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# An Automatic Curtain System for Indoor Daylight Control

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---***ABSTRACT***---
*This study aims to create a climate-responsive design idea to control direct sunlight entering the building. Direct sunlight provides natural lighting but might overheat the environment. A shade device can control direct sunlight entering the room. In contrast to its residents' desire for natural light, the static shade mechanism cannot block direct sunlight whose incident angle changes throughout the year or cover the full glass area. To achieve this, we must design a shade device that works automatically, adjusts room illumination, and doesn't overheat. We designed, installed, and tested automatic curtains to show their ability to alter illumination levels in real time and reduce room heat. This device was tested in a 1:1 scale humid tropics the house, confirming its dependability and usefulness.*

***KEYWORDS;-*** *daylight, automatic curtain, shading device, illumination control*

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## I. INTRODUCTION

A significant portion of energy consumption in the construction sector is attributed to air conditioning, particularly in the humid tropical climate. This applies to both public buildings and residential buildings, accounting for approximately 40% of the energy usage. When a building is designed without considering the location and environmental conditions, and when improper materials are used, it can lead to increased energy consumption. In humid tropical climates, buildings often grapple with the challenge of balancing the need for comfortable indoor conditions while minimising direct sunlight. This involves finding ways to filter the light and utilise it as a source of natural daylight illumination. This issue needs to be resolved urgently as the uncontrolled entry of direct sunlight into the room is causing overheating. This, in turn, leads to an increased cooling load and higher energy consumption. Applying shading devices that can regulate the amount of light entering while preventing excessive heat can be implemented in the mentioned scenarios. Shade devices that are meant to be permanent may not always be effective in blocking sunlight, as the angles of the sun change periodically, even throughout the year. The design of a shading device must take into account the varying angles of light and heat that it will be exposed to, as a fixed imaging device would not be able to accommodate these changes. It is crucial to have shading devices that can be adjusted automatically to prevent the room from being exposed to excessive light and heat.

Kindangen et al. (1993-2006) carried out a number of studies, particularly in the area of parametric studies of architectural elements' performance to enhance natural ventilation. The distribution and pattern of air flow, particularly the input from the intake and exhaust, determine how well natural ventilation works, particularly in terms of achieving thermal comfort. When automatic shading devices are integrated with windows or apertures for ventilation, the results will be mutually reinforcing. In general, ventilation plays a helpful role in clearing out hot air and replacing it with fresh air, which has a cooling psychological effect.

When engineers encounter variations in climate parameters like air temperature, humidity, and daylight, the matter of solar heating and shading device control becomes crucial. A study conducted by Ahmed et al. (2011) examined the effectiveness of smart permanent shading devices. Their findings indicated that the implementation of these devices can enhance the thermal performance of office spaces. Matusiak et al. (2006) also present a method for permanently exterior shading device patterns. In her research, Marie Claude Dubois (2003) presents the findings of her study on a technique for identifying shade devices. These studies primarily focus on temperate climates and may yield different results when applied in humid tropical climates. In a study by Chia-Peng (2004), it was found that shade devices in architectural design have the ability to regulate the amount of daylight entering a space. Similarly, Carmody et al. (2006) conducted research on commercial building objects with similar objectives.

The daylight factors are influenced by various factors, including the sky components, external reflected components, and internal reflected components. This can be observed and documented:

