**Research & Development**
2022; 3(1): 64-72
http://www.sciencepublishinggroup.com/j/rd
doi: 10.11648/j.rd.20220301.21

# Indoor Thermal Comfort Analysis of Curtain Wall Front Façade Office Building Through Field Measurement in Addis Ababa, Ethiopia

**Amanuel Hailu*, Nebyou Yonas**

Department of Architecture, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia

**Email address:**
amanuelhailu27@gmail.com (A. Hailu)
*Corresponding author

**To cite this article:**
Amanuel Hailu, Nebyou Yonas. Indoor Thermal Comfort Analysis of Curtain Wall Front Façade Office Building Through Field Measurement in Addis Ababa, Ethiopia. *Research & Development*. Vol. 3, No. 1, 2022, pp. 64-72. doi: 10.11648/j.rd.20220301.21

**Received**: January 11, 2022; **Accepted**: February 5, 2022; **Published**: February 28, 2022

**Abstract:** The façade is one of the foremost imperative impacts on indoor thermal comfort, because it directly controls the amount of natural lighting and passive heat gains that enters a building's interior. This means it has a crucial impact on the thermal comfort of the users (occupants) and indoor environment. Ultimately, this research contributes to the question of how a building curtain wall façade have an impact on indoor thermal comfort. To study the thermal comfort in curtain wall façade office buildings with naturally ventilated, a field study was carried out for two months on four office buildings to evaluate indoor thermal comfort in Addis Ababa. This study was based on the adaptive model of ASHRAE-55. Findings suggest that the four office buildings perform differently in terms of thermal comfort (based on field study), environmental parameters (air temperature, mean radiant temperature, relative humidity, and air velocity) and surface temperature. As a result, the building 1, 2 and 3 shows thermal discomfort to the indoor environment during a period of extreme heat, compared to building 4. It is postulated that the higher surface temperature will cause higher indoor temperature levels in all buildings, except building 4. In both months a maximum of 30.6°C, 29.6°C, 28.3°C and 25.7°C of indoor ambient temperature for Building 1, Building 2, Building 3 and Building 4 have recoded respectively. The large temperature differences also have the expected consequences on indoor relative humidity fluctuation. The relative humidity value ranges from 16% to 71% in all 4 buildings. Most of the time air velocity that within buildings is generally less than 0.2m/s, which is generally unnoticed. The temperature difference between surface temperature and indoor temperature is between 11.2°C and 25.2°C. At the maximum exterior surface temperature of 55.5°C, at same time maximum indoor temperature recorded which 25.2°C. The study benefits architect, designers and construction managers by broadening the perspective of the field toward using a more customized optimization framework in early design that will further guarantee the requirements of sustainable indoor thermal comfort in office building development.

**Keywords:** Thermal Comfort, Curtain Wall Façade, Field Measurement, Office Building

## 1. Introduction

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation [1]. It can only be maintained when the heat produced by metabolism equals the heat lost from the body [2]. The main factors that influence thermal comfort are those that determine heat gain and loss, namely metabolic rate, clothing insulation, air temperature, mean radiant temperature, air speed and relative humidity. The environmental parameters are air temperature, mean radiant temperature, relative humidity and air velocity. The people-related parameters are metabolism and clothing [3]. Thermal comfort is also the outcome of the interaction and adaption of environmental and human body characteristics, according to studies [4, 5] and according to ASHRAE [1], a building's indoor thermal state is appropriate when 80% of the building's inhabitants are satisfied and comfortable. Temperature, air velocity, humidity, and radiation are all environmental influences. [6]. A curtain wall is defined as a thin, usually aluminum framed wall, containing in-fills of glass, metal panels or thin stone in addition to glazed-in window and door openings [7]. The extensive use of glass directly affects the energy needs of the building and its level of internal thermal comfort [8]. The development of modern architecture in 1960s and 1970s has led to the use curtain wall façade. Since then, the use curtain wall façade has become predominant in Addis Ababa, especially for the last two decades. Addis Ababa lies on 2350m above sea level; the climate is warm and temperate. The summers are much rainier than the winters in Addis Ababa.

The kind or color of glass used in glass facades has been demonstrated to be an important influence in defining the thermal, visual, and environmental comfort within the space, as well as helping to convey the architectural identity of the location [9]. In the last two decades, the growth of office building design and construction in Addis Ababa has shown a rapid growth. This led to a platform, which create and explore to emerging modern building façade construction and materials. The facade represents a separating shell that interacts between the interior space and the outside climatic conditions, its performance must be identical to that building. The study undertaken by Fanger [10] reveled that thermal environments, personal factors, and other contributing factors determine thermal comfort. Environmental factors include air temperature, air velocity, humidity, and radiation [10].

## 2. Materials and Methods

There are several most common methods for studying the thermal comforts, the building façade quality. There were five commonly used methods by the researchers, which are the real simulation, numerical & experimental methods, questionnaires and observation, case studies and computer simulation. The methodology and analysis used in this study is one of the most common and effective method, which is field measurement.

