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Temperature Control Using Solar Control Devices: A Case Study of Tepetlixpa Crafts Market

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Abstract: The study was conducted in a public building situated in Tepetlixpa, State of Mexico. The building was previously used as a municipal market but is currently underutilized. As part of the 'Tepetlixpa Tourist Corridor' project, it needs to be converted into a handicrafts market. A bioclimatic analysis was carried out on the interior of the building in order to control the temperature. The building is situated in a temperate climate zone with minimal fluctuations, according to the Köppen-García classification. It is classified as semi-cold in terms of bioclimatic grouping.

Solar control devices were proposed based on a solar analysis, which involved two stages. The first stage studied the incidence of the sun's rays inside the building using stereographic graphics. This determined the critical dates and hours of sunlight on the building's facades, as well as the ideal orientations for placing control devices to block direct sunlight.

The second stage involved creating a scale model of the building, which was evaluated in the heliodon of the Bioclimatic Architecture Laboratory at Universidad Autónoma Metropolitana, Azcapotzalco Campus. This analysis enabled us to observe the solar trajectory at latitude 19°03' north, longitude -98°82' (solstices and equinoxes) to verify the effectiveness of the proposed solar control devices.

We then used the Design Builder ® software (DesignBuilder, 7.0.2.004) to evaluate the thermal behavior inside the building, before and after the implementation of solar control devices to achieve passive temperature control and avoid the implementation of mechanical systems; evaluations were carried out in the most critical months: January and May, whose results indicate good thermal behavior with the proposed devices.

Keywords: solar control device, operating temperature, thermal comfort, thermal comfort, solar incidence, stereographic graph, heliodon, Design Builder software

Introduction

A constant topic in bioclimatic studies has been the search for and adaptation of the thermal comfort of human beings in a given architectural space. Undoubtedly, climatic conditions play a very important role in conjunction with the pulses of the earth, such as the equinoxes and solstices, when the solar loading and its effects on buildings pose different challenges in terms of design and adaptation of buildings.

This research presents the solar analysis of a building located in the Municipality of Tepetlixpa, State of Mexico. The analysis is part of the bioclimatic assessment of the building's performance. The building, known as the 'Old Market' (see figure 1), was originally built as a municipal market but has had various uses over time, including a dance workshop, offices for government agencies, and currently functions as a gymnasium. (Secretaría de Desarrollo Urbano y Obra, 2004)

The building has a rectangular floor plan of 47.30 m long x 8.24 m wide x 8.17 m high, with a built area of 389.75 m², a double-height level (see figure 1), with a roof section (see figure 1) and a gable roof. The construction system consists of 70 cm thick reinforced concrete columns covered with mortar-cement-sand mortar and painted in orange and beige tones, 3 mm windows with black ironwork, gray block wall plastered with mortar-cement-sand mortar and painted in orange and beige tones, volcanic stone wall with an apparent finish, and a gable roof of galvanized sheet supported by a metal structure made on site.

Figure 1. Northwest façade andInterior of the "Old Market". Photograph by Tania Osorio

Upon the request of the municipality, and following the objectives of the Tepetlixpa Municipal Development Plan to promote this area as a tourist corridor, a project was proposed to remodel the entire building and convert it into a handicrafts market, workshops, and cafeteria. The objective is to promote tourism, reinforce the identity of the locality, and provide an efficient use for the building. The building has been underutilized for several years because it has not been adapted to the specific needs of the activities that take place there.

The building has problems of overheating, despite being located in a temperate climate, due to the characteristics of the construction system, because it does not have any type of ventilation; the accesses are the only entrances that allow air exchange. Due to the thermo-physical properties of the materials that make up the construction system, the indoor temperature behaves similarly to the outdoor temperature during hours of extreme temperature.

Methodology

To carry out the analysis, the climatological normals of the site were taken, to determine the comfort zone, the neutral temperature was calculated using the Auliciems formula. Stereographic graph and heliodon were used to evaluate solar control devices. Finally, the behavior of the operating temperature was analyzed using the Design Builder software.

Discussion

Solar control devices can be an effective strategy to control the temperature inside spaces. Its effectiveness can be verified with the geometric method and specialized software.

