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Executive Summary

Quantifying the Impact of External Movable Shading System (EMSyS) on Thermal Comfort and Air-conditioning Energy

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EXECUTIVE SUMMARY

Quantifying the Impact of External Movable Shading System (EMSyS) on Thermal Comfort and Air-conditioning Energy

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1. Introduction

Windows serve multiple purposes of providing ventilation, daylighting, outdoor view, etc. At the same time, windows can also be a source of heat gain through radiation and conduction within a building. However, the heat gain aspect of windows is often neglected while designing them in new buildings.

In urban India, there is a trend towards having larger glass façades and larger window-to-wall ratio (WWR) in both commercial and middle/high income residential buildings. Another noticeable trend is the absence or provision of small, fixed shading like *chajjas*. These large, glass façades and windows, which are largely unprotected from solar radiation, become an important source of heat gain, thus, causing thermal discomfort to occupants due to higher indoor temperatures and temperature asymmetry. They also result in higher energy use for cooling the building. Contrary to general perception, the large windows do not necessarily result in better daylighting. Owing to excessive glare and high radiant temperature of the glazing, it is common that in such buildings, the internal curtains are drawn during the daytime to restrict the daylighting. Adequate shading of these glass façades can effectively (a) optimize lighting, (b) control glare, (c) improve the thermal comfort, and (d) even reduce the consumption of electricity for cooling and lighting. In this context, External Movable Shading Systems (EMSyS), which can provide shading to the glazed surfaces, serve as an effective solution.

As the name suggests, EMSyS units are installed outside on the glazed surface of the building façade, and they are dynamic and can be closed or opened as per the requirements of the occupant. Through closing and opening, EMSyS allows the occupant to control both the solar heat gains and natural daylight (**Figure 1**).

