Energy and Buildings 55 (2012) 77–84

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# Study on the cool roof effect of Japanese traditional tiled roof: Numerical analysis of solar reflectance of unevenness tiled surface and heat budget of typical tiled roof system

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ARTICLE INFO

*Keywords:*
Japanese traditional tiled roof
Solar reflectance
Heat budget
Observation
Uneven surface
Urban heat island measure technology

ABSTRACT

To assess the effect of uneven tiled surfaces on solar reflectance, a numerical calculation was utilized to estimate the solar reflectance of several kinds of surface shapes. In addition, the relationship between solar reflectance of uneven surfaces and surface shapes was analyzed. Drawing on the calculation results, the reduction of solar reflectance from the flat surface was also estimated. A heat budget model of the tile surface and sectional direction of the roof system was developed on the basis of observation results relating to the thermal characteristics of a traditional tiled roof system. A comparative simulation with other urban heat island mitigation technologies, such as green roofs, was carried out under typical weather conditions.



## 1. Introduction

The urban heat island phenomenon, i.e., increased air temperature in urban areas, is recognized as a serious problem in Japan. Various urban heat island mitigation strategies have been developed, and their effectiveness has been verified in several applications, for example, cool roofs, green roofs, cool pavements, and HVAC systems with a little exhaust heat. Although the characteristics of each technology used for reducing the urban heat island phenomenon have been comprehensively examined by many researchers [1,2], an evaluation method to assess their effectiveness has not been developed; there are only a few examples of the implementation of mitigation technologies to address the urban heat island effect. Therefore, it is necessary to establish an evaluation method to analyze mitigation strategies to ensure that residents can identify the most suitable technology and industry can make technological advancements to further improve mitigation measures.

A majority of detached houses in Japan are wooden structures with tile roofs, and the tiles act as a mitigation measure to help prevent the spread of fire between houses. Through a geographic information system-based analysis of polygon data of buildings and digital aerial photographs, the rooftop region of the Tokyo metropolitan area was found to have a ratio of approximately 43% low-rise wooden houses [3]. Further, the ratio of clay tiles and cement slate tiles in residential houses is approximately 53% and 24%, respectively. Roofs are frequently in the shade of surrounding buildings. However, as the roofs of low-rise houses are often aligned, the roofs of such houses have the capacity to influence the urban heat island effect. Reflective solar radiation from high-reflectance roof tiles of such houses may increase the cooling load of neighboring buildings. The influence of solar reflection on roofs of surrounding buildings is estimated by a coupled simulation of radiation and convection around buildings [4]. The results show that reflective solar radiation from high-reflectance roofs to the walls of neighboring buildings is considerably less than direct radiation from the sun and sky. Consequently, it is critical to consider high-reflectance tiles as an urban heat island mitigation strategy. High-reflectance tiles have been developed and studied in the U.S. and Europe [5,6]. In Japan, glaze is a standard characteristic of roof tiles. Some of Japanese companies market high-reflectance tiles that are produced by altering the tile glaze. Compared to high-reflectance paint and green roofs, high-reflectance tiles are unpopular in Japan because consumers prefer to use traditional colored tiles. This study examines the cool roof effect of a traditional Japanese tiled roof through observation and numerical calculation of the surface heat budget of a typical tiled roof system.

## 2. Observation

### 2.1. Field observation of a typical tiled roof system

The observation site selected to investigate the surface heat budget of several types of typical Japanese tiled roof systems is located

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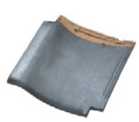
doi:10.1016/j.enbuild.2011.09.023

**Table 1a**
Image of tile, solar reflectance measure, and type of tile form (typical products).

| Name | Kimachi 1 | Kimachi 2 | Kimachi 3 | Wine red |
|---|---|---|---|---|
| Image |  |  |  |  |
| Reflectance | 0.23 | 0.22 | 0.17 | 0.21 |
| Type of form | J-type | J-type | J-type | J-type |
| Ibushi 1 | Ibushi 2 | Red | Choco | Black |
|  |  |  |  |  |
| 0.19 | 0.18 | 0.18 | 0.13 | 0.10 |
| J-type | J-type | J-type | J-type | J-type |

**Table 1b**
Image of tile, solar reflectance measure, and type of tile form (arranged products).

| Name | Shirakaba | White glace | Karin | Summit red |
|---|---|---|---|---|
| Image |  |  |  |  |
| Reflectance | 0.34 | 0.34 | 0.27 | 0.26 |
| Type of form | S-type | S-type | S-type | S-type |
| Eran | Kangen | Willow green | Tsuwano | Gao |
|  |  |  |  |  |
| 0.17 | 0.17 | 0.15 | 0.12 | 0.12 |
| F-type | J-type | F-type | S-type | J-type |

in Sekisyu region, as illustrated in Fig. 1. With imminently suitable soil for the production of high-quality tiles, Sekisyu region is one of three major traditional clay tile production zones in Japan. Images of tiles, solar reflectance, and the type of tile form are presented in Tables 1a and 1b. The tiles of "a-group" are typical products of the Sekisyu region and those of "b-group" are arranged tiles. Some arranged tiles that are light in color have a somewhat enhanced solar reflectance. Observation points and equipment are shown in Table 2 and Fig. 2. Solar reflectance of each tile is expressed as the average value at a high solar angle as measured by a net radiation meter set at 300 mm above the center of the tiled roof (about 1850 mm × 1900 mm). View factor between the tile surface and the net radiation meter is about 0.89. All data were recorded every minute, with the exception of surface temperature distribution, and 10 min averaged data were analyzed to produce the heat budget examination. An example of surface temperature distribution of the tile (solar reflectance is 0.22) observed by using an infrared thermal camera at 15:16 JST, August 17, 2005, is shown in Fig. 3. Variability of surface temperature dependent on an incident angle of solar radiation and tile shape is thus confirmed. Observation results detailing solar reflectance of the typical tiles are presented in Fig. 4. There are a number of tiles that display varied solar reflectance influenced by surface luster and/or tile shape.

**Table 2**
Observation points and equipment.

| Elements | Points | Equipment | Remarks |
|---|---|---|---|
| Net solar radiation | Roof surface | Net radiation meter at 300 mm high from tile surface | 0.305–2.8 μm |
| Temperature | Surface | Infrared thermo-couple | 6.5–14 μm |
| | Surface and backside of tile, air layer, surface and backside of board and inside air | Thermo-couple | T-cc; $\phi = 0.32$ mm |
| Surface temperature | Distribution | Infrared thermal camera | 8–13 μm |
| Weather condition | Solar radiation | Pyrheliometer | 1.5 m high from ground |
| | Air temperature | Thermistor-type thermometer | |
| | Relative humidity | Polymer membrane-type hygrometer | |
| | Wind direction and velocity | Propeller-type anemometer | |