$$DF = SC + ERC + IRC \qquad (1)$$

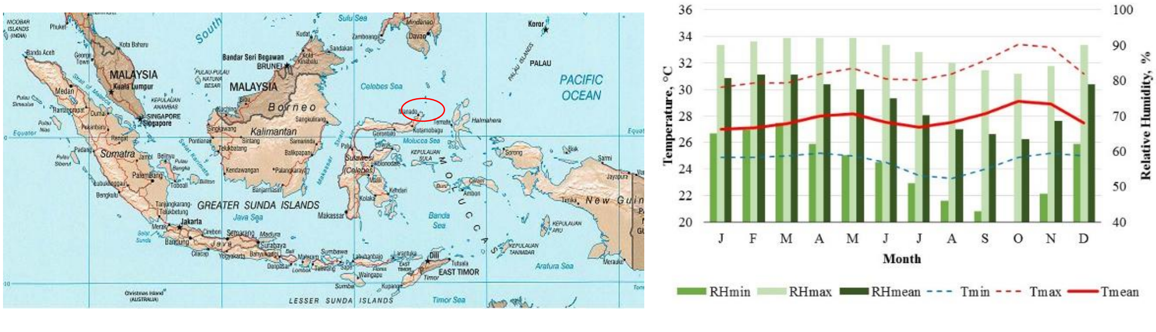
An investigation into dynamic window systems and new switchable technologies was conducted by Karlsson (2001). The study focused on the control system and the potential energy savings. This was followed by research conducted by Lee et al. (2004) and Jian Yao et al. (2011), which primarily examined the economic aspects of construction and the energy-saving operation of these systems. The European Commission (2002) published a programme called Thermie that included a system of shadings for the European climate. However, there is still very limited information available regarding the Southeast Asian climate, and similar studies have not been made public yet. A study conducted by Gutierez et al. (2007) focused on researching the material, typology, and orientation of shading devices. The study found that the experimental subjects were highly valuable in creating a database for shading design. Kim et al. (2009) conducted a study on external shading devices to enhance views and optimise visual performance, particularly in relation to lighting. In addition, the studies conducted by Wong et al. (2003) and Corrado et al. (2004) provided a thorough examination of the significant impact that external shading devices have on lighting and natural ventilation. In his doctoral thesis research, Rosencrantz Tobias (2005) highlighted the significance of evaluating the performance of windows and shading devices in order to enhance energy efficiency. By measuring and simulating their performance, valuable insights can be gained.

Research on smart shading devices has yielded limited findings, leaving countless researchers searching for more. In their study, Lu, Jiakang et al. (2011) demonstrated the application of a straightforward light sensor for the purpose of obtaining intelligent lighting. In 2006, Pablo La Roche proposed a smart passive system aimed at achieving carbon neutral buildings or zero emission buildings. In 2005, he was conducting research on the shadowing effect of combining smart technology and ventilation to enhance thermal comfort. A researcher who has made significant contributions to the field of intelligent control is Selkowitz et al. (2006, 2008, 2009). Their work primarily focuses on the automation of shading devices and smart glass for natural lighting control. Buhagiar et al. (2008) conducted research to enhance the findings of Selkowitz, particularly with regards to their applicability in the Mediterranean climate. Most studies on this topic have focused on subtropical climates. However, the use of automatic curtains for indoor lighting in humid tropical climates is still uncommon and has not been extensively researched.

## II. METHODOLOGY

**Location**

The research was carried out in Manado, which is situated in the province of North Sulawesi, Indonesia. Manado has an astronomical position at latitude 1.4583 °N and longitude lines 124.8260 °E. Manado experiences a humid tropical climate, with the hottest month being October, where the average temperature reaches 29.10 °C, and the coldest month being January, with an average temperature of 26.90 °C. In terms of temperature, there isn't a significant difference between the hottest and coldest months. During the months of November to March, there is a significant amount of rainfall, with the highest average occurring in January at 465 mm. Yearly variations in air temperature amplitudes on a daily and monthly scale are relatively small. Figure 1 presents the varying relative humidity of the air throughout the year, with levels ranging from 64% in October to 81% in January and March.




(a) (b)

Fig. 1. Map of Indonesia where Manado is (a); Climatic data for North Sulawesi Province, Indonesia (b).

**Hardware Design**

The basic framework design of the automatic shading system incorporates various sensors, actuators, and motorization controls based on the necessary device functions. To obtain the fundamental model and the appropriate algorithm, multiple steps are undertaken. Figure 1 depicts a block diagram of an automatic illumination control device.