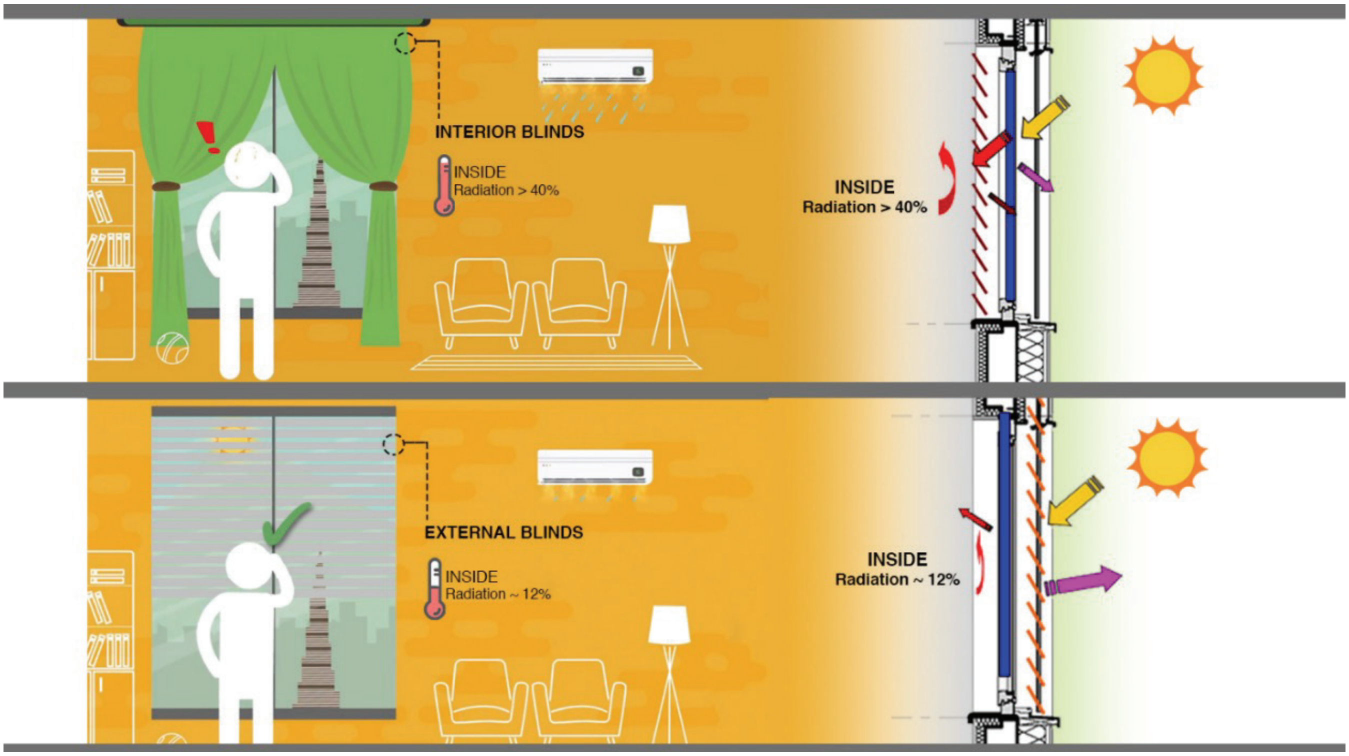


Figure 1. Principle of EMSyS

EMSyS could be of many types: shutters, vertical screens, retractable awnings, vertical louvers, lamella blinds, etc. (**Figure 2**).

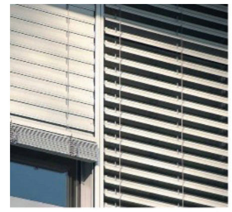
			
Retractable awnings	**Vertical screens**	**Vertical louvers**	**Lamella blinds**

Figure 2. Types of EMSyS

During the past few decades, the market for modern EMSyS products such as vertical screens and lamella blinds has expanded rapidly in some parts of Europe (Switzerland, Germany, Austria, France, etc.) having cold or mild climates. However, the use of modern EMSyS in new buildings in tropical countries like India remains negligible. This is a little intriguing because there was widespread use of both fixed shading such as *chajjas* and *jalis* as well as EMSyS in the form of shutters, bamboo chiks and curtains in traditional Indian architecture. One of the key barriers to popularizing modern EMSyS is the lack of results available in public domain of real-life monitoring studies that quantify the energy savings and thermal comfort improvements through the use of EMSyS. Also, there is no simplified methodology available for performance monitoring of EMSyS in real-life buildings. This study essentially is a small, but useful contribution to address these barriers.

2. Study Objectives

The study had primarily two objectives as listed below.

1. Development of a simplified methodology for performance monitoring of EMSyS and conducting pilot monitoring study in residential apartment in tropical climate. This consisted of the methodology development and pilot monitoring to quantify the impact of EMSyS in reducing the indoor operative temperatures in naturally ventilated (NV) mode and in reducing the space cooling load in air-conditioned (AC) mode.

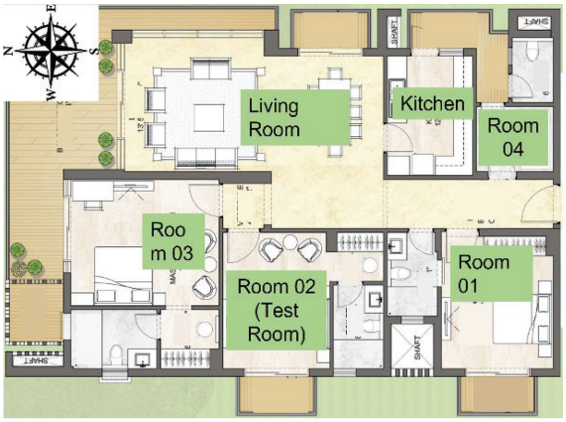
2. Development of building energy simulation model to compare simulation outputs with measured performance and carrying out further parametric studies to understand the impact of orientation, location, climate, and glazing types.

3. Monitoring Space and EMSyS

3.1 Selection of Flat and Test Room

For the monitoring, two identical flats (3 BHK with a covered area of 114 m^2) located at 10^{th} and 11^{th} floor of a multi-story residential tower located at Gurugram were selected (**Figure 3**). Within these flats, a west-facing bedroom (Room 02) was selected as the test room for conducting the measurements (Figure 3). Prior to the selection of the flats, simulations were carried out to show that incident solar radiation falling on the west façade of the 10^{th} and 11^{th} floor is similar. **Table 1** gives the key constructional features of the test room.

