Frontiers of Architectural Research (2013) 2, 1–10

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Frontiers of Architectural Research

RESEARCH ARTICLE

Improvement of thermal environment and reduction of energy consumption for cooling and heating by retrofitting windows

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Received 15 October 2012; accepted 24 October 2012

KEYWORDS
Double-skin windows;
Retrofitting windows;
Thermal environment;
Energy saving

Abstract
Various techniques for creating a comfortable thermal environment and saving energy have been proposed and employed in residential buildings in many countries, including Japan. For these techniques to be introduced, existing houses should be renovated. Among the techniques available, installation of additional inner windows is effective in creating a comfortable and energy-efficient living environment. In the present research, the effect of additional inner windows on the thermal environment and energy saving was investigated by measuring indoor climates. Windows were renovated in two rooms on the fourth floor of a four-story reinforced concrete building. Air temperatures, the humidity, the global solar radiation on horizontal and vertical surfaces, radiant temperatures, and the electricity consumption of air-conditioners were measured. A comparison of these values before and after the installation of inner-windows showed that the thermal environment and energy saving had improved. Results obtained from a thermal model agreed well with measured results by changing the value of solar transmittance and heat transmission coefficient of the glazing following renovation. Furthermore, in a questionnaire survey conducted in summer, more than half of the occupants answered "comfortable" to a question on the overall thermal comfort.

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Peer review under responsibility of Southeast University.

Production and hosting by Elsevier

1. Introduction

Various techniques for creating a comfortable living environment and saving energy have been proposed and employed in residential buildings. Among the available techniques, the

2095-2635
http://dx.doi.org/10.1016/j.foar.2012.10.006

installation of additional inner windows appears promising for creating a comfortable and energy-efficient living environment in existing houses. Since the outdoor temperature and solar radiation significantly influence the indoor thermal environment through openings, window renovation will improve the indoor climate and reduce the cooling and heating loads. As related research, Ismail and Henriquez (2005) investigated double-glazed windows with a ventilation system. Garvin and Wilson (1998) studied the influence of double-glazed windows on the indoor environment. Arici and Karabay (2010) attempted to determine the optimum thickness of double-glazed windows. Double-glazed windows were also investigated by Aydin (2006), Gordont (1987), and Carlos et al. (2011). Hayatsu et al. (2009) and Sakamoto et al. (2009) reported the effectiveness of inner windows on the basis of measurements and a simulation. However, it is important to evaluate the effectiveness of the inner windows in various situations since their effectiveness depends on the airtightness, the lifestyle of the inhabitants, and many other factors.

In the present research, the effect of additional inner windows on the thermal environment and energy saving in both summer and winter was investigated by measuring differences in the indoor climates, electricity consumption, and the thermal sensation of the occupants before and after the installation of the inner windows.

2. Outline of measurements

2.1. Measured building

The windows were renovated in two rooms on the fourth floor of a four-story reinforced concrete building used for research and educational purposes. The windows in Room A (one user, EHP air-conditioner) face south, while those in Room B (15 users, 2 GHP air-conditioners) face east. The floor plans are shown in Fig. 1, and the details of the windows are listed in Table 1. The inner windows were installed on August 11, 2010, and removed on February 1, 2011. They were installed again on February 16, 2011. The effectiveness of the inner windows was examined in both summer and winter.

2.2. Measured parameters and time period

The air temperature, humidity, solar radiation, radiation temperature, and energy consumption of air-conditioners were measured. The measuring points are shown in Fig. 1. The thermometers were positioned on bookshelves at three different heights from the floor (10, 100, and 230 cm). The horizontal and vertical global solar radiations were measured outside the windows. The radiation temperature was measured several times during the measuring period. The measurements started one month before the installation of the inner windows.

3. Results for summer

3.1. Measured results

The measured results obtained before the installation of the inner windows (8/5/2010–8/11/2010) were compared with those obtained after the installation (8/12/2010–8/18/2010). The measurement periods were decided such that the climatic conditions before and after installation were similar. It can be said that the selected periods were appropriate for comparison because the climatic conditions were almost symmetric with respect to the installation day as a result, and the thermal inertial of the object rooms are about three days.

Table 1 Details of windows.

Room A	Steel sash and double-glazed windows (outer) + resinous sash and single glass (inner)
Room B	Steel sash and single glass (outer) + resinous sash and double-glazed windows (inner)

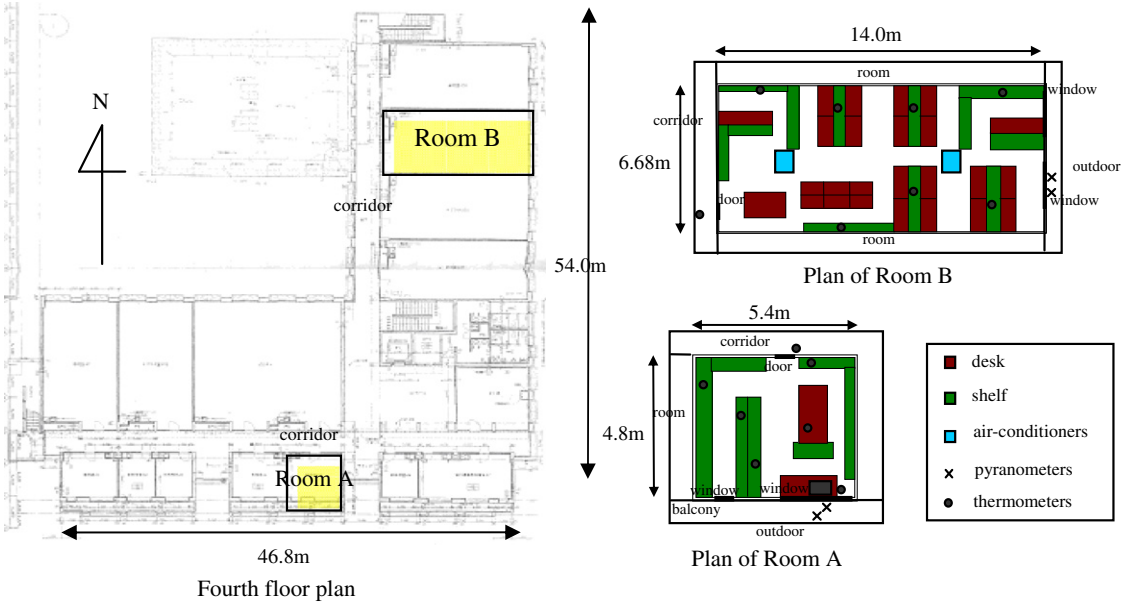

Fig. 1 Floor plans and location of measuring apparatus.