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# Effect of facade components on energy efficiency in office buildings

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## HIGHLIGHTS

- Investigation of facade properties for energy efficiency of Tokyo office buildings.
- Higher reflectance for opaque parts may slightly reduce energy demand.
- Lower window *U*-value and solar heat gain coefficient are potential solutions.
- Decreased heating due to insulation did not always compensate increased cooling.
- Fundamental data for adjustment of facade properties of buildings are provided.

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## ABSTRACT

Properties of facade materials should be considered to determine which of them strongly affect building energy performance, regardless of the building shapes, scales, ideal locations, and building types, and thus may be able to promote energy efficiency in buildings. In this study, the effects of four fundamental facade properties related to the energy efficiency of office buildings in Tokyo, Japan, were investigated with the purpose of reducing the heating and cooling energy demands. Some fundamental design factors such as volume and shape were also considered. It was found that the reduction in both the solar heat gain coefficient and window *U*-value and increase in the solar reflectance of the opaque parts are promising measures for reducing the energy demand. Conversely, the reduction in the *U*-value of the opaque parts decreased the heating energy demand, and this was accompanied by an increase in the cooling energy demand in some cases because the total energy demands were predominantly for cooling. The above-mentioned promising measures for reducing building energy demands are thus recommended for use, and an appropriate *U*-value should be applied to the opaque parts based on careful considerations. This study provides some fundamental ideas to adjust the facade properties of buildings.



## 1. Introduction

The use of an energy-efficient facade is indispensable for reducing carbon emissions during the operational phase of a building. Facade factors related to energy performance are thermal quantities (e.g., *U*-value) and solar heat gain quantities (e.g., solar heat gain coefficient (SHGC)). Indeed, several new facade materials have been developed that are aimed at reducing the energy demands of buildings [1–5]. The development of facade materials should be promoted to realize a more energy-efficient facade, which could potentially be a universal solution regardless of the two facts that (1) locations, weather, and user behavior strongly affect energy performance and its distribution and (2) facade properties (e.g., reflectance, *U*-value of opaque and window parts, and SHGC) and design factors (e.g., building shape, volume, and window configuration) dependently affect the building energy properties. From a material point of view, there is no universal solution recommended for the former fact. Regarding the latter fact, there may be a potential demand for considering facade properties that affect energy performance in a phase such as the material development phase. It is therefore important to estimate which facade properties could have a strong effect in reducing energy demands, regardless of the design factors. Thus far, previous studies have focused on either a specified building shape or a specified component as described below.

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With regards to the design factors, building configuration with fixed envelope properties has been investigated as a factor affecting the heating and cooling energy requirements in a residential space of Rome and Hong Kong [6,7]. As an example of using the facade properties, the reflectance of roofs has been specifically aimed at reducing the cooling energy requirements by minimizing the solar energy gain in the relatively warm and hot regions of the US [8–11]. Facades with a relatively high reflectance of a room composed of specific components have also been discussed in not only hot and warm regions such as Hong Kong and China but also cold regions such as Sweden [12–15]. The emphasis on reflectance has been prompted by the development of highly reflective materials [16–20] that are capable of reflecting greater amounts of near infrared (NIR) solar radiation without the need to change the surface color. The properties of windows significantly affect the energy performance of a building owing to two factors, namely, their relatively high *U*-value compared with the opaque parts and their solar heat gain moderated by glazing systems. A desirable window-to-wall ratio (WWR) has been given from the perspective of minimizing the sum of cooling, heating, and lighting energy demands, assuming a facade property set with a controlled shade of an office space in Germany, the US, and the Netherlands [21–23]. Thermally insulated windows of a building have attracted attention in cold countries owing to their high *U*-values compared with the insulated opaque parts [1]. Transparency is another important factor to maximizing the usage possibility of daytime lighting [24]. Conversely, in the warm parts of Europe, a lower window *U*-value has increased the cooling energy requirements of a stipulated room [25]. In the warm parts of Asia, a few studies have investigated the relationship between energy savings and the properties of advanced windows and shown that windows with low *U*-values (e.g., triple glazing windows) reduce energy consumption in some regions [26]. By focusing on windows of a fixed shape building in India and China, a few studies have also shown that reducing the *U*-value and SHGC could contribute to reducing the sum of cooling and heating demands [27,28]. The *U*-value of the opaque parts of a building is likewise an important factor. Well-insulated walls often save energy, although they tend to be expensive. The optimum insulation thickness of a space was given from the payback period for a given insulation type and thickness [29–31]. The energy saving effect of external insulation, due mainly to nonthermal bridging, has been noted in various regions (e.g., Greece), although the cost of insulation increases [32]. By focusing on an office building with a floor plan, another study has shown that walls with thick insulation do not always enable energy savings in some cities of China [33].