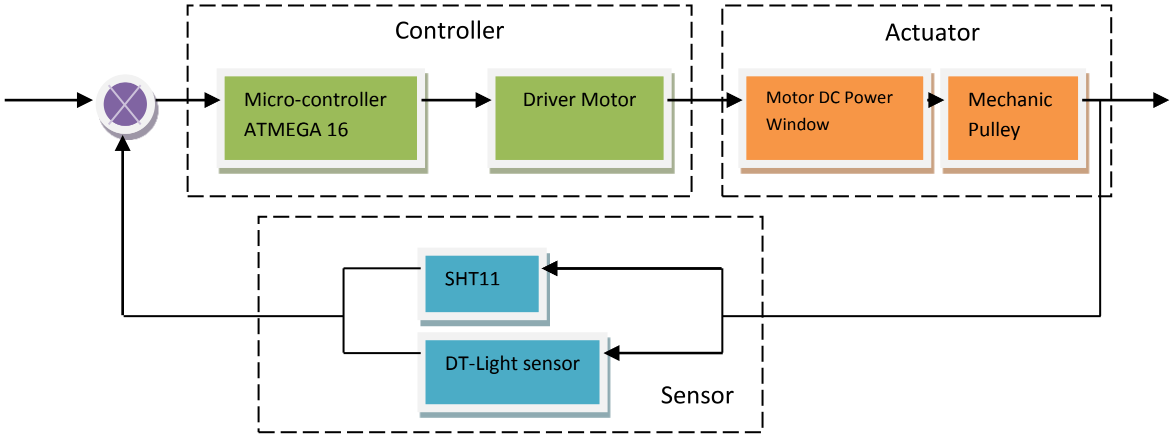



Fig. 2. Automatic illumination control device block diagram.

The process employed in designing this device involves breaking it down into sub-systems and individual components. Block diagrams visually represent the integration of different sub-systems to form a complete system. The sub-system is composed of controllers, sensors, and actuators. The system incorporates the ATMEGA 16 micro-controller and motor driver, in addition to a range of sensors such as SHT11 sensors for monitoring air temperature and humidity, and DT-Light sensors for measuring light levels. The actuator is composed of a DC power window motor and a mechanical pulley that is used to raise and lower the shade curtain.

The voltage source for the ATMEGA 16 AVR microcontroller system is obtained by combining a 12 Volt voltage, an 18 Volt motor driver, and a current of 5 amperes. The DC motor driver is used to determine the rotation direction of the motor, which will either raise or lower the shade panel. The SHT11 sensor, multi-rotation potentiometer, and DT-Light sensor are designed to operate using a 5 Volt voltage source. The rotation of a DC motor is regulated using a multi-round potentiometer.

The test model employed in this study is a wooden house measuring 5.5 x 6 metres. The house is a traditional wooden structure that is widely accessible in the public market. The structure comprises a terrace and two rooms, designated for both living and bedroom purposes. The selection of this bedroom as the subject of investigation was made. The room is equipped with two windows, located on the West and South sides. The roof is constructed using corrugated zinc sheets, while the window frames are made of wood and feature standard transparent glass. The test house was located on a parking lot that was paved with paving blocks at the Faculty of Engineering, Sam Ratulangi University in Manado, Indonesia. The position and orientation of the test model, as depicted in Figure 3, represent the extreme condition of maximum solar heating. The placement of automatic curtain devices is optimised on windows located on the West side, where the effects of lighting and solar heating are most favourable.

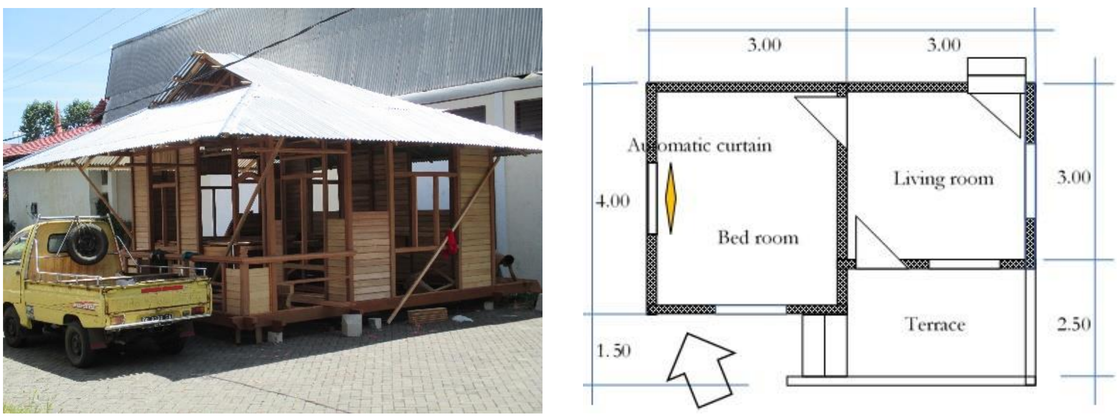



Fig. 3. The description of a test model.

