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RESEARCH ARTICLE

# Effect of façade systems on the performance of cooling ceilings: In situ measurements

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Effect on comfort

**Abstract**
This article presents an innovative façade system designed to increase the thermal comfort inside an office room and to enhance the cooling capacity of the suspended cooling ceiling. A series of measurements is conducted in an existing office building with different façade systems (i.e., a combination of glazing and shading). An innovative façade system is developed based on this intensive set of measurements. The new system enhances the thermal comfort and cooling capacity of the suspended cooling ceiling. The main usage of the new system is the refurbishment and improvement of existing façade systems.


## 1. Introduction

In accordance with building standards, massive changes in the field of energy-efficient buildings have occurred in the last ten years. The goal of such changes is to develop plus-energy buildings (residential and non-residential) and the vision behind them is to build plus-energy districts and cities. Their primary focus is the energy efficiency of buildings.

Research and development in the field of sustainable design have led to the improvement of methods, design processes, and products. On the one hand, detailed studies have been conducted on the efficiency of façade systems and their influence on buildings, such as reviews of solar façades (Quesada et al., 2012) and the effect of multi-skin façades on energy demand (Radhi et al., 2013). Hamza (2008) investigated the effect of different façade systems on energy demand and compared double-skin façades with single-skin façades. Hien et al. (2005) and Shameri et al. (2011) discussed the details of double-skin façades. Mathematical models for the detailed calculation of façade systems have also been developed; for example, Ghadamian et al. (2012) described the analytical solution to the energy modeling of double-skin façades.

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On the other hand, detailed studies have been conducted on the behavior and efficiency of cooling ceilings and their effect on rooms. Examples include the work of (Causone et al., 2009), which described the experimental evaluation of heat transfer coefficients between the radiant ceiling and room, and the experimental evaluation of cooling capacity by Andrés-Chitote et al. (2012). Beck (2002) described the thermal behavior of cooling ceilings. Glück (1999), (2003) elucidated the heat transfer coefficients of cooling ceilings. *TABS Control* provides a good summary and overview of the possible control strategies for the energy-efficient operation of thermal-activated building elements (Tödtli, 2009).

Schittich (2001) states that the façade should be treated not only as a decorative layer but also as a responsive skin. Lang (Schittich, 2001) extended this idea and suggested that the building skin by definition should be treated not as a skin but as a system that interacts with the entire building and building-service systems, given that it fulfills a huge range of functions and is one of the main influencing factors on energy demand.

The total system—the façade and its interaction with the cooling ceiling capacity—is the main topic of the present work. The effects of different façade systems on the performance of the cooling ceiling and cooling capacity of the ceiling are researched. Fonseca et al. (2010) described the effect of a radiant ceiling system coupled on its environment and found that the façade influences the cooling ceiling capacity.

The assumption of this research is that new concepts are accepted and deemed successful based on whether or not they significantly improve the comfort of users relative to the comfort provided by conventional systems. The cooling ceiling guarantees high comfort because of the high proportion of radiation. However, the limits of the cooling capacity of a cooling ceiling are often reached in a typical office building design, such as in Austria. Given the combination of high glass content and high internal heat gains, the cooling capacity insufficiently guarantees a room temperature of 26 °C.

Determining the resulting thermal comfort is an important issue in the design of façade systems. For highly glazed office spaces, the correct calculation of the local heat balance is an important factor but is not often well known. The provision of comfort using EN ISO 7730, (2005) can lead to an underestimation of the operative temperature if direct solar radiation is not considered. The measurement of the cooling capacity according to DIN EN 14240 (2004) is conducted independent of the external effects of radiation (i.e., the boundary conditions are defined by the temperatures of surrounding surfaces). The calculation of the cooling load according to VDI 2078 (1996) can lead to incorrect calculation results. The influence of cooled surfaces on the cooling load is discussed in VDI 2078 Sheet 1 (2003). Given this regulation, a qualitative correction of the calculation is conducted based on the results of the main calculation method according to VDI 2078 (1996). The present study measures the performance of a cooling ceiling in an existing office building under different façade types to determine the effects of different façade systems on operative temperatures, cooling capacity, and comfort; the results are presented below.

According to EN 15255 (2007), calculating the dynamic cooling load requires that surface temperatures be calculated according to EN 15377-1 (2009) for surface cooling systems. The calculation is divided into four classes, and a class 4 calculation must be conducted for surface cooling systems. EN 15255 (2007) provides the basis for a simplified dynamic calculation of the cooling load.

The measurement results are intended to be the basis for developing a method of mathematical calculation of cooling capacity in relation to innovative/different façade systems.

## 2. Building/room setup

A series of measurements was conducted in an existing office building located in Vienna, Austria; this building had different façade systems. The 34$^{th}$ floor consists of four identical rooms with an area of approximately 10.8 m$^2$ each. The façade is a west-orientated and totally glazed surface. Given that the rooms are situated on the 34$^{th}$ floor, they are not shaded by other buildings or geographical surroundings.

Figure 1 shows the floor plan of the test rooms. The rooms are adjacent to one another and are separated by a gypsum plasterboard wall. Rooms 01 and 04 are adjacent to an open-space office area, which was empty during the measurement period. The floor is a raised floor and is open throughout the entire story because of its air leading properties (i.e., the supply of air is realized over the raised floor). The floor cannot be closed; otherwise, the test rooms will not obtain fresh air. The suspended ceiling of the measurement rooms is separated by a foreclosure (mineral

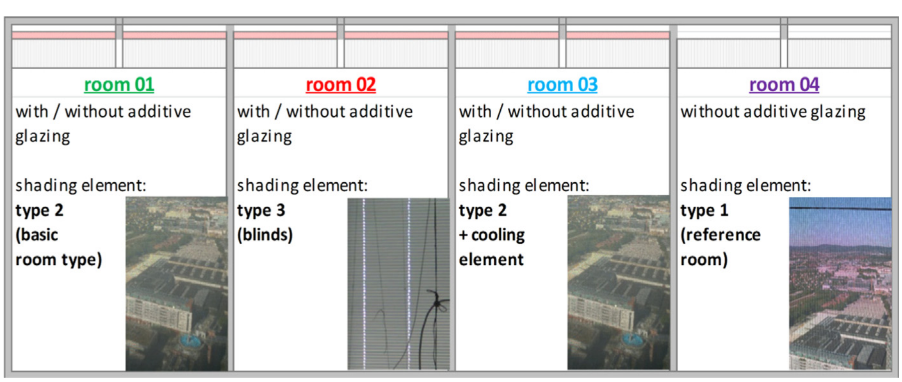


**Figure 1** Floor plan of the test rooms.