*Figure 1. Study area and building location (a) study area, (b) Ethio-Life and General Insurance building (building 1), (c) Oromia International Bank building (building 2), and (d) Lebenz Tower building (building 3) and Rizq building (building 4).*

### 2.1. Location of the Study

This study is focused on specifically office buildings in Addis Ababa. Addis Ababa is selected due to the current capital city of Ethiopia and which is primary area for building construction industry, especially in growth of modern curtain wall façade office building design and construction. Due to the street orientation (south and west facing façade) and the fact that the front facades face south and west for data comparison, low curtain wall façade performance, and a lack of exterior shade devices, these offices are exposed to radiation. Since the detrimental effects of solar radiation and direct sunlight can be mitigated through the use of shade devices [11].

*Figure 2. Selected office building – Ethio-Life and General Insurance building (a), Oromia International Bank building (b), Lebenz Tower building (c) and Rizq building (d).*

The study site is located around Bole Dembel and road to Meskel Flower in Addis Ababa located at latitude 9.00109 and longitude 38.76705.

### 2.2. Field Measurement Tools

Three types of tools were used in the experiment for measuring and monitoring ambient temperature, relative humidity, air velocity and façade surface temperature. Hygrometer was used to measure room temperature and humidity, anemometer used to measure air velocity and infrared thermometer used to measure surface temperature.

*Figure 3. Field survey measurement tools (a) hygrometer, (b) anemometer and (c) infrared thermometer.*

***Table 1.*** *Field survey measurement tools description.*

| Description | Tools | | |
|---|---|---|---|
| | **Hygrometer** | **Anemometer** | **Infrared thermometer** |
| Model | HTC-2 Digital Hygrometer | Smart sensor anemometer | HW600 Handheld Non-Contact Infrared Thermometer |
| Measuring range | T: -50°C – +70°C<br>H: 8% – 99% | 0 – 45 m/s | -50°C – +600°C |
| Accuracy | T: ± 1°C<br>H: ± 10% | ± 3% ± 0.1dgts | ± 1.5°C |

### *2.3. Data Collection and Methods*

Since the study is focusing on the effects, process and consequences, the research method could take both qualitative and quantitative. Relative humidity of the room, indoor and outdoor ambient temperature, indoor and outdoor air velocity and exterior and interior surface temperature of front curtain wall facades were collected. These data were collected from single floor space at all 4 office buildings at Bole Olympia and Meskel Flower in Addis Ababa.

Actual measurements of indoor air temperature, relative humidity, air velocity (air speed) and surface temperature are undertaken by digital hygrometer thermometer, infrared thermometer and anemometer. Study and measurement comprise three stages from April 12 up to 16 and May 17 up to 21 in 2021: first, in the morning (3:00); second, in mid-day (6:00); and the third stage is afternoon (9:00).

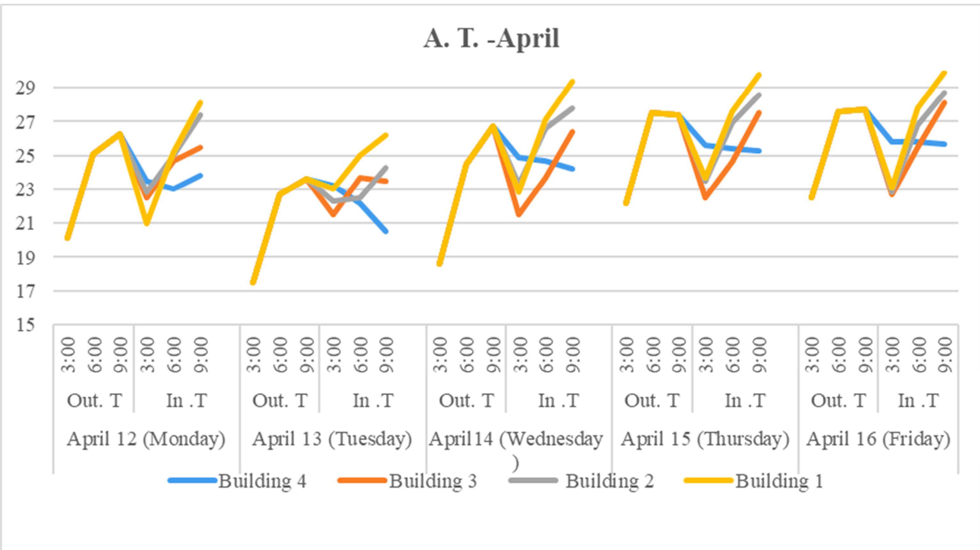
## 3. Results and Presentation

Thermal conditions in buildings are seldom steady, due to the interaction between building structure, climate, occupancy, and HVAC system [12]. The readings on air velocity, relative humidity, operative temperatures and surface temperatures, were made with high-precision sensors. The measuring period was 20 min. The readings were then directly stored in a notebook to avoid their manual loading. Excepting the air temperature sensors, which are located at 1.2 m above ground level, the remaining instruments are located at 1.1 m.