Building showing the location of flats on the 10th and 11th floor



Floor plan of the flat showing the test room

Inside view of the test room with sliding door orientation and coordinates

Balcony of the test room

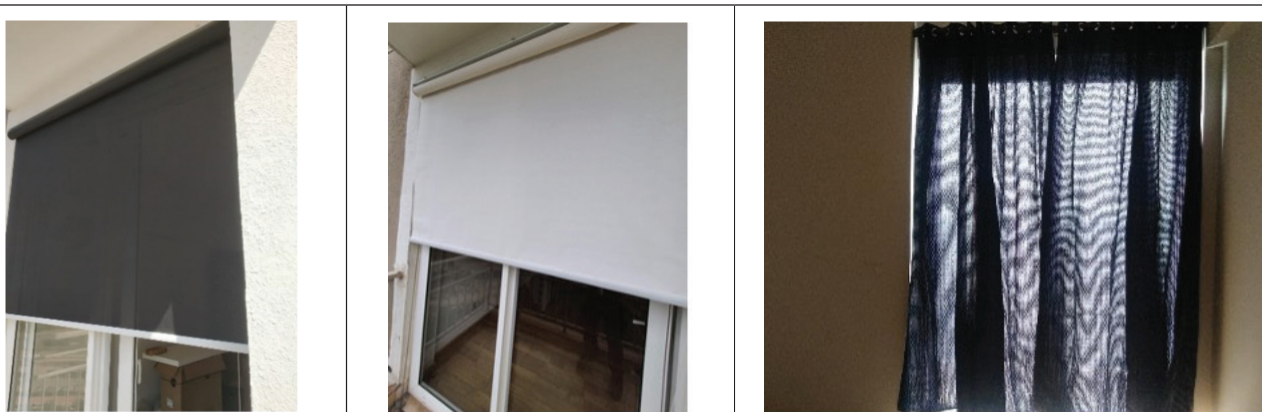
Figure 3. Flats for monitoring and test room

Table 1. Constructional features of the test room

Floor area	14.41 m^2
Envelope area	8.60 m^2
Glazed opening (door) area	4.93 m^2 (41% openable; 6-mm single clear glass; 3-inch uPVC frame)
Window-to-wall ratio	58%
Wall material	AAC block (200-mm external wall and 150-mm internal partition)

3.2 External Movable Shading and Internal Curtains

For comparing the performance, the glazed door in the test room of 10th floor flat was equipped with internal curtains (IC), while the test room of the 11th floor flat was equipped with EMSyS. **Figure 4** shows the photographs of the EMSyS and IC. Two types of EMSyS (both clutch roller blinds) were used. **Table 2** provides the specifications of the two EMSyS products (Product 1 and Product 2). Product 1 was used in the monitoring conducted during March–April 2021, while Product 2 was used during the monitoring conducted in June 2021.



EMSyS Type 1	EMSyS Type 2	Internal Curtain (IC)

Figure 4. Photographs of the EMSyS (11th floor) and internal curtain (10th floor)

Table 2. Key specifications of EMSyS tested

Parameter	Product 1	Product 2
Product material	Polyester, vinyl on polyester	
Operation mode	Chain	Chain
Frame material	Aluminium and steel	Aluminium and steel
Effective SHGC (obtained from simulation)	0.248	0.18
Openness factor	10%	4%
Reflectivity	4%	46%

4. Methodology and Performance Monitoring in Naturally Ventilated Mode

4.1 Calculation of Operative Temperature

The key output parameter here is the ‘**operative temperature***’[1] at ‘**hourly**’ interval for ‘Test room with EMSyS’ and ‘Test room with IC’. The raw data, which was at 15-minute interval, was processed to get the data at ‘hourly’ interval. The processed hourly data was used to calculate the operative temperature, using following parameters:

- Air temperature (DBT), T_a in ^oC
- Globe temperature, T_g in ^oC
- Air velocity (omnidirectional), v_a in m/s

1 The operative temperature is calculated using the given formula as per ISO 7726. The formula includes the term of ‘globe temperature’, which is measured using a globe thermometer within a range of velocity. However, at the time of experiment in NV mode, the air velocity was significantly high. This resulted in high convective heat transfer around the globe thermometer, and thereby affecting the globe temperature. Therefore, the mean radiant temperature and operative temperature are also affected. Hence, the operative temperature calculated is marked with asterisk sign.

