m^2)
TQ2	22 ^{o}C	24.5 ^{o}C	26.5 ^{o}C	2.5 l/(s.m^2)
TQ3	21 ^{o}C	24.5 ^{o}C	28 ^{o}C	2.1 l/(s.m^2)
TQmin	20 ^{o}C	24.5 ^{o}C	35 ^{o}C	1.2 l/(s.m^2)

The Operating Energy

The annual cooling loads of the building, and the demanded electricity use for the operation of fans and the bore-hole based heat-pump system are estimated using a software application for the heat balance of buildings (BV2, 2002). The bore-hole system is assumed to work in the refrigeration mode in accordance with a seasonal performance factor (SPF) of 2.5. In both systems, there is only a negligible amount of annual heat energy required (less than 1 MWh) due to the low temperature of the supply air (15^{o}C). Therefore, this amount of energy is excluded from the analysis.

The environmental consequences are analysed for two scenarios:

A) The specific fan power (SFP) factor is set to 1.1 for all variations of the indoor thermal criteria. To meet this requirement, consequently, the size of the air-handling unit increases with each TQ class due to the increased air flow volume, except the TQ3 class which demands the same size as the TQ2 class.

B) The various indoor thermal climate criteria should be met by operation of an air-handling unit of the same size. This assumption leads to a variation of the SFP factors. The size of the air-handling unit used for these calculations is that designed for the original case study (Heikkilä, 2006) which is optimized for TQ1-TQ2. However, the size of the air-handling unit for the TQ3 and TQmin has to be reduced by one size due to the technical limitations.

The Environmental Evaluation

The environmental evaluation is based on the results of the LCA study of a bore-hole based air-conditioning system described in Heikkilä (2006), and form the reference system for this study. The environmental impacts of the material phase are linked to the production of materials for its assembly, as well as to its end of life (EoL) stage. The environmental impact of each size of the air-conditioning system is modify due to the different air flow volume demanded to meet the predefined TQ criteria, is calculated in accordance with the ratio of the actual system to the reference system. The environmental impact of the operating energy is based on the same energy source, which is the electricity source representative for the general generation of electricity in Europe.

RESULTS AND DISCUSSION

Operating Energy Use

The electricity for operation of fans and the heat pump system for supply of cooling energy are shown in Figure 1, for the scenario A, and in Figure 2 for the scenario B. The unbroken line shows the SFP factor which is linked to the secondary y-axis.

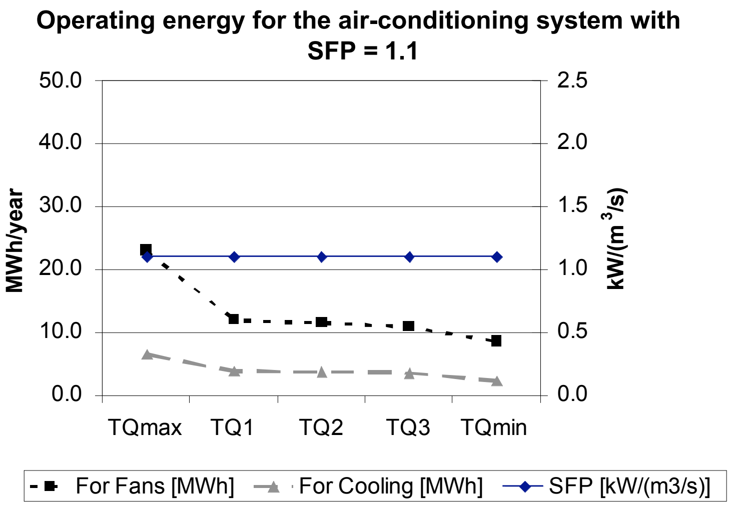

Figure 1: Operating energy for systems with a constant SFP (varying unit size):

From Figure 1 can be concluded, that the operating energy increases with the higher criteria of the indoor thermal climate. The rise is moderate for the usual range of the thermal indoor climate criteria, TQ1 to TQ3. For the two extreme cases, TQmax and TQmin, the changes are more rapid. Since the SFP factor is the same for all the TQ classes, the different amount of energy used corresponds with the demanded air flow volumes that are different for each TQ class, see Table 1. Figure 2 shows, that the trend in increase of operating energy for TQmin to TQ1 classes follows the rise of SFP, but the operating energy for the TQmax class rises more significantly.