Climatic Analysis

The municipality of Tepetlixpa is located at the following coordinates: latitude 19°03' north, longitude -98°82' west at an altitude of 2298 masl. The climatic classification according to Köppen-García is Cb s(x') (i') (temperate with little oscillation, not Ganges type, canicule). The bioclimatic grouping is considered semi-cold, since the average temperature of the hottest month (May) is below 21°C and its annual rainfall is between 650 and 1000 mm, with a total of 912.9 mm per year. There is little annual variation; the difference between the average temperature of the coldest month (January 11°C) and the hottest month (May 17°C) is between 6 and 7°C. The climatological data were obtained from the climatological normals of the Nepantla station of the National Water Commission (CONAGUA) and an EPW file of Tepetlixpa generated in Meteonorm®. (CONAGUA, Comisión Nacional del Agua, 2010)

Spring is the season that presents the months with the highest average temperature, with May being the warmest month of the year with an average temperature of 17°C, an average minimum temperature of 10.5°C and an average maximum temperature of 23.8°C. The season with the lowest average temperature is winter, with January being the coldest month of the year with an average temperature of 11°C, an average minimum temperature of 4.2°C and an average maximum temperature of 19°C.(CONAGUA, Comisión Nacional del Agua, 2010)

The comfort zone for January is 18.5°C - 23.5°C (64°F - 73°F). The comfort zone for the month of May ranges from 20.3°C - 25.3°C.

Tn January =17.6+(0.31x11) = 21.0°C Tn May =17.6+(0.31x17) =22.8°C
ZC January =21.01°C ±2.5°C =18.5°C-23.5°C ZC January =22.87°C ±2.5°C =20.3-25.3°C

Equation (1). Neutral temperature. Source. Steven Szokolay, Andris Auliciems, Thermal Comfort, PLEA, University of Queensland, 1997.(Andris Auliciems, 1997)

Architectural Proposal

The architectural program of the proposal is as follows: on the ground floor: handicraft area 162 m², cafeteria 93 m², shops 50 m², toilets 18 m², circulation 25 m², on the upper floor: workshops 115 m², warehouse 22 m² and circulation 34 m. Initially, the architectural proposal proposed to replace the galvanized sheet metal roof with a Sanwich Tile® panel roof, maintaining the two-slope system, and to add a skylight in the center of the building along the longitudinal axis to improve the lighting of the building. The openings on the southwest and northeast facades were eliminated, leaving only the openings on the southeast and northwest facades. A 30° overhang was proposed on the northwest façade, which is the main façade. (Panel Sandwich, s.f.)

To assess the effectiveness of the overhang, we used a stereographic graph to plot hourly temperature data. Our findings indicate that the southeast façade falls below the comfort zone throughout the year, while the northwest façade remains comfortable almost all year round. To maintain these comfort conditions, it is necessary to block direct solar incidence on this façade with a protection angle of 70°. The skylight receives solar incidence from 7:00 am to 4:00 pm throughout the year. The analysis of the skylight was conducted during the summer solstice, while the northwest facade was analyzed during the spring equinox.

Summer Solstice 7:00hrsSummer

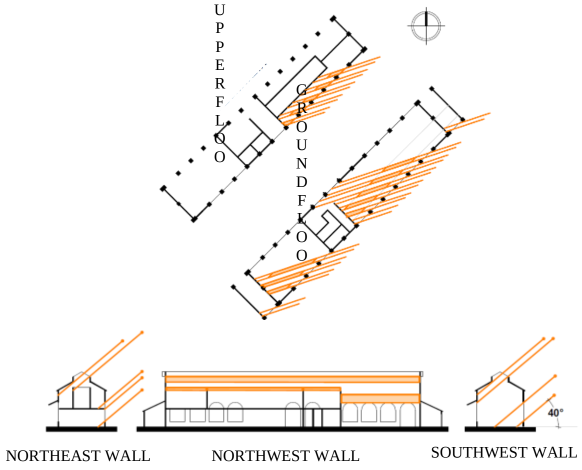


Figure 2. Summer Solstice 7:00hrs. Drafted by Tania O.