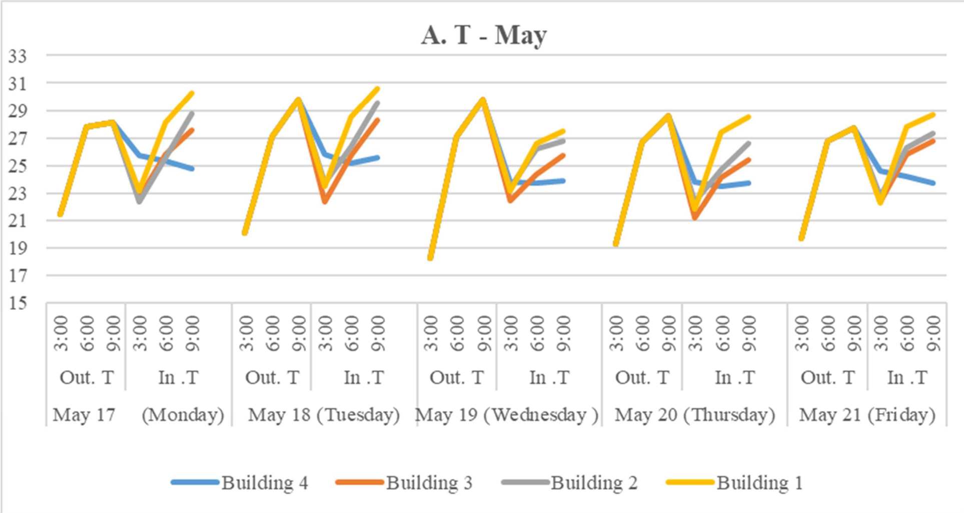
### *3.1. Relative Humidity (R. V.), Ambient Temperature (A. T.) and Air Velocity (A. V.)*

Thermal comfort is determined by the room's temperature, humidity and air speed. In the context of a study to assess the influence of the building curtain wall façade on the indoor climate the transient temperature, relative humidity conditions and air velocity were continuously measured (in 20-minute cycles) in four of different office building in the area around Bole Olympia to Meskel Flower, Addis Ababa.

The measuring parameter that is usually utilized in these types of studies is regarded as critical for evaluating internal climatic facts. As figure 4, showed indoor and outdoor ambient temperature have similar pattern throughout the day recorded from the four buildings except building 4 in April. The outdoor ambient temperature shows colder and slightly warm at 3 o'clock and 6 o'clock respectively. Indoor ambient temperature of the three building showed a fast increase throughout the day, but for building 4 showed slight decrease pattern. In both months a maximum of 30.6°C, 29.6°C, 28.3°C and 25.7°C of indoor ambient temperature for Building 1, Building 2, Building 3 and Building 4 respectively.

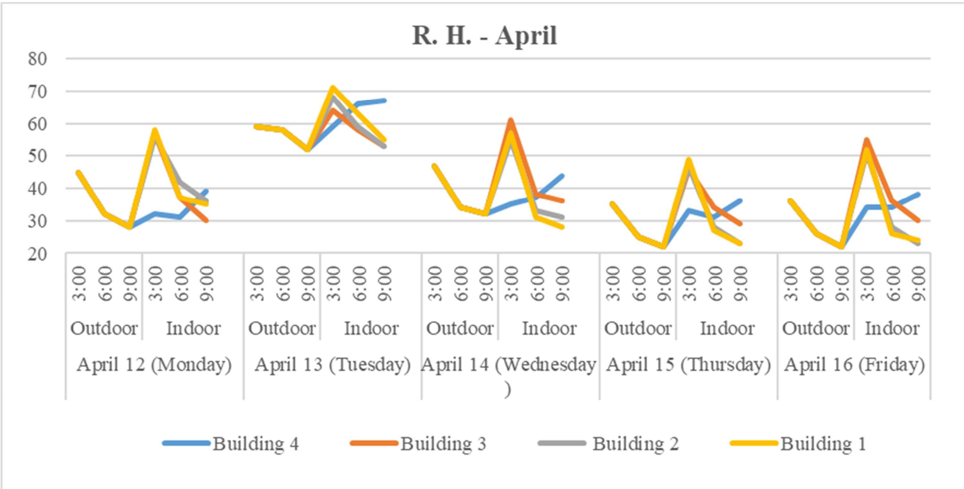



(a)