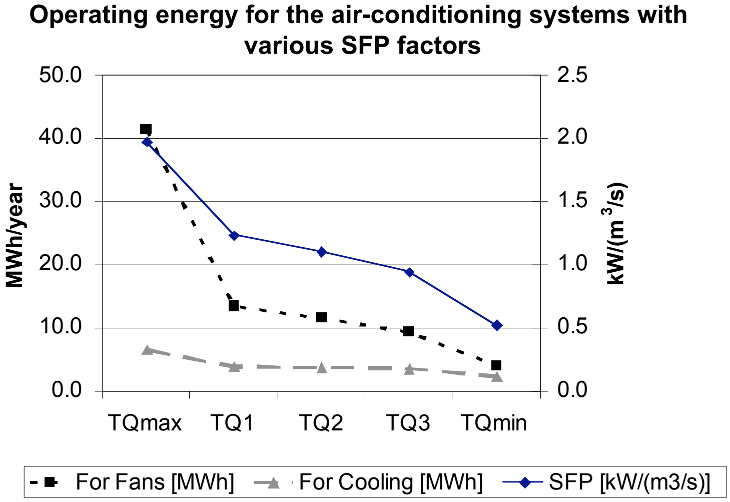

Figure 2: Operating energy for systems with a constant unit size (varying SFP):

Environmental Performance

The environmental consequences for the various TQ classes, taking into account the material and the user stages are shown in Figure 3 for Scenario A, and in Figure 4 for Scenario B. The unbroken lines in Figures 3 and 4 show the demanded air flow volume (the same in both cases) and are linked to the secondary y-axis.

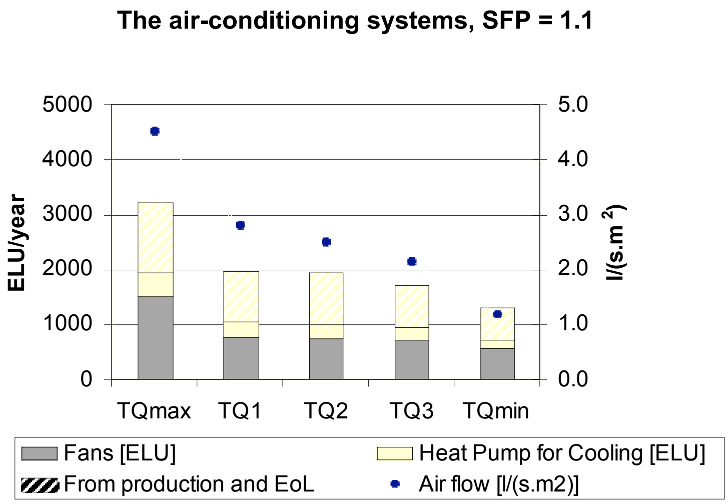

Figure 3: Environmental impacts of systems with a constant SFP (varying unit size):

Basically, the environmental impact for scenario A shown in Figure 3, follows the trend from Figure 1; i.e. the environmental impact increases only moderately within the interval of TQ1 to TQ3 classes, but more rapidly for the two extreme TQ classes, TQmax and TQmin. For all TQ classes, the contribution of user stages (the range of 52% to 60%) to the total environmental impact is higher than that of material phases (the range of 40% to 48%). Figure 4 shows that the environmental profile for TQ1 to TQ3 classes has not changed significantly compared to that shown in Figure 3. This result can be explained by the fact that in both scenarios, the required size of the air-handling unit is the same for TQ1 and TQ2 classes. The environmental impact of the system for TQmax in scenario B, however, is about 26% higher compared to that in scenario A, the system with SFP of 1.1, shown in Figure 3.