The multiturn potentiometer serves as the input device for regulating the rotation of the DC motor power window. The sensor is employed to accurately modify the position and condition of shading. The sensor generates an analogue voltage output, which is subsequently compared to the shade position measurements of the room. The actuators utilised in this system are the Super High Torque (DC) motor and internal gear. These actuators have the ability to lift loads weighing up to 70 kg. The engine's rotational velocity is approximately 67 revolutions per minute (rpm). The shade panel can be retracted using a pulley system that incorporates a 7 cm pulley diameter. This pulley is connected to a DC power window motor and a multi-bit potentiometer. The manipulation of the shade through rolling and stretching techniques provides a means of achieving precise control over its vertical movement. This allows for the adjustment of the shade to the desired position and condition. The shade material is fabricated using synthetic wood and features a folding pleated design, which enhances its suitability for modelling and testing applications. The dimensions of the shading panel used are 50x50 cm, as shown in Figure 4. The shading panels are positioned on the interior side of the window, as depicted in Figure 5.

Fig. 4. Shading panel used.

Fig. 5. Installation of automatic curtain in the test model.

**Software Design**.

The main programme consists of several routines, including an initialization routine, a sensor readings routine, and an actuator control method that relies on sensor readings. The programme will be executed when the microcontroller receives a 12 Volt power supply. The code initialises the Chip, PORT, I2C, ADC, and performs the standard procedure for retrieving data from the sensor. The DT-Light sensor is calibrated in Lux units, the SHT11 sensor is calibrated in degrees Celsius for temperature measurement and percentage for air humidity, and the multi-turn potentiometer is calibrated using a 10-bit Analog-to-Digital Converter (ADC). The actuator executes a predetermined sequence to ascertain the position of the shading panel, which can be either raised or lowered. This determination is made by analysing inputs received from temperature sensors, air humidity sensors, and light level sensors. The actuator is capable of controlling the shading panel in five distinct positions, which are categorised as state 0 through state 4.

The actuator's matching sensor readings are determined based on inputs received from light sensors, temperature sensors, and air humidity sensors. The location or condition of shading is determined by comparing the readings to a defined threshold value. The automated curtain has the capability to be adjusted to five distinct positions.

| Parameters | Thresholds | | |
|---|---|---|---|
| | I | II | III |
| **Illumination (Lux)** | <200 | 200-350 | >350 |
| **Temperature (°C)** | <25 | 25-30 | >30 |
| **Humidity (%)** | <50 | 50-60 | >60 |

**Table 1. Input sensor threshold specifications.**

| State | Position Shading |
|---|---|
| **0** | Fully Closed |
| **1** | Partial Closed |
| **2** | Half-Closed/Open |
| **3** | Partially Open |
| **4** | Fully Open |

**Table 2. Position of the shading panel.**

The subsequent table illustrates the states of shading response with respect to light, ambient temperature, and humidity parameters.

| **Illumination** (lux) | **Temperature** (°C) | **Humidity** (%) | **State of Shading** |
|---|---|---|---|
| **>350** | >30 | <50 | 0 |
| **>350** | >30 | 50-60 | 0 |
| **>350** | >30 | >60 | 0 |
| **>350** | 25-30 | <50 | 0 |
| **>350** | 25-30 | 50-60 | 1 |
| **>350** | 25-30 | >60 | 1 |
| **>350** | <25 | <50 | 0 |
| **>350** | <25 | 50-60 | 1 |
| **>350** | <25 | >60 | 1 |
| **200-350** | >30 | <50 | 1 |
| **200-350** | >30 | 50-60 | 1 |
| **200-350** | >30 | >60 | 2 |
| **200-350** | 25-30 | <50 | 1 |
| **200-350** | 25-30 | 50-60 | 2 |
| **200-350** | 25-30 | >60 | 2 |
| **200-350** | <25 | <50 | 1 |
| **200-350** | <25 | 50-60 | 2 |
| **200-350** | <25 | >60 | 3 |
| **<200** | >30 | <50 | 2 |
| **<200** | >30 | 50-60 | 3 |
| **<200** | >30 | >60 | 4 |
| **<200** | 25-30 | <50 | 3 |
| **<200** | 25-30 | 50-60 | 3 |
| **<200** | 25-30 | >60 | 4 |
| **<200** | <25 | <50 | 3 |
| **<200** | <25 | 50-60 | 4 |
| **<200** | <25 | >60 | 4 |

**Table 3. Shaded state parameters.**

## III. RESULTS AND DISCUSSION

The automatic curtain design plays a critical role in regulating the level of indoor illumination. The daylight factors are influenced by several factors, including the sky components, external reflected components, and internal reflected components. The values of these parameters can vary depending on the current atmospheric conditions. Under these circumstances, it can be assumed that the influence of both the external reflected component and the internal reflected component is either insignificant or remains consistent. The correlation between indoor and outdoor illumination is clearly demonstrated by Figures 4a and 4b, revealing a noticeable pattern. The level of exterior illumination varies between 3000 and 12000 lux throughout the day. The peak level of illumination is commonly observed during the time frame of 6 a.m. to 3 p.m. Nevertheless, the primary factor affecting this phenomenon is the state of the sky, which is subject to variation.