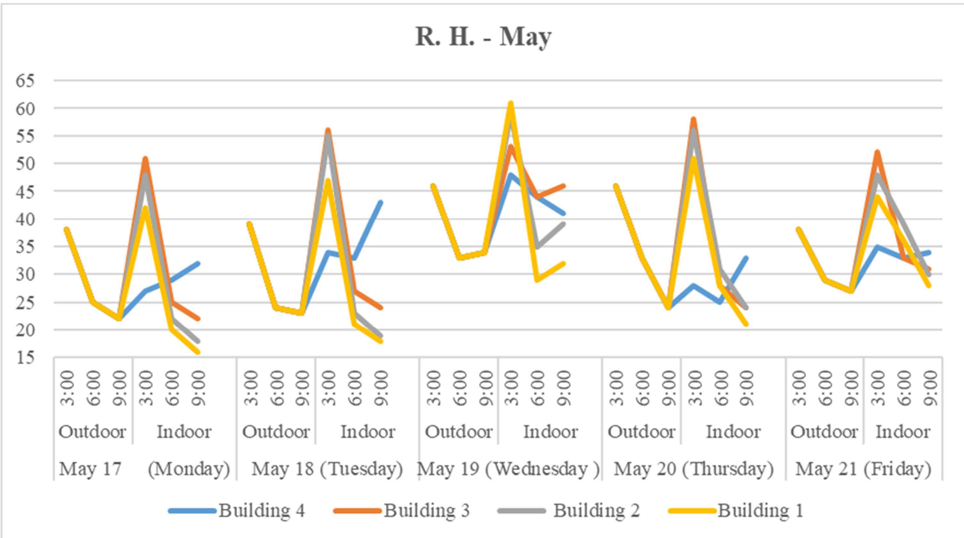



(b)

***Figure 4.*** *Indoor and outdoor ambient temperature of all four buildings in (a) April and (b) May.*

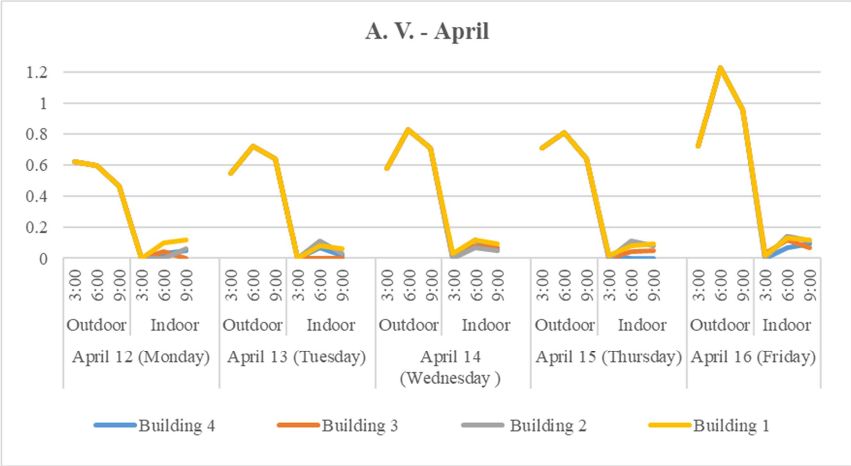



(a)

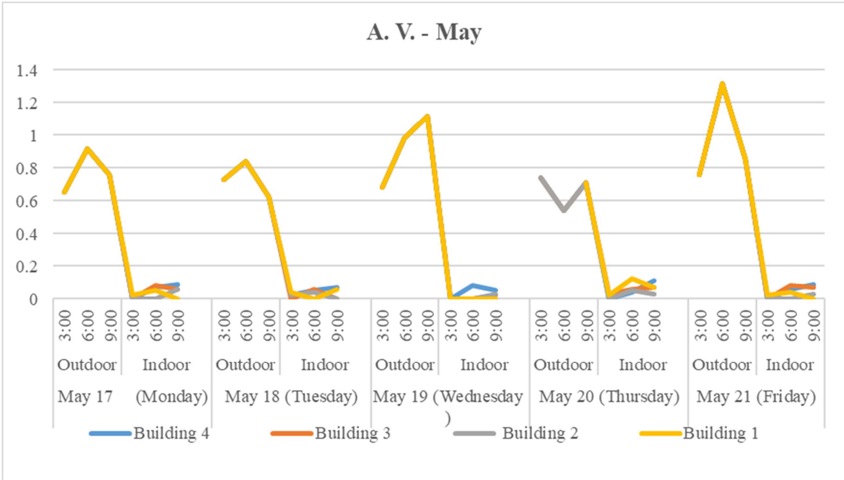



(b)

***Figure 5.*** *Indoor and outdoor relative humidity of all four buildings in (a) April and (b) May.*




(a)



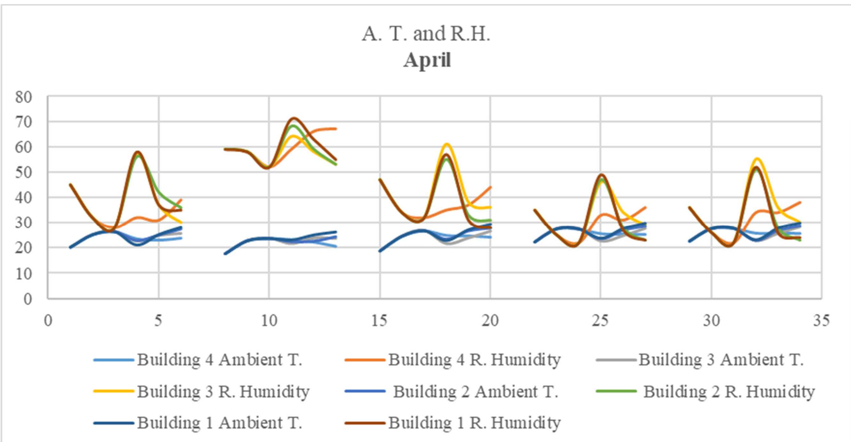

(b)