The purpose of this study was to investigate the facade properties that affect energy performance for reducing energy demands for a wide range of office buildings in Tokyo, Japan. This was done by dynamic simulations using the simulation tool WUFI Plus [34]. The considered facade properties were the solar reflectance of the opaque parts of the facade, the *U*-value of the externally/internally insulated opaque parts of concrete walls, the *U*-value of the windows, and the SHGC of the windows. There are numerous energy saving solutions that can be applied to the facade components of buildings, and the focus of this study was the static components; dynamic components such as blinds and electrochromic glazing systems were not considered. The building form, volume, and window-to-wall ratio were also varied. Such combinations of factors have not been investigated in previous studies. The facade properties were varied to determine how each affected the heating and cooling energy consumption. Facade properties do not affect energy demands independently. Nonetheless, this study varied the facade properties, aiming to provide a rule-of-thumb approach for understanding the impact of facade components on heating and cooling energy demands of buildings with various designs. Based on the results, this study proposes measures for saving energy in office buildings in Tokyo through the variation in the facade properties and the building design parameters. A previous study showed that heating and cooling energy consumptions account for approximately 45% of total energy consumption of an office building in Japan [35]. This study therefore focused on heating and cooling demands.

## 2. Methodology

Both heating and cooling energy simulations were performed by varying the facade properties and building design factors. An analysis was used to determine how each facade property affected the annual energy savings.

### *2.1. Annual energy simulation*

The annual energy consumption simulation was conducted using the simulation tool WUFI Plus, which is capable of computing the heating and cooling energy demands in buildings with various types of envelopes in Tokyo [34]. WUFI Plus has been experimentally validated by Antretter et al. [36] for a simulation period of one year. Our study used the weather data shown in Fig. 1, titled Standard Expanded AmeDAS Weather Data, 1995 Version, authorized by the Architectural Institute of Japan.

Using the conditions described below, the cooling and heating energy demands were simulated and the annual energy was calculated by summing up both energy demands.

#### *2.1.1. Parameters*

According to the ASHRAE standard, Tokyo is categorized as a Zone 3 cooling-dominated area [37], where the main facade design strategies are aimed at controlling solar radiation and reducing external heat gain using well-insulated opaque parts or shading devices, and natural ventilation and light sources are exploited [38]. Table 1 lists the parameter combinations for the annual energy demand simulation, wherein nine parameters were considered, comprising four related to design issues and five related to facade properties.

(1) Number of floors, floor area, and floor aspect ratio

The design factors are normally determined by the surroundings (e.g., road connectivity, environmental conditions, and maximum allowable building volume), and they affect the energy consumption. The geometrical parameters such as the number of floors, floor area, and floor aspect ratio were therefore considered, as listed in Table 2. These parameters are the fundamental factors

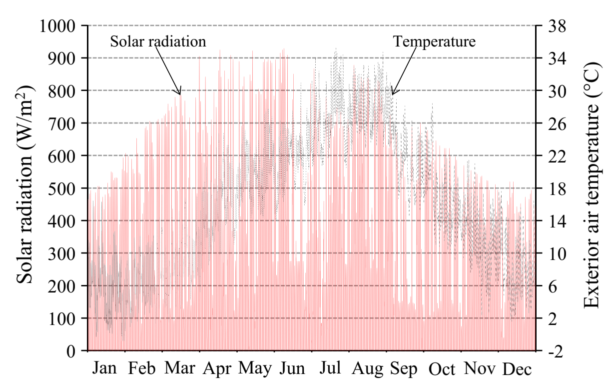


**Fig. 1.** Exterior weather in Tokyo. The solar radiation is the sum of the diffusive and direct solar radiation on a horizontal plane.