Calculation steps:

Step 1: Calculation of 'mean radiant temperature', T_{MR} in °C

For forced convection with the standard globe (Diameter = 150 mm, Emissivity = 0.95 [matt black paint])

$$T_{MR} = \left[\left(T_g + 273\right)^4 + 2.5 \times 10^8 \times {v_a}^{0.6} \times \left(T_g - T_a\right)\right]^{1/4} - 273$$

Step 2: Calculation of 'operative temperature*', T_{OT} in °C

$$T_{OT^*} = \frac{T_{MR} + T_a \times \sqrt{10 v_a}}{1 + \sqrt{10 v_a}}$$

(**Source:** ISO 7726. Ergonomics of the thermal environment - Instrument for measuring physical quantities. Geneva, Switzerland: International Organization for Standardization. November 1998.)

Operative temperature can be used as a key output parameter for defining the thermal comfort. The **difference in operative temperature* results** for 'Test room with IC' and 'Test room with EMSyS' will quantify the **improvement in thermal comfort** due to EMSyS.

4.2 Schedule for opening and closing of sliding door and shading devices

Table 3 gives the schedule for opening and closing of the sliding door and shading devices for both rooms – 'Test room with EMSyS' and 'Test room with IC'. The ceiling fans in the test rooms of both flats are operated at full speed to imitate real-life cooling scenario in summers. However, in principle, it will affect the measurement of globe temperature.

Table 3. Opening and closing schedule for sliding door, internal curtain, and EMSyS in naturally ventilated mode

	Test room with EMSyS (11^{th} floor)		**Test room with IC (10^{th} floor)**				
Duration	***Sliding door opening in the balcony (D1)***	***EMSyS***	***Sliding door opening in the balcony (D1)***	**Curtain (internal)**	**Internal door connecting the test room to the rest of the flat (D3)**	**Washroom door (D2)**	**Ceiling fan**
Sunshine hours (8.30 am–7.00 pm)	Closed	Closed	Closed	Closed	Closed	Closed	On. At full speed
Non-sunshine hours (7.00 pm–8.30 am)	Open	Open	Open	Open	Closed	Closed	On. At full speed

4.3 Measurements

The following measurements were made:

- Inside the room: dry bulb temperature, relative humidity, globe temperature, air velocity (omnidirectional), wall temperature for selected surface
- Ambient: dry bulb temperature, relative humidity, solar radiation (direct and diffuse)

Figure 5 gives the locations of the measurement. Annexure 1 provides the specifications of the instruments.