***Figure 6.*** *Indoor and outdoor air velocity of all four buildings in (a) April and (b) May.*

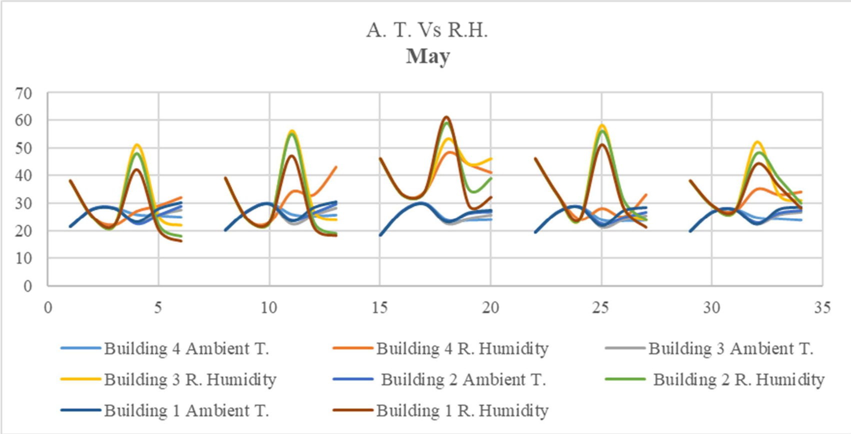
Indoor humidity levels in the office show fluctuation at different time intervals or stages. As Figure 5, shows the relative humidity is between 16% and 71% in April and between 18% and 61% in May. The air velocity is between 0m/s and 1.23m/s. Most of the time air velocity that within buildings is generally less than 0.2m/s, which is generally unnoticed.

### 3.2. Comparison of Four Buildings in Terms of A. T., R. H. and A. V.

Ambient temperature and relative humidity



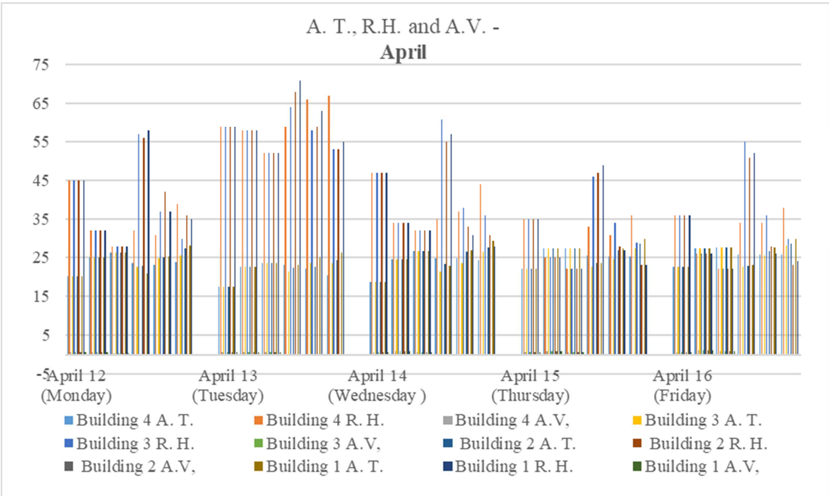

(a)



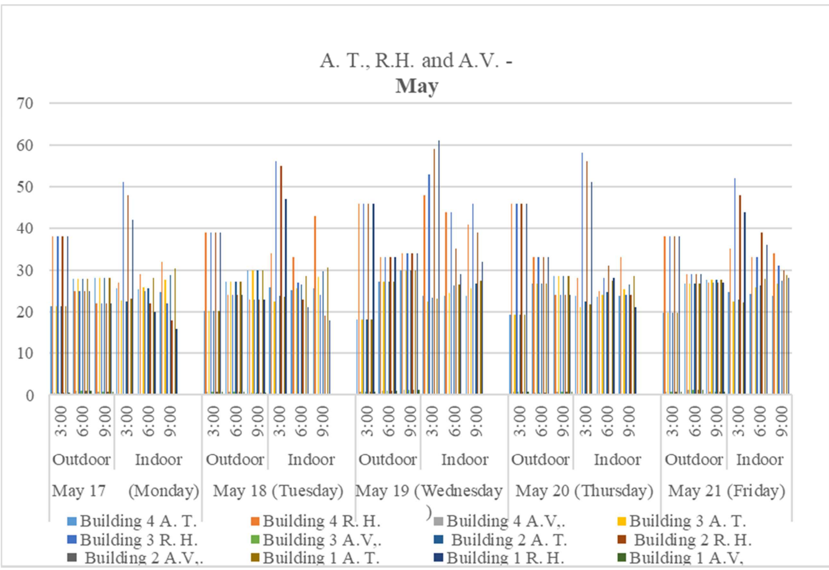

(b)

***Figure 7.*** *Ambient temperature and relative humidity of all buildings in (a) April and (b) May.*

Ambient temperature, relative humidity and air velocity.