Solstice 16:00hrs

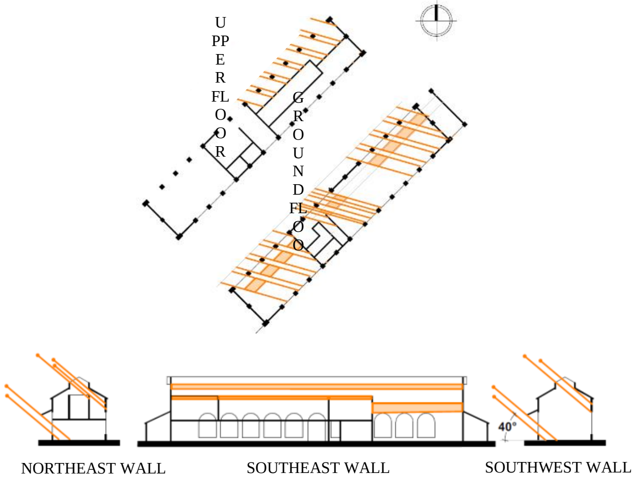


Figure 3. Summer solstice 16:00 hours. Drafted by Tania O.

Spring equinox 15:00hrs

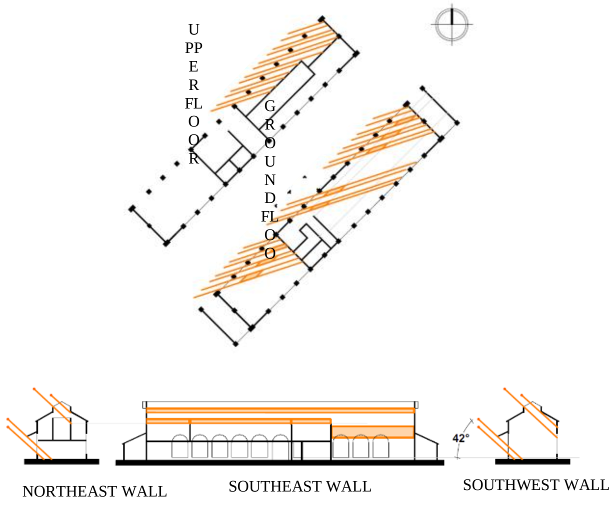


Figure 4. Spring equinox at 15:00. Drafted by Tania O.

Spring equinox 17:00hrs

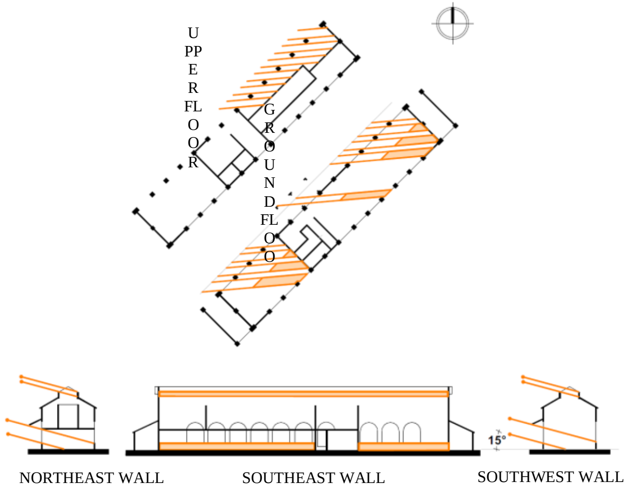


Figure 5. Spring Equinox 17:00hrs Drafted byTania O.

During the summer solstice, at 7:00 a.m., the sun's rays strike the skylight and enter the building through the northwest wall (refer to figure 2). At 4:00 p.m., the rays strike the skylight and enter the building through the southeast wall (refer to figure 3).

During the spring equinox, from 3:00 PM to 5:00 PM, the solar ray strikes the northwest façade and penetrates the interior of the building on the ground floor and the southeast wall. This occurs when the solar ray height is 42° and the azimuth is 108° north, and when the solar ray height is 15° and the azimuth is 95° north. The overhang does not prevent the incidence of the solar ray, as shown in Figures 4-5.

Design of Solar Control Devices

In order to protect the northwest façade from solar incidence, a series of sunshades made of reinforced concrete of 2.10 x 0.50 x 0.10 m thickness with an inclination angle of 70° (see Figure 6-7) and a spacing of 0.40 m between each element, these elements were designed and anchored to a reinforced concrete wall of 0.50 x 0.60 m attached to the lower part of the façade throughout the year. The device is designed to prevent direct sunlight from entering the interior of the building throughout the year. (Michael Docherty, 1999)