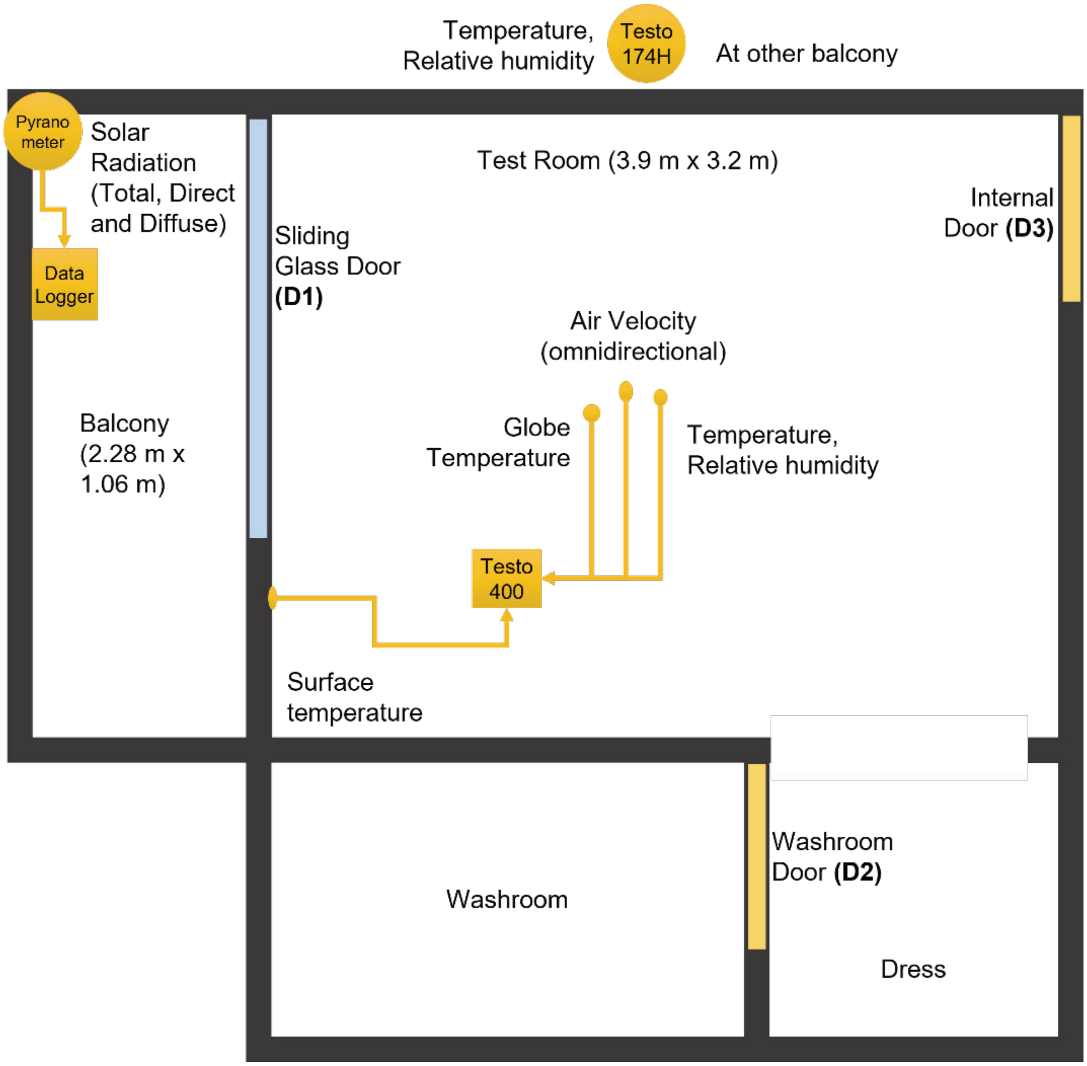


Figure 5. Instruments and their locations

4.4 Key Results of Naturally Ventilated Mode

Figure 6 shows the calculated operative temperatures in the two rooms based on the monitored parameters, along with solar radiation and ambient dry bulb temperature, for a typical clear day (28 March 2022). Figure 6 also shows the opening and closing time of the sliding door as well as the operation of EMSyS and IC. **Figure 7** and **Figure 8** show the operative temperature for a week in March (22–28 March 2021) and for a five-day period in June (19–24 June 2021), respectively. Based on the results obtained, the following conclusions can be drawn.

- For the month of March, on clear days (25, 27, 28, and 29 March 2021), the average peak direct normal irradiance (DNI) varies between 600 and 750 W/m^2. During the day, the operative temperature in the room having EMSyS remains lower compared to the room having internal curtains. During the clear days, the peak operative temperature in the room having EMSyS is lower by 3.5 °C as compared to the room having internal curtains.
- For the month of June, on a clear day (24 June 2021), the peak DNI is around 750 W/m^2. The peak operative temperature in the room having EMSyS is lower by 3 °C as compared to the room having internal curtains.