(a)




(b)

***Figure 8.*** *Relative humidity, ambient temperature and air speed/velocity of all building (a) April and (b) May.*

The results of ambient temperature, relative humidity and air velocity based on 4 of building layout are shown in Figures 7 and 8 to compare from one building to another. The above (Figures 7 and 8) data are analyzed and presented on a single graph from four different office buildings in April 12 up to 16 and May 17 up to 21 at different time interval, which are 3, 6 and 9 o'clock from field measurement to compare each building, from one another.

Figure 7 (a and b) shows the 20-minute-cycle in three different time intervals throughout the day values of ambient temperature and relative humidity measured in all building and the running daily value over a period of 10 days in 2 months. Due to the periodic warmest month in combination with the relatively low thermal performance of building curtain wall façade extreme daily temperature difference, occur at a maximum of up to 30.6°C in during the heating period. However, the temperature fluctuations are much lower in building 4 in comparison to other building due to building orientation.

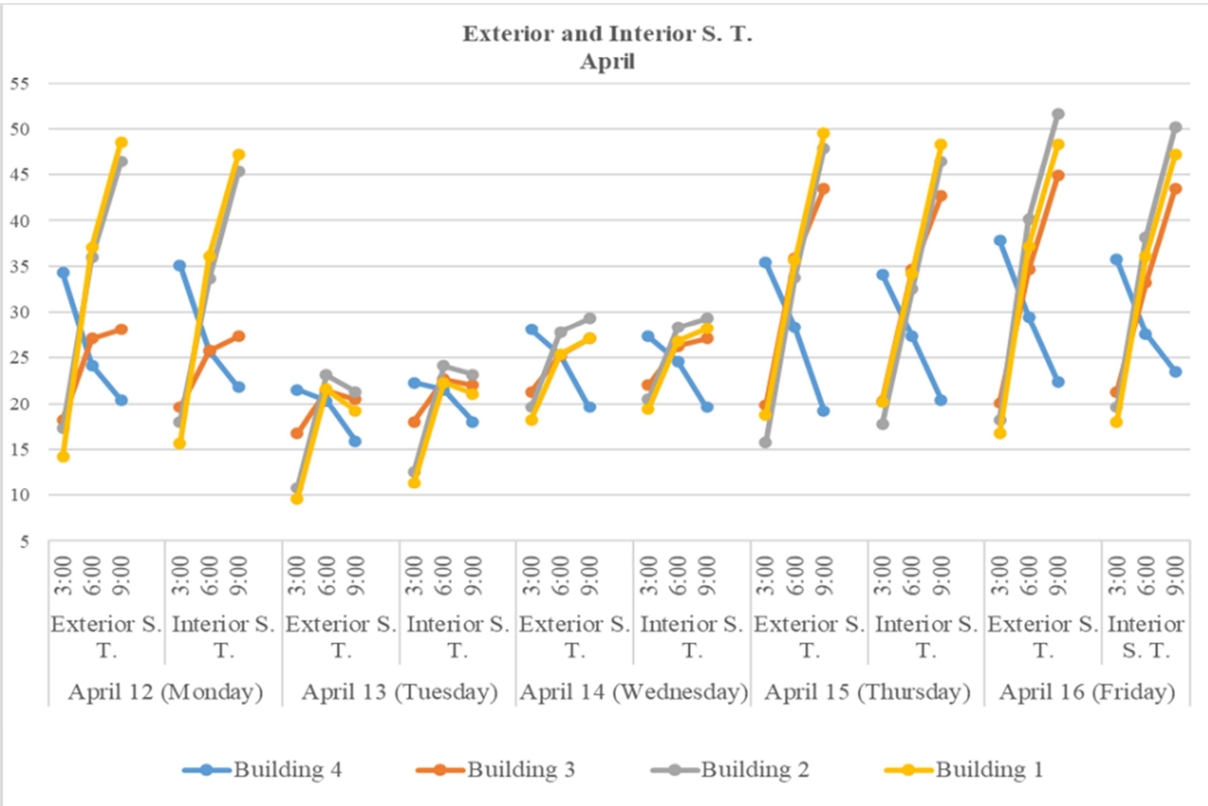
The large temperature differences also have the expected consequences on indoor relative humidity fluctuation. The relative humidity value ranges from 16% to 71% in all 4 buildings. So, this shows there is high fluctuation, which will cause a distinct discomfort will be experienced because of the dryness when its lower than 25% or if it is above 80% it will create a feeling of dampness (ideally the level should not drop below 40% and not exceed 70%). It remains comparatively with daytime maximum amplitudes of approximately 71% and minimum of 16% of R. H.

