DYNAMIC THERMAL SIMULATIONS FOR DEVELOPING EARLY-STAGE ASSESSMENTS FOR OFFICE BUILIDINGS

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ABSTRACT

Office buildings account for a large portion of the total energy consumption in Europe because due to increased comfort requirements almost all recent buildings are air-conditioned. This project is focused on the influence of thermal storage capacity of commonly used structure types of office buildings and different technical strategies on energy efficiency and thermal comfort. The technical parameter ventilation strategy is essential compared to the parameters structure type or window-to-wall ratio. Additionally a lighting control system based on solar radiation shows a high influence on the internal gains and in consequence on the overheating hours. The slab type respectively the accessibiltiy of the thermal mass has a significantly higher influence than the differences of “massivity” between solid and light weight structures.

INTRODUCTION

A tendency towards highly glazed facades for office buildings can be noticed despite their sometimes bad reputation for being a cause of comfort problems. In contradiction to that trend, current scientific research results recommend a lower window-to-wall ratio and structure types with a high proportion of thermal mass to reduce energy consumption and overheating hours. On the other hand, light weight composite structures are an interesting alternative because of pre-fabrication possibilities and higher design flexibility. Due to this conflicts and dependencies in the early design phase the aim of this project is to develop guidelines and planning recommendations for office buildings with different window-to-wall ratios of facade glazing and light weight composite structures.

METHOD

All the evaluations of this project are based on a representative reference zone with typical input parameters of office buildings. A reference zone method has been used for the parametric study of the main features of the building concerning energy demand and thermal comfort. The advantage of this method lies in the fact that a rather simple simulation model allows to quantify directly the influence of constructional and technical design parameters [1].

Office building and reference zone

The reference zone can be applied to different types of building geometry and the commonly used office organisation concepts. It is located in an intermediate storey of a low- or medium-rise building of three to seven stories. The exterior wall is highly insulated. The floor area is 110 m^2, which provides a work space for about ten persons (typical occupancy rate), see Figure 1. The thermal conditions of the boundary zones are identical to those of the reference zone. The climate is equivalent to the moderate Western European climate of Saarbrücken, Germany.

Figure 1 Floor plan and cross section of office building and reference zone

Structure and Facade

Two structure types of office buildings are defined for this study: one solid structure (SOLID 1) and one steel composite structure (STEEL 1), see Table 1. Both are already optimised with regard to structural and material efficiency.

Structure type	Definition	Image
SOLID 1	280 mm reinforced concrete, 70 mm screed and suspended ceiling	
STEEL 1	steel beam, profiled sheeting C77 + 130 mm concrete slab, floating screed and suspended ceiling	

Table 1 Structure types of office building

The facade system of the reference zone consists of a curtain wall structure as commonly used in office buildings. Three selected window-to-wall ratios represent a punctuated facade with a ratio of 48% (F 48), a band window facade with a ratio of 77% (F 77) and a fully glazed facade (F 100). The window-to-wall ratio calculation is based on the inside surface of the exterior wall and each window area consists of 80% glazing and 20% frame.

Parametric study

Reliable building dynamic thermal simulation tools are required to assess energy efficiency as well as environmental and thermal comfort performances [2]. In this project the transient simulation tool TRNSYS 17 has been selected to determine the energy demand and the overheating hours of the reference zone. A further objective is to analyse the influence of new technologies for example electrochromatic glazings or phase change materials.

In an office building the number of input parameters that influence the energy consumption is very high and it is necessary to identify and concentrate on the most important parameters in order to reduce the number of parametric studies [3] and parameter combinations. Several parameters are fixed or defined as categorical in the course of this project like the window-to-wall ratio and the structure type. Additionally some technical parameters, like the schedule, the set points and the control strategies for heating and cooling, are fixed. Heating has a set point indoor temperature during daytime of 22°C and during night time of 16°C. Cooling starts with a set point indoor temperature of 26°C during USE time (7h-18h). The categorical parameters for glazing types, shading devices, ”Lighting control” and “Ventilation strategy” are variable.