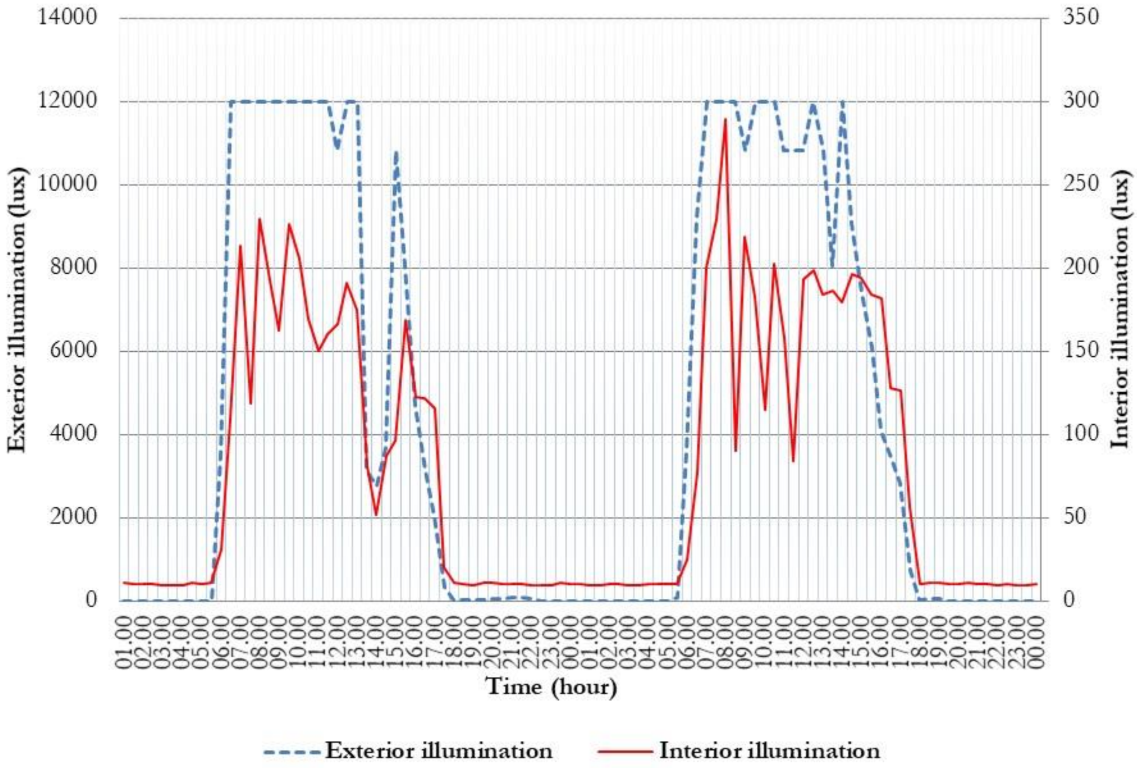



Fig. 6. Exterior and interior illumination profiles.

Figure 6 illustrates the interior illumination curve, which is subject to variation depending on the level of exterior illumination. The applicability of this curve is limited to room illumination levels between 50 and 300 lux. The bedroom in the sample building exhibited an average lighting level of only 1.7% of the exterior lighting. The bedroom illumination is determined by multiplying the level of exterior illumination by a factor of 0.017. The fluctuations of the automatic curtain reaction are influenced by factors beyond the lighting level parameters. The fluctuation of the curve is significantly influenced by the position of the curtain, as well as the air temperature and humidity parameters.