Based on all building layouts except building 4, no significant difference was observed from the maximum relative humidity obtained which is 58% to 71%, whereas for the minimum relative humidity, the difference was from 16% to 38%. The air velocity of all four buildings shows between 0 m/s and to the maximum of 1.32 m/s.

### *3.3. Curtain Wall Front Façade Surface Temperature*

Façade surfaces available in conventional multi-story buildings for integration of solar collector systems are restricted [13]. Façade systems are critical to occupant comfort and well-being, but frequently bring a high level of complexity to the design process due to the inherent difficulty of striking a balance between occupant comfort needs [14].

Analysis for interior and exterior curtain wall front façade has been conducted. As on figure 9 depicted the accurate prediction of the temperature distribution through a glazing curtain wall system depends strongly on how the glass material is analyzed. Therefore, there are two types of curtain wall glazing façade, which are single glazing and double-glazing under conducted for all four buildings. The type of glass is a significant aspect that can either improve or degrade the system. Single pane glass is preferred for the exterior glazing layer because it allows a large quantity of direct solar radiation to pass to the cavity, which functions better when heated [15]. From case study, apart from building 3 all are single glazing curtain wall façade and for building 3 is double-glazing type of curtain wall façade.



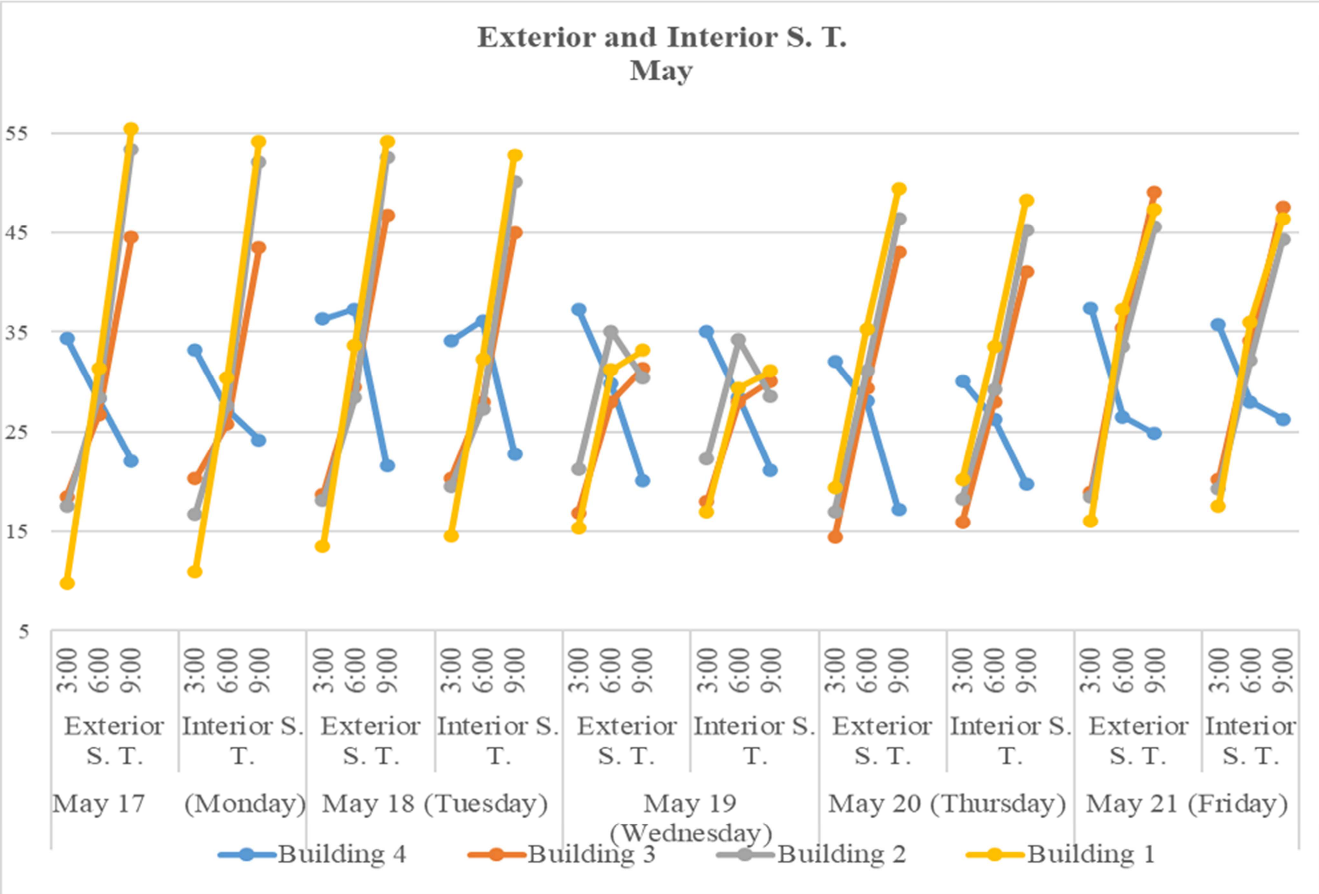



***Figure 9.*** *Interior and exterior curtain wall front façade surface temperature in (a) April and (b) May.*


***Figure 10.*** *Indoor ambient temperature and exterior curtain wall front façade surface temperature.*

Observing Figure 9, it was noticed that the variable external wall surface temperature and internal glass surface temperature has similar pattern throughout the day. The trend lines demonstrate that this variable has indicated that the difference between interior and exterior surface temperature is at the maximum of 2.4°C.