RESULTS

Lighting control system

Lighting control systems are currently used in many new office buildings in order to save energy for electricity. Thewes illustrates that a lighting control system can reduce the energy consumption used for lighting by 50% and additionally it can improve thermal comfort in summer [4].

In the standard 3D building project of TRNSYS 17 the lighting control system depends only on the global solar radiation on the horizontal outside. The light is turned on respectively turned off according to switching values suggested by default of 120 W/m^2 respectively 200 W/m^2. For a daylight factor of 2% these values correspond to the illuminance values of 300 lx and 500 lx [5]. The installed power is 10 W/m^2 including 40% fluorescent tubes which are commonly used in office buildings. This control system leads to 1.500 work light hours a year for the reference zone. However, neither the orientation of the facade nor the window-to-wall ratio, the glazing and shading type have been considered. As a consequence, a new lighting control system was developed, which is based on the short wave solar radiation through the external windows of the reference zone. The illuminance values correspond to the same radiation values as in the standard model. The switching values are defined as 5 W/m^2 respectively 10 W/m^2. This design approach depends on the amount of work light hours and leads to reasonable results in case of a triple glazing and a radiation controlled external shading device, see Figure 2. It allows to consider the influence of the work light hours on the internal gains of the reference zone.

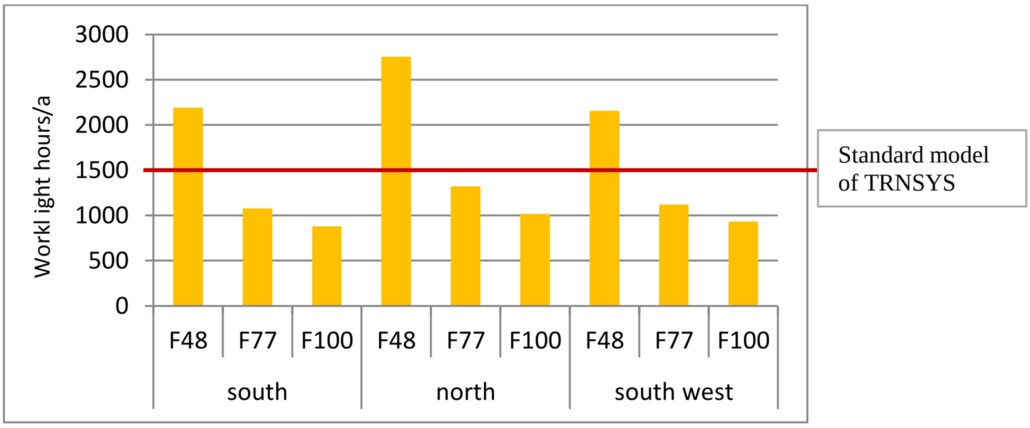

Figure 2 Work light hours/a of the new model based on solar radiation of reference zone compared to the standard model of TRNSYS

Simulation results

A previous analysis has shown that the south west orientation of the reference zone is the most critical orientation concerning thermal comfort and that the design challenges lie in cooling demand and not in heating issues. Any other simulation results present the overheating hours of the south west orientation and consider the new lighting control system.

Shading devices and glazing types

The electrochromic switchable glazing technology allows the variation of visible light transmission and solar heat gain coefficient to adjust heat and light in relation to interior comfort requirements [6]. The system works with a thin solid electrochromic film, sandwiched between two layers of glass which can be activated with low voltage to change transparency [7]. The tool WINDOW 7.2 and the International Glazing Data Base (IGDB) has been applied to simulate such a system in TRNSYS. A control signal algorithm depending on solar radiation on the facade regulates the glazing state from very transparent with a radiation level of 0 - 120 W/m^2 to fully tinted with a level higher than 420 W/m^2. An electrochromatic glazing (ELEC) and a triple glazing (EW 1) with and without external shading devices have been analysed, see Table 2. The analysis is based on the window-to-wall ratio of 77% and the defined ventilation strategy VENT_NAT, see Table 3 below.