Sunshades, Northwest Façade

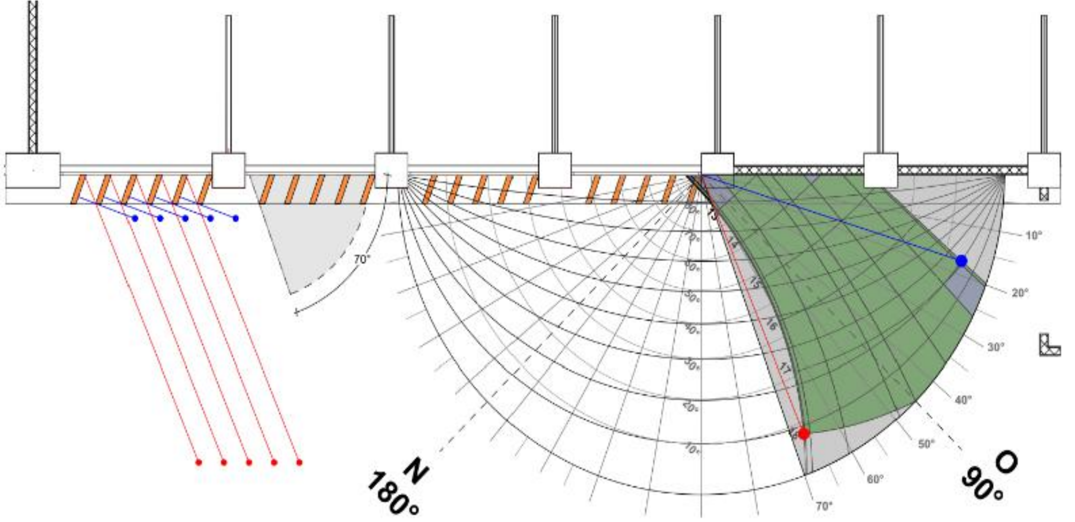


Figure 6. Sunshades, northwest façade. Drafted by Tania O. using Archicad 23®

View of Sunshades, Northwest Façade

Figure 7. View of Sunshades, northwest façade. Drafted by Tania O. using Archicad 23®

To prevent solar rays from entering the building through the skylight, a device was designed using screens arranged at different inclinations. The screens are set at 180° to prevent lightning when it is at the zenith, 150° to prevent lightning when it strikes the southeast facade in the mornings, and 30° to prevent lightning when it strikes the northwest facade in the afternoons (refer to Figure 8). The screen is composed of 2.4 x 1.2 m Panel Rey Light Rey® gypsum panels, each 12.7 mm thick, suspended with steel wire anchored to the roof structure. (Yovane, 2003)

To test the effectiveness of the devices, a 1:50 scale model was made and analyzed in the heliodon. The analysis confirmed that the screen blocks solar incidence from the skylight and the sunshades on the northwest facade block solar incidence during the afternoons. Figure 10 displays the southeast facade, roof, and northwest facade during the summer solstice at 7:00, 12:00, and 16:00 hours. Figure 11 displays the northwest facade during the vernal equinox at 15:00 and 17:00 hours.