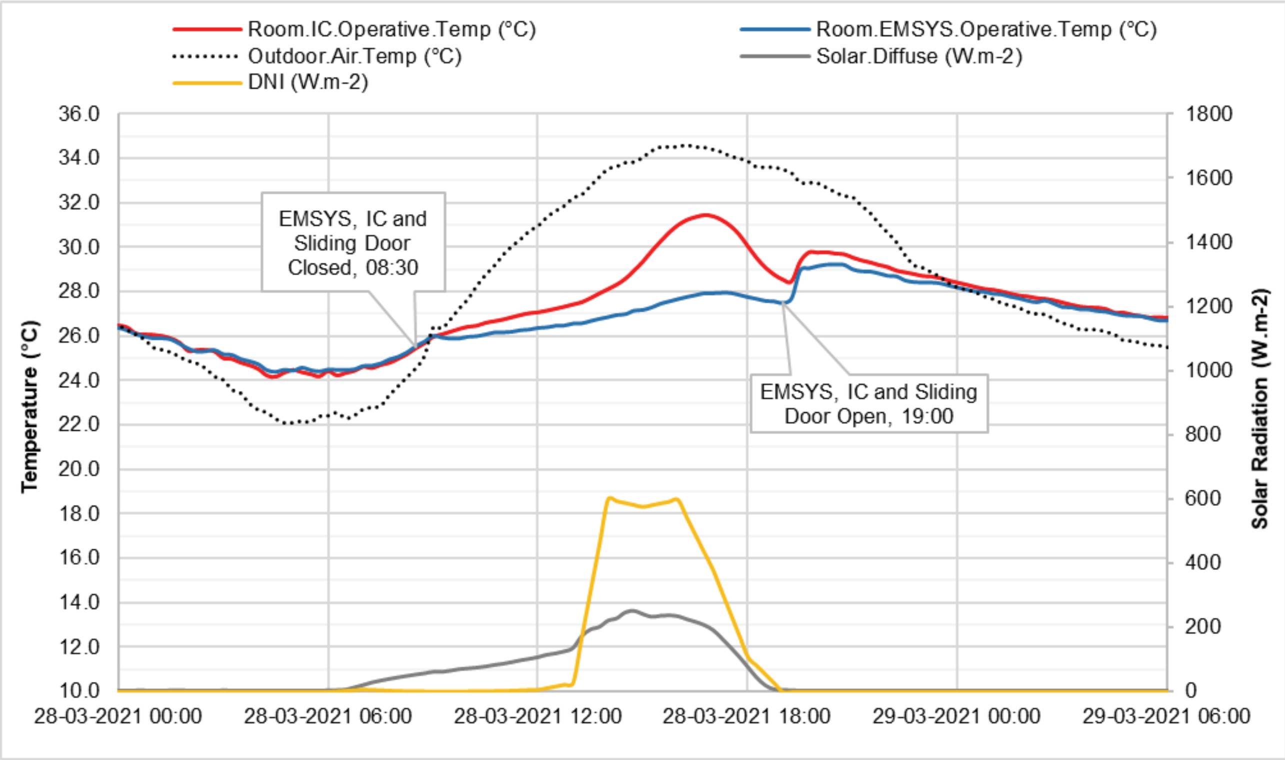


Figure 6. Operative temperature for naturally ventilated case for a typical 24-hour period (28 March 2021)