Shading and glazing types	**Definition**
SHON	External, radiation controlled, shading factor 0.7
SHOFF	Without external shading
EW1	Standard triple glazing, Ug = 0.6 W/m^2K, g = 0.584
ELEC	Electrochromatic triple glazing, Ug = 0.78 W/m^2K, g = 0.407 - 0.05

Table 2 Shading and glazing types of reference zone

The application of a radiation controlled external shading device in combination with the triple glazing (EW 1_SHON) has an enormously positive effect to reduce overheating hours. The electrochromatic glazing (ELEC) shows approximatively the same performance and a combination of both would lead to another small improvement (ELEC_SHON), see Figure 3, but of course costs for two systems will arise.

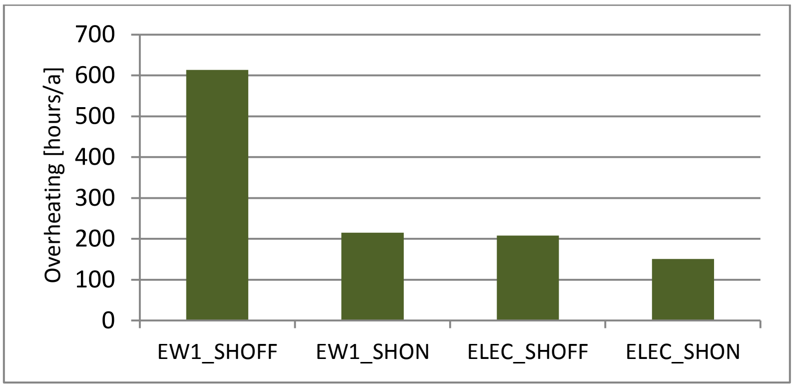

Figure 3 Overheating hours of different shading devices

Ventilation strategy

Three different ventilation strategies have been analysed: a mechanical system with a constant air supply during USE time (VENT_MECH) and a system with enhanced night time ventilation (VENT_NIGHT). The latter benefits from the cooling effect of outside air during periods of overheating risk. The third system is a natural ventilation system (VENT_NAT) with a similar air change rate as the other two systems and an enhanced day- and night time ventilation, see Table 3.

Ventilation strategy	**Definition**
VENT_MECH	Mechanical ventilation, constant air flow during USE, air change rate 1 h^{-1}, constant supply temperature of 18°C, heat recovery 70%
VENT_NIGHT	VENT_MECH + optional enhanced night ventilation, air change rate 4 h^{-1}
VENT_NAT	Natural ventilation, base rate 0.7 h^{-1} + enhanced daytime, air change rate 2 h^{-1} and night ventilation, air change rate 4 h^{-1}

Table 3 Ventilation strategies of reference zone

The results show that the ventilation strategy has a significantly higher influence compared to the parameters window-to-wall ratio and structure type, see Figure 4.