The air-conditioning systems with various SFP factors

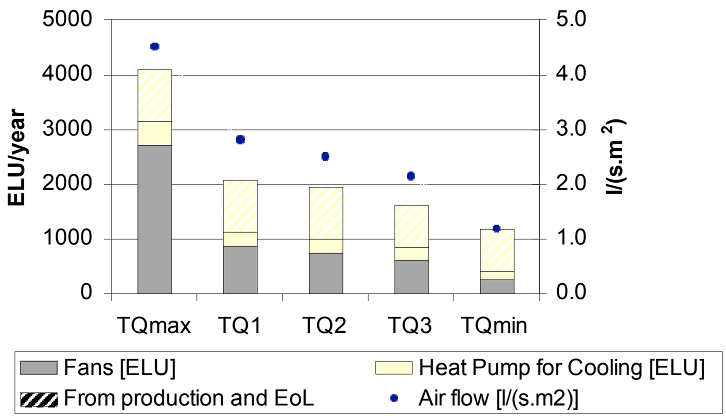

Figure 4: Environmental impacts of systems with a constant unit size (varying SFP):

The environmental impact of the system for TQmin, even so for the TQ3 class, is slightly lower (6% and 10% respectively) than that in scenario A. In scenario B, similarly, the user stages for almost all TQ classes contribute with a larger part to the total environmental impact (range of 52% to 77%) than the material phase (in range of 23% to 48%). For the TQmin class, the material stage contributes with 64% to the total environmental impact, and the user stage with 36%. This result can be explained by the fact that the size of the air-handling unit for TQ3 and TQmin was necessary to reduce due to technical limitations in spite of the ambition that, in scenario B, the same size of air-handling unit should maintain the different indoor thermal climates in accordance with the predefined TQ classes. Moreover, this reduction was done without any specific optimization for the specific performance.

For both scenarios, the results are based on several assumptions for the estimation of operating energy in the two scenarios, as well as for the environmental evaluation. However, the same assumptions were made in all cases; if the calculations were performed with refined assumptions, it would possibly affect only the total amounts of energy used, but would have only negligible impact on the proportions of results for the various TQ classes.

The highest environmental impact is related to TQmax class, which represents thermal climate with highest requirements and allows the temperature of indoor air vary with ± 1°C. Such high requirements should only be applied in specific and well motivated cases.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The environmental impact of the air-conditioning system varies with the indoor thermal climate desired, and depends also on the design of the whole system. The main contribution to the environmental impacts is related to operating energy for almost all TQ classes within the SFP interval 0.94 to 1.98. Only the system working with SFP of 0.52 has shown better performance in the user stage compared to the material phase. However, the differences in the environmental performance are small within the range of TQ1 to TQ3 classes. The total normalized environmental impacts are shown in Table 2.

TABLE 2
Normalized environmental impact for the various TQ classes and the two scenarios A and B

Criteria for the indoor hermal climate	Normalized environmental impact	
	Scenario A	Scenario B
TQmax	1.66	2.1
TQ1	1.02	1.07
TQ2	1	1
TQ3	0.88	0.83
TQmin	0.67	0.61

Based on the analysis presented in this paper, following observations can be made:

- There is not a significant difference in environmental impacts between an air-conditioning system designed for TQ1 and one designed for TQ3 within the SFP range of 0.94 to 1.2 kW/(m^3/s).
- The main contribution to the environmental impact is related to the operating energy within the SFP range of 0.94 to 1.98 kW/(m^3/s).

The requirements on the indoor climate should be established at appropriate levels to reflect the real demand in each particular case, taking into account the environmental performance of the air-conditioning system. Communication of the environmental consequences of the desired indoor climate to the commissioner of a building project or future owner is also essential.

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