The air temperature measurements conducted over a span of two consecutive days in a room equipped with an automatic curtain have been presented in Figure 7, alongside the corresponding exterior air temperature. The humidity levels exhibit consistency in both indoor and outdoor air environments. The measurement was conducted using a digit-data logger TLH, which was placed both inside the room and outside. The windows and doors of a room equipped with shading panels were intentionally kept closed for a full day, leading to insufficient ventilation for regulating the microclimate within. The shading device has been proven to effectively regulate indoor air temperature, keeping it lower than the outdoor temperature. The pronounced effect is observed primarily between the hours of 6 am and 4 pm. During the remaining hours, the room temperature exceeds the temperature outside. The air humidity within this enclosed space exhibits a higher degree of control, with a range of 55% to 77%. This is in contrast to the external environment, where humidity levels are prone to greater fluctuations.

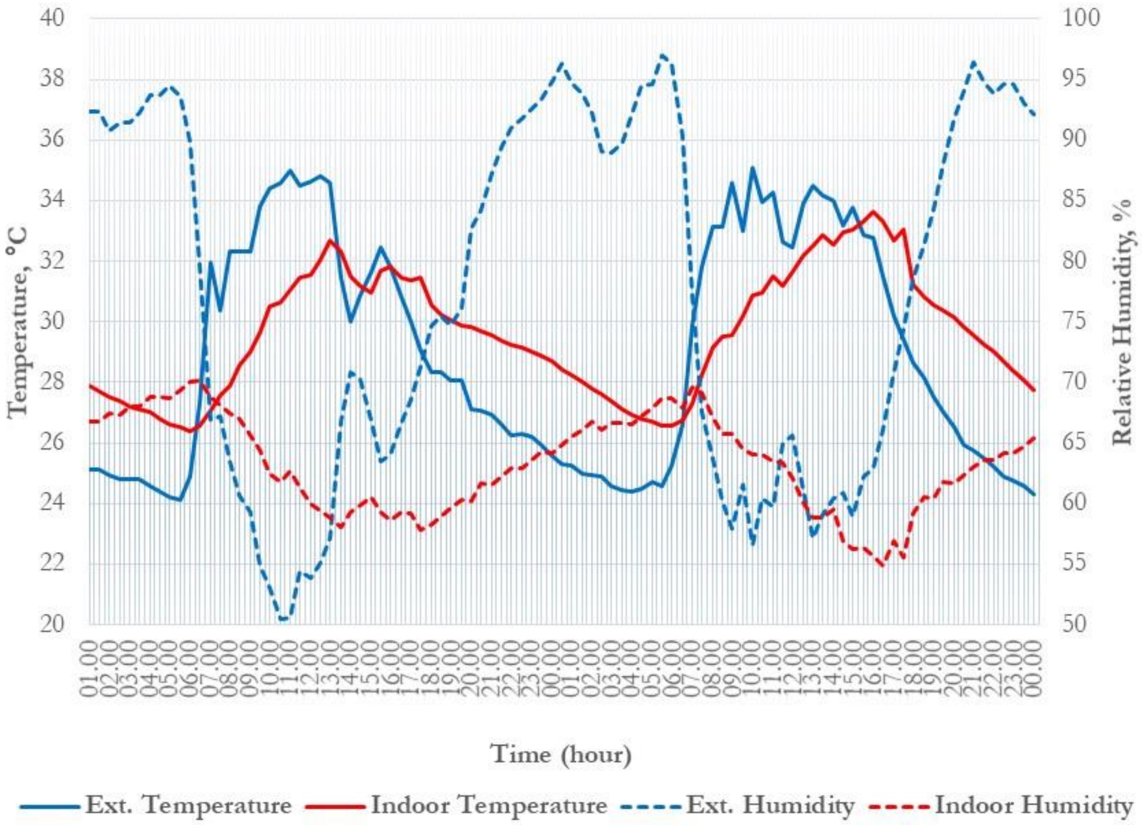



Fig. 7. Examining the profile of exterior and indoor air temperature and air humidity.

## IV. CONCLUSION

The design of a smart shading device has been carried out in the primary aspects, specifically the design of the hardware and software, as well as the design of the device more generally. It has been demonstrated that applications can be used at a scale of 1:1 in a building model. Throughout the course of the tool, tests have been practiced, and they have been successful. Although there are many different kinds of shading devices that may be used, the selection of the type of shading device should be based on the materials and tools that are accessible. It is advisable to continue this study, specifically concentrating on reliability tools and their implementation in industrial settings. Additionally, there is a requirement for enhancements, notably in the form of more intricate algorithms, and significant efforts are necessary to establish these as viable commercial products.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