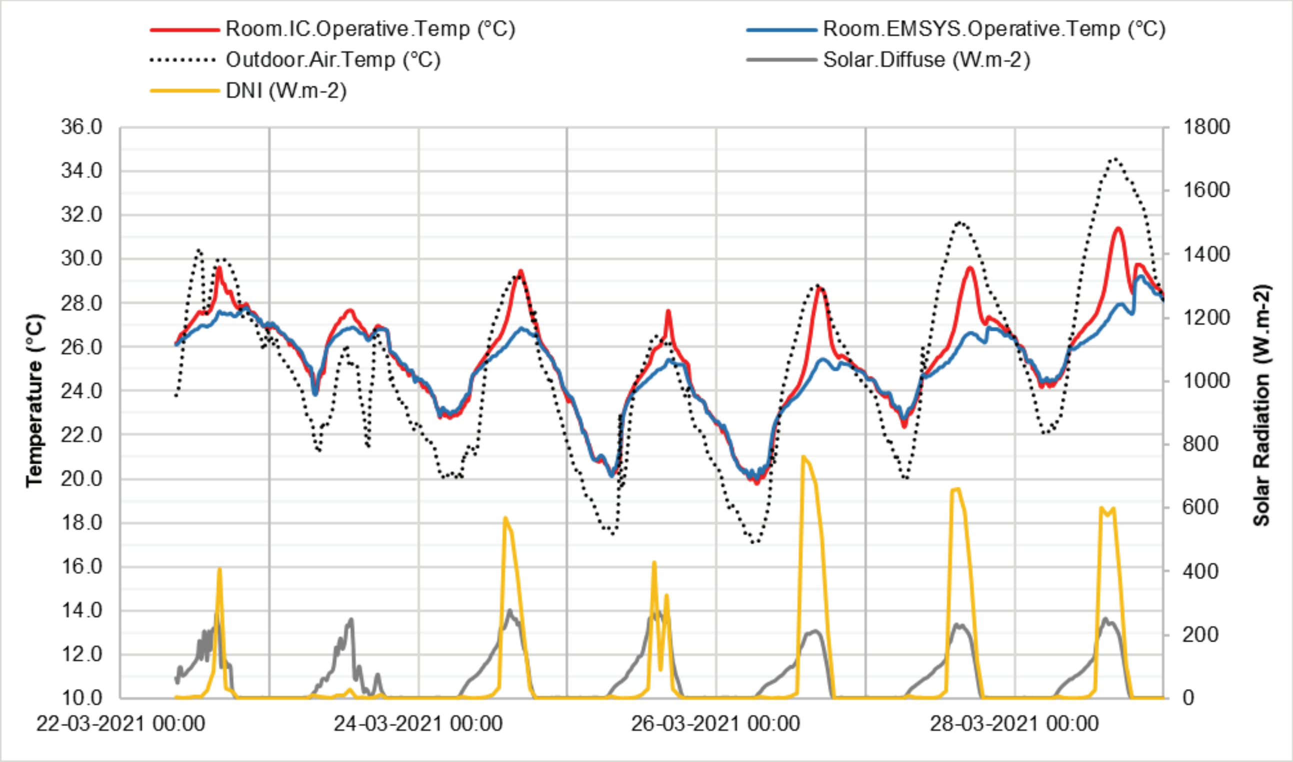


Figure 7. Operative temperature based on performance monitoring (March 2021)