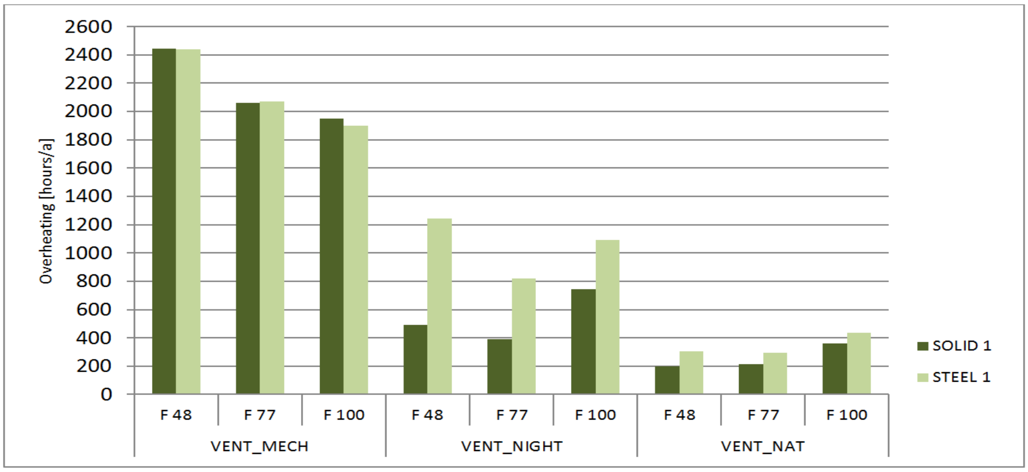

Figure 4 Overheating hours of different types of ventilation strategy

The system VENT_MECH without enhanced ventilation for heat removal causes the most overheating hours. The strategy VENT_NIGHT with enhanced night time ventilation improves the situation but an acceptable range of overheating hours can only be reached if a consequent day- and night time ventilation during periods of overheating is applied. In this case the reference zone complies almost with general comfort requirements, if a lower window-to-wall ratio is selected. The steel composite structure causes more overheating hours in case of an advanced ventilation strategy. Whether the structure type or the slab type is decisive will be discussed in the next chapter.

Influence of structure and slab type

The solid structure (SOLID 1) and the steel composite structure (STEEL 1) are analysed. First both slabs are covered with a suspended ceiling, which has been removed in the next step (marked in Figure 5 with "WCS"). The evaluation is based on the ventilation strategy VENT_NAT, a window-to-wall ratio of 77%, a triple glazing and an external shading device.

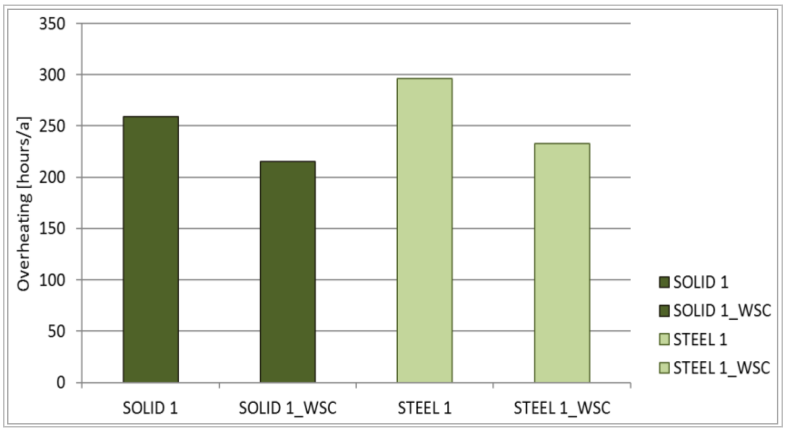

Figure 5 Overheating hours of different slab types

The differences between the solid and the steel composite structure are not as striking as expected. For both structures types it is beneficial (in terms of overheating hours) to renounce on a suspended ceiling as the thermal storage capacity of the slabs can be used more effectively, see Figure 5.

DISCUSSION AND CONCLUSION

The study has been focused on the influence of the main technical parameters lighting control, ventilation strategy and shading devices. The results presented have shown that an adequate ventilation strategy is more important for energy demand and thermal comfort than other building-related design parameters like the window-to-wall-ratio or the structure type. However, in addition to an adequate ventilation strategy the accessibility of the thermal mass and an external radiation-controlled shading device are essential to improve thermal comfort. An electrochromatic glazing is an interesting alternative to conventional shading devices because it shows a similar performance.

A lighting control system which is based on the solar radiation of the reference zone allows a more realistic presentation of the work light hours in future simulations and shows their influence on the internal gains of an office building. Phase change materials will also be integrated in further research because it is assumed that they can increase the thermal capacity of light-weight systems to improve thermal comfort.

A design optimisation and a systematic sensitivity analysis by means of an optimisation tool [8] will be carried out due to a growing amount of input parameters and thus a large number of thermal simulations required. The aim is to rank the parameters according to their impact and importance on energy demand and thermal comfort and to give easy applicable design guidelines for the early planning phases.

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