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Exploring the relationship between structurally defined geometrical parameters of reinforced concrete beams and the thermal comfort on indoor environment

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Abstract

The paper presents a research exploring the thermal mass effect of reinforced concrete beams with structurally optimised geometrical forms. Fully exposed concrete soffits in architectural contexts create more than just visual impacts on the indoor climate through their possible interferences with light, sound and thermal conditions. It is considered that the characteristics of interferences would have close relationship with material and geometrical properties of the soffits; especially when the soffits are other than flat form. In the current investigation the relationship between the thermal mass effect (and the implication on thermal comfort) and the given geometrical parameters of exposed soffit reinforced concrete beams are explored.

The geometrical parameters of the beams are initially defined in means of structural optimisation. The beams consist of flange and web in likeness of T-sectioned beams. However, both flange and web are curved vertically for the required bending and shear capacity of the sections. At the same time, the web is also curved horizontally for increased shear capacities. In the research, both the vertical and horizontal geometrical parameters are varied to observe the resultant heat exchange behaviour, and the implication on thermal comfort indoor environment. However, the current paper presents the thermal mass characteristics of one geometrical type.

The study is based on results derived from computational fluid dynamics (CFD) analysis, where Rhino 3D is used for geometrical modelling of the beams and office space.

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Keywords: Thermal mass; CFD; geometrical optimisation; integrated design solutions; exposed concrete soffit

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1. Introduction

Research and developments for more innovative applications of thermal mass has its fundamental aim in the utilisation of initial embodied energy for minimising the total operational energy consumed from heating, cooling, and for other powering appliances. The accurate applications of thermal mass for indoor comfort requires more complex insights to how materials respond in dynamic environments based on numerous correlated variables. Throughout the decades global researchers have developed numerous analytical methods, and explored to identify significant factors that govern thermal mass effects. In contexts of forced convection, the explanation of heat transfer mechanism for thermal mass effects becomes more complex as it involves dynamic airflow, which is rapidly influenced by both material and geometrical configurations of the given three-dimensional space.

In both cases of natural and forced convection, the heat transfer between air and thermal mass is closely affected by geometrical configurations of the given space; dimensions of the space, furniture layouts, window locations and sizes, air inlet and outlet locations and the capacities, locations of heat sources etc. For such complexity, there is limit to develop further insights using only two-dimensional based analytical methods, and full-scale experiment based research methods often have restrictions with resources.

It is one of the main intentions of the current research to examine and explore the known thermal mass effects on indoor climate through application of computational fluid dynamic (CFD) method. Depending on the nature of the analysis and size of the built models, CFD analysis can demand high-performance computation specifications. However, with increasing efficiencies of computational analysis methods; in conjunction with growing possibilities of cloud-based computing methods, CFD seems to be one of the most economical and practical methods for current investigation purposes.

Nomenclature

A	surface area of mass
a	thermal diffusivity
c	specific heat capacity
h_c	convective heat transfer coefficient
k	thermal conductivity
q	rate of energy transfer
T_{air}	air temperature
$T_{surface}$	surface temperature of building element
v	velocity
ρ	density

2. Literature review

2.1. Thermal mass and building components

Thermal mass characteristics and adequate design application of concrete for reducing mechanical cooling as well as heating energy for indoor comfort have been widely discussed as part of academic discourses. In warmer climates, indoor temperatures often increase above thermal comfort level of the occupants. Thus, the excess heat is directly controlled by mechanical air-conditioning systems. The amount of energy used for the air-conditioning can be reduced through active use of building's thermal mass; the excess heat in an indoor space is absorbed by building elements such as walls and floors. The rate at which the heat in the air is transferred/absorbed into the building elements can be described as below:

$$q = h_c A(T_{air} - T_{surface}) \tag{1}$$

Thus for a given surface point of a building component, the rate of energy transfer, q, increases with the