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The effect of suspended ceilings on energy performance and thermal comfort

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ABSTRACT

The objective of this study is to determine the potential energy savings and thermal comfort benefits of exposing concrete in the ceiling to the indoor air as an alternative to suspended ceiling. The performances were assessed through monitoring of room air and surface temperatures in an office building in operation, and simulation of different scenarios with a calibrated building simulation model. In this study, it is shown that ESP-r is capable of simulating an advanced controlled office building in operation with good agreement with the measurements. The results presented in this paper indicate that exposed concrete in the ceiling both reduces the number of hours with excessive temperatures considerably and create a better and more stable thermal environment during the working day. Also, exposed concrete increases the achievements of utilizing night free cooling significantly. However, by removing the suspended ceiling, only minor annual heating energy savings are achieved.

1. Introduction

In the literature, several studies have evaluated the effects of thermal mass on energy use and thermal comfort, both parametrically and experimentally. However, there are only few studies that both assess the potential heating and cooling load benefits of exposed thermal mass in office buildings. Moreover, the experimental studies found are solely on test cells, and they are not taking user behaviour and advanced building control systems into account. The objective of this study is to determine the potential energy savings and thermal comfort benefits of exposing the concrete ceiling to the indoor air as an alternative to the original suspended ceiling. This is assessed through monitoring of room air and surface temperatures in an office building in operation and simulation of different scenarios with a calibrated building simulation model.

As a consequence of the Norwegian partnership in the EEA, Norway is obliged to implement the EU Energy Performance of Buildings Directive (EPBD) [1] in the national laws and regulations. Thus, the new building codes and guidelines are also revised. The former regulations only set requirements for *U*-values and air tightness. The new regulations introduce an *energy frame* for different building categories. If the net energy demand calculated according to the methodology established in the new Norwegian Standard NS 3031 [2] is within the frame, regulations are satisfied. Since the frame is based on net specific energy demand per year, the efficiencies of the energy systems are not taken into account. This means that for example the coefficient of performance of a highly efficient mechanical cooling system is not rewarded. However, passive measures that reduce the net cooling demand will contribute to satisfy the energy frame. This has led to a renewed interest in utilizing passive measures to decrease the total energy use in buildings.

Thermal mass can give a positive contribution to the indoor environment and the energy performance of buildings, both summer and winter. In the summer time, excessive heat is absorbed and reduces the need for cooling during the day-time. The absorbed heat will gradually be released when the temperature decreases during the night. Buildings that are unoccupied during the evening and night may be cooled down, in order to empty the thermal storages and heat may be absorbed the following day. In the winter time, energy from the sun and internal heat gains can be absorbed in the thermal mass during the day, and gradually released to the indoor air at night, thus completely or partially reduce the need for heating.

Several studies have shown that thermal mass together with night ventilation may reduce the indoor maximum temperature and the cooling energy demand. Thermal mass combined with

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Nomenclature

ACH	air changes per hour
BEMS	building energy management system
EC	exposed concrete
EEA	European Economic Area
EPBD	Energy Performance Of Buildings Directive
ESP-r	energy systems performance (r stands for research version)
NS	Norwegian standard
Q	airflow rate (m^3/h)
SC	suspended ceiling
SP	set-point

night ventilation may reduce the maximum indoor temperature by 2–6 K (e.g. Givoni [3] and Shaviv et al. [4]), provided that the diurnal outdoor temperature swing is adequate. Dependent on the climate and building type, the cooling energy savings found in the literature span from 5% to 36% (e.g. Burch et al. [5] and Ruud et al. [6]). Moreover, some studies (e.g. Kolokotroni et al. [7] and Gratia and De Herde [8]) conclude that if the heat gains are not too excessive in office buildings, thermal mass and night ventilation should be sufficient in order to cover the cooling demand alone in moderate climates. A recent study by Artmann et al. [9] assesses the climatic potential for passive cooling of buildings by night-time ventilation. The study concludes that the whole Northern Europe, and in particular the British Isles and Scandinavia, has a very high potential for night-time ventilative cooling.

Some studies also conclude that thermally heavy buildings have lower space heating energy demand than light buildings. According to Norèn et al. [10] and Bellamy et al. [11], heavy residential buildings demand about 15% less space heating energy compared to equivalent light buildings. Ståhl [12] has estimated the energy savings to be about 20% for offices. Heating energy savings are most significant in the intermediate seasons in cold climates and in climates where the balance temperature of the building is close to the mean outdoor temperature [13,14].

However, there are several obstacles preventing use of thermal mass in office buildings. A survey among 750 corporate managers in the Nordic countries reveals that every third leader plan to reorganize or rebuild the office plan within the next 2 years [15]. Hence, modern office buildings should have a high degree of adaptability to meet varying requirements. Clearly, use of heavy materials in partition walls may come in severe conflict with the desire of having a flexible building. This, together with building materials' heat capacity, makes external walls, floors, and ceilings the most common alternatives for use and possible exposure of thermal mass.

As Shaviv et al. [4] and Norén et al. [10] conclude on the ability of thermal mass to reduce energy demand for cooling and heating, respectively—the greatest effect of thermal mass is going from a light structure to a medium heavy structure. The effect is less significant by a further increase of thermal mass. Thus, the focus in this paper is to assess the potential benefits of increasing the thermal mass by exposing concrete in the ceiling as an alternative to the original suspended ceiling.

2. Method

To investigate the effect of exposing concrete in the ceiling, six identical office cells were studied from which three of the suspended ceilings were removed. The purpose was to monitor

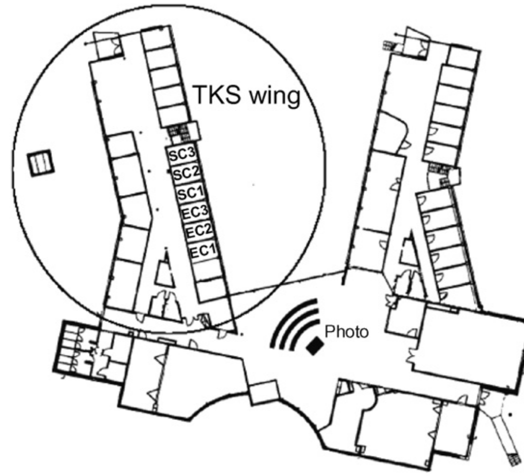

Fig. 1. Plan view of the second floor showing the common area and the two office wings. The point labelled "Photo" is from where the photo in Fig. 2 is taken.

the room parameters and compare the overall energy and thermal comfort performance. Further, the measurements were used to calibrate a detailed simulation model in ESP-r [17] to compare the energy demand for the whole building and the thermal environment in the office rooms.

3. Building description

The case used in this study is an office building at the Nord-Trøndelag College (HiNT) campus in Levanger (63.75°N), located 80 km north of Trondheim, Norway. The building, which from this point will be referred to as *Røstad*, is located in rural surroundings in a coastal climate. The building was ready for occupation in August 2002, and has a common wing with meeting rooms and educational areas. Two other wings are office areas, see Figs. 1 and 2. In this paper only one of the office wings (the TKS wing) is studied. The two storey building has no basement, but a culvert for supply of ventilation air is embedded in the ground along the central axis of the wing.

3.1. HVAC system and control

The hybrid ventilation is of the so-called culvert type. In principle it is constructed as shown in Fig. 3. The ducts from the

Fig. 2. The TKS wing viewed from south-east, showing the air exhaust tower and the glazed staircase.