Cutaway View of the Screening Device

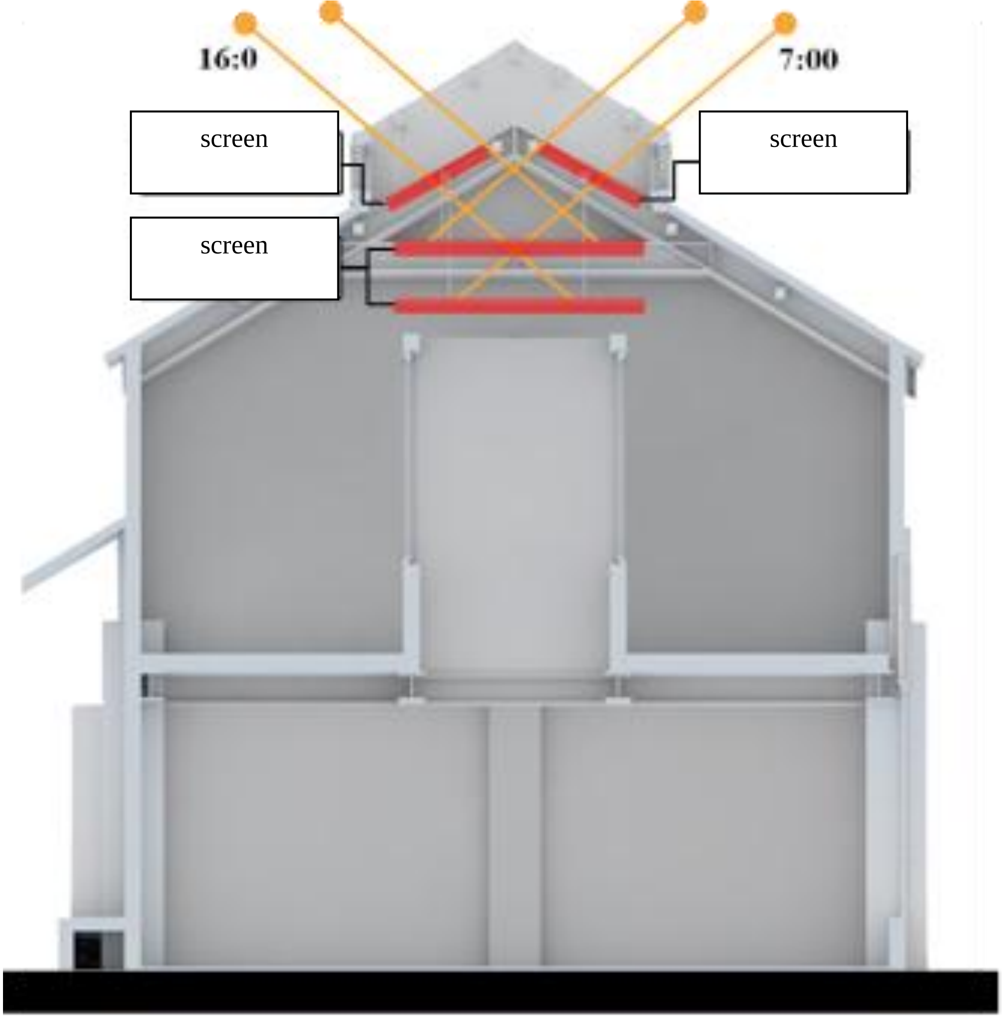


Figure 8. Cutaway view of the screening device. Drafted by Tania Osorio using Archicad 23®

Solar Control Devices on Summer Solstice 7:00, 12:00 And 16:00 Hrs

Figure 9. Solar control devices on summer solstice 7:00, 12:00 and 16:00 hrs. Photographs by Tania Osorio using the heliodon

Solar Control Devices in Spring Equinox 15:00 and 17:00 Hr

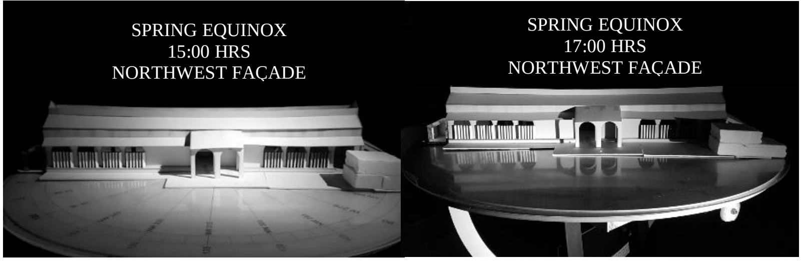
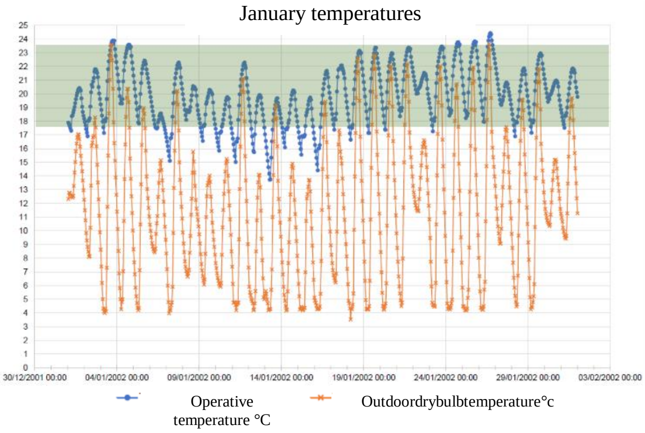


Figure 10. Solar control devices in spring equinox 15:00 and 17:00 hrs. Photographs by Tania Osorio using the heliodon

To determine the temperature behavior inside the building, we utilized the Design Builder® software as a thermal analysis tool. The building was modeled using the thermo-physical properties of the construction system's materials. For the project's location and climatic data, we loaded the .EPW Tepetlixpa file obtained from Meteonorm®. The analysis was conducted based on the adaptive ASHRE standard 55 parameters. Sinusoidal graphs were generated to display the monthly temperature behavior inside and outside the building. The operating temperature and dry bulb temperature were recorded, showing the comfort zone for January and May, as well as the temperature for all days and hours. The coldest month of the year, January, corresponding to winter, and the warmest month of the year, May, corresponding to spring, are both displayed. The building operates from 8:00 am to 9:00 pm all year, and the comfort zone was calculated accordingly to this hours of each month.