The Figure 10, represent external glass surface temperatures and indoor ambient temperatures crossing values for both models. An investigation comparison between surface temperature and indoor temperature are needed in order to assess indoor thermal comfort because of their direct relation. In accordance to the graphs, it was noticed that the increase in external surface temperature would increase indoor temperature. The temperature difference between surface temperature and indoor temperature is between 11.2°C and 25.2°C. At the maximum exterior surface temperature of 55.5°C, at same time maximum indoor temperature recorded which 25.2°C. The massive heat-up of the glass curtain wall panel, on the outside as well as the inside glass surface of up to 55°C significantly heats up the air inside the room and for a long period.

## 4. Conclusion

The effect of curtain wall façade on indoor thermal comfort of office building was explored by studying four different office buildings in Addis Ababa. This study aim and the associated objectives by conducting field or on-site measurements during the warmest months in April and May. Curtain wall façade buildings were not protected in any way from adverse external influences, especially from direct solar radiation, resulting in thermal discomfort indoor environment. In addition, problem with inside sun protection results from the fact that the heat rays have already reached the inside of the building. In general, Findings regarding thermal comfort of the current applied façade in all office buildings show that almost no façade technology has met the users' office activity requirements and ASHREA standard, which is used as a benchmark. The relation between surface temperature and indoor temperature has direct impact on the indoor thermal environment, when surface temperature increase indoor ambient temperature will increase.

## Acknowledgements

First, praises and thanks to the God, the Almighty, for His showers of blessings throughout my research work to complete the research successfully. I would like to express my sincere gratitude to my advisor, Nebyou Yonas (Ph. D) for giving me the opportunity to do research and providing invaluable guidance throughout the study. I am extremely grateful to my parents for their love, prayers, caring and sacrifices for educating and preparing me for my future. Finally, yet importantly, I would like to thank Addis Ababa Science and Technology University for providing such opportunity.

## References

[1] S. 5. ASHRAE, "Thermal Environment Conditions for Human Occupancy, American Society of Heating, Ventilating and Air-Conditioning Engineers," in *ASHRAE*, Atlanta, GA, 2020.

[2] Nikolina Pivac, Sandro Nižetić, Thermal comfort in office buildings: General issues and challenges, 2017.

[3] N. K. Süleyman Toy, "Evaluation of human thermal comfort ranges in urban climate of winter cities onthe example of Erzurum city.," *Environ. Sci. Pollut. Res,* 2017.

[4] A. Haruna, U. Muhammad and O. Oraegbune, "Analysis of indoor thermal comfort perception of building occupants in Jimeta, Nigeria," *Civ. Environ. Res.,* vol. 10, 2018.

[5] D. Ormandy and V. Ezratty, "Thermal discomfort and health: Protecting the susceptible from excesscold and excess heat in housing.," *Build. Energy Res.,* 2016.

[6] H. Y. J. L. L. Yang, Thermal comfort and building energy consumption implications - a review, 2014.

[7] B. M. Vigener N, Building Envelope Design Guide–Curtain Walls Washington, DC: National Institute of Building Sciences, 2012.

[8] E. &. D. H. A. Gratia, Greenhouse effect in double-skin facade. Energy and Buildings, 2007.

[9] Mohamed Ahmed Alaa El Din Ahmed Sayed, Mohamed Anwar Fikry, Impact of glass facades on internal environment of buildings in hot arid zone, 2019.

[10] P. Fanger, Thermal Comfort—Analysis and Application in Environmental Engineering, Copenhagen, Denmark.: Danish Technical Press, 1970.

[11] Wageh, M., & Gadehlak, M., Optimization of Facade Design for Daylighting and View to-Outside: A case study in Lecco, Lombardy, Italy, 2017

[12] J. L. M. Hensen, Literature review on thermal comfort in transient conditions, Build Environ, 1990.

[13] C. A. A. a. F. P. Hachem, "Effect of Housing Density on Energy Performance of Solar-optimized Residential Configurations," *CISBAT,* 2013.

[14] Alessandra Luna-Navarroa, Roel Loonenb, Miren Juaristic, Aurora Monge-Barrioc, Shady Attiad, Mauro Overenda. Occupant-Facade interaction: a review and classification scheme. International journal of Building and Environment, 2020.

[15] Kifah Alhazzaa, Double Skin Façade and Potential Integration with Other Building Environmental Technologies and Materials, 2020.