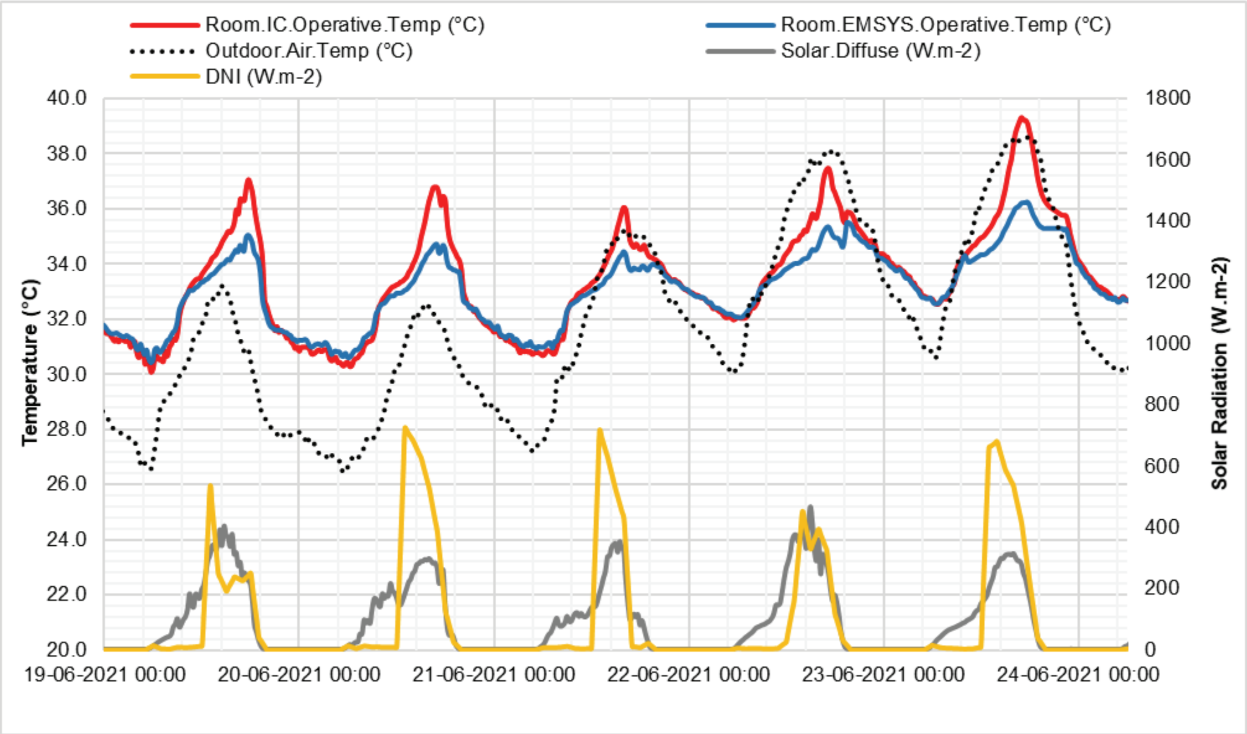


Figure 8. Operative temperature based on performance monitoring (June 2021)

5. Methodology and Performance Monitoring in Air-conditioning Mode

5.1 Calculation of Cooling Demand

The key output parameter here would be the '**cooling demand**' at '**hourly**' interval for 'Test room with EMSyS' and 'Test room with IC'. The raw data with 15-minute/1 second interval was processed to get the data at 'hourly' interval. The following processed hourly data was used to calculate the cooling demand:

- Velocity of air at exit of indoor unit (IDU), v_{IDU} in m/s
- Temperature of air at exit of IDU, T_{IDU} in °C
- Relative humidity of air at exit of IDU, RH_{IDU} in %
- Cross-section area of the duct added at IDU, A in m^2
- Air temperature (DBT), T_a in °C
- Relative humidity of room air, RH_a in %

Calculation steps:

Step 1: Calculation of mass flow rate of air through the IDU, m_{IDU} in kg/s

$$m_{IDU} = \rho_{IDU} \times A \times v_{IDU}$$

where,

ρ_{IDU} is the density of air at the exit of IDU in kg/m^3

Step 2: Calculation of enthalpy

Enthalpy to be read from the psychrometric chart for two conditions:

- Enthalpy of air at the exit of IDU, h_{IDU} in kJ/kg, (based on the T_{IDU} and RH_{IDU})
- Enthalpy of room air, h_a in kJ/kg, (based on the T_a and RH_a)

Step 3: Calculation of 'cooling demand', Q, in kW

$$Q = m_{IDU} \times (h_a - h_{IDU})$$

Cooling demand was used as a key output parameter and the difference in cooling demand for 'Test room with IC' and 'Test room with EMSyS' will quantify the impact of EMSyS.

Same set points were maintained at the entire flats to minimize the heat transfer across the test room's internal partition wall. The flats were equipped with multi-split air conditioner system. In total, there are five indoor units. The indoor unit of the air-conditioning system installed inside the test room is of 4.5 kW capacity.

5.2 Schedule for opening and closing of sliding door and shading devices

Table 4 gives the schedule for opening and closing of the sliding door and shading devices for both rooms – 'Test room with EMSyS' and 'Test room with IC'. The ceiling fans in the test rooms of both flats are operated at half speed, just enough to remove air stratification effect.

Table 4. Opening and closing schedule for sliding door, internal curtain, and EMSyS in AC mode

	Test room with EMSyS (11th floor)		**Test room with IC (10th floor)**				
Duration	***Sliding door opening in the balcony (D1)***	***EMSyS***	***Sliding door opening in the balcony (D1)***	***Curtain (internal)***	**Internal door connecting the test room to the rest of the flat (D3)**	**Washroom door (D2)**	**Ceiling fan**
Sunshine hours (7.00 am–9.00 pm)	Closed	Closed	Closed	Closed	Closed	Closed	Speed 2/4
Non-sunshine hours (9.00 pm–7.00 am)	Closed	Open	Closed	Open	Closed	Closed	Speed 2/4

5.3 Measurements

The following measurements were made:

- Inside the room: dry bulb temperature, relative humidity, globe temperature, air velocity (omnidirectional), wall temperature for selected surface
- At the exit of IDU: dry bulb temperature, relative humidity, air velocity
- Ambient: dry bulb temperature, relative humidity, solar radiation (direct and diffuse)

Figure 9 gives the locations of the measurement. Annexure 1 provides the specifications of the instruments.