In January (see Figure 11), the comfort zone ranges from 18.51°C to 23.5°C, while the outside temperature (TBS) ranges from 3.5°C to 23.5°C. The operating temperature during this month ranges from 14°C to 24.5°C. There were 21 days when the temperature was below the comfort zone, occurring between 1:00 am and 9:00 am. Additionally, there were 5 days when the temperature was above the comfort zone, occurring between 12:00 pm and 3:00 pm. Finally, there were 9 days when the temperature was completely within the comfort zone. The operating temperature is within the comfort zone most of the operating time. (Victor, 1962). In May (see Figure 12), the comfort zone ranges from 20.37°C to 25.37°C, while the outside temperature (TBS) ranges from 6.5°C to 28.3°C. The operating temperature during the month ranges from 17°C to 27.7°C. There are 9 days when the temperature falls below the comfort zone, ranging from 3:00 am to 7:00 am, and 10 days when it exceeds the comfort zone, ranging from 12:00 pm to 6:00 pm. 14 days are completely within the comfort zone. The operating temperature is within the comfort zone most of the operating time. (Olgyay, 2019 5ta edición)



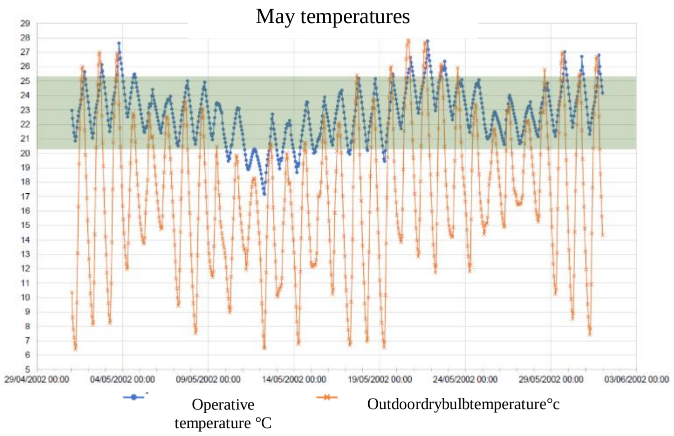


Figure 11. January temperatures. using data from Design Builder

Figure 12. May temperatures. using data from Design Builder.

Conclusions

The proposed horizontal solar control device (overhang) does not provide adequate protection from solar incidence during critical hours of summer and spring on the northwest facade. However, the vertical device (sunshade) with 70° of protection effectively prevents solar incidence on the northwest facade. During the summer solstice and spring equinox, these parasols effectively blocked the sun's rays for the entire afternoon on the northwest façade. (DesignBuilder, 7.0.2.004)

The screen device proposed to block the solar incidence that the building receives on the skylight from 7:00 to 17:00 hours managed to avoid the incidence inside the building during the mornings when the solar ray hits the southeast facade, during the middle of the day when the sun is at the zenith and during the afternoons when the solar ray hits the northwest facade. By avoiding solar incidence inside the building, comfort is maintained during the afternoon, and by leaving solar control devices on the southeast façade, heating is achieved during the morning when temperatures are below comfort. (DesignBuilder, 7.0.2.004)

The implementation of these solar control devices demonstrated that during May, the hottest month of the year, there were 14 days within the comfort zone, 2 days with an operating temperature exceeding the comfort zone by less than 1°C, 5 days exceeding the comfort zone by less than 2°C, and 3 days exceeding the comfort zone by more than 2°C. Additionally, the operating time in May had more hours within the comfort zone than outside it, and the operating temperature had less oscillation than the outside temperature. In January, the coldest month of the year, the operating temperature is within the comfort zone for 9 days, exceeds it by less than 1°C for 4 days, exceeds it by 1°C for 1 day, and is below the comfort zone by less than 2°C for 8 days. The operating time in January has more hours within the comfort zone than outside it, and the operating temperature has less oscillation than the outside temperature. (DesignBuilder, 7.0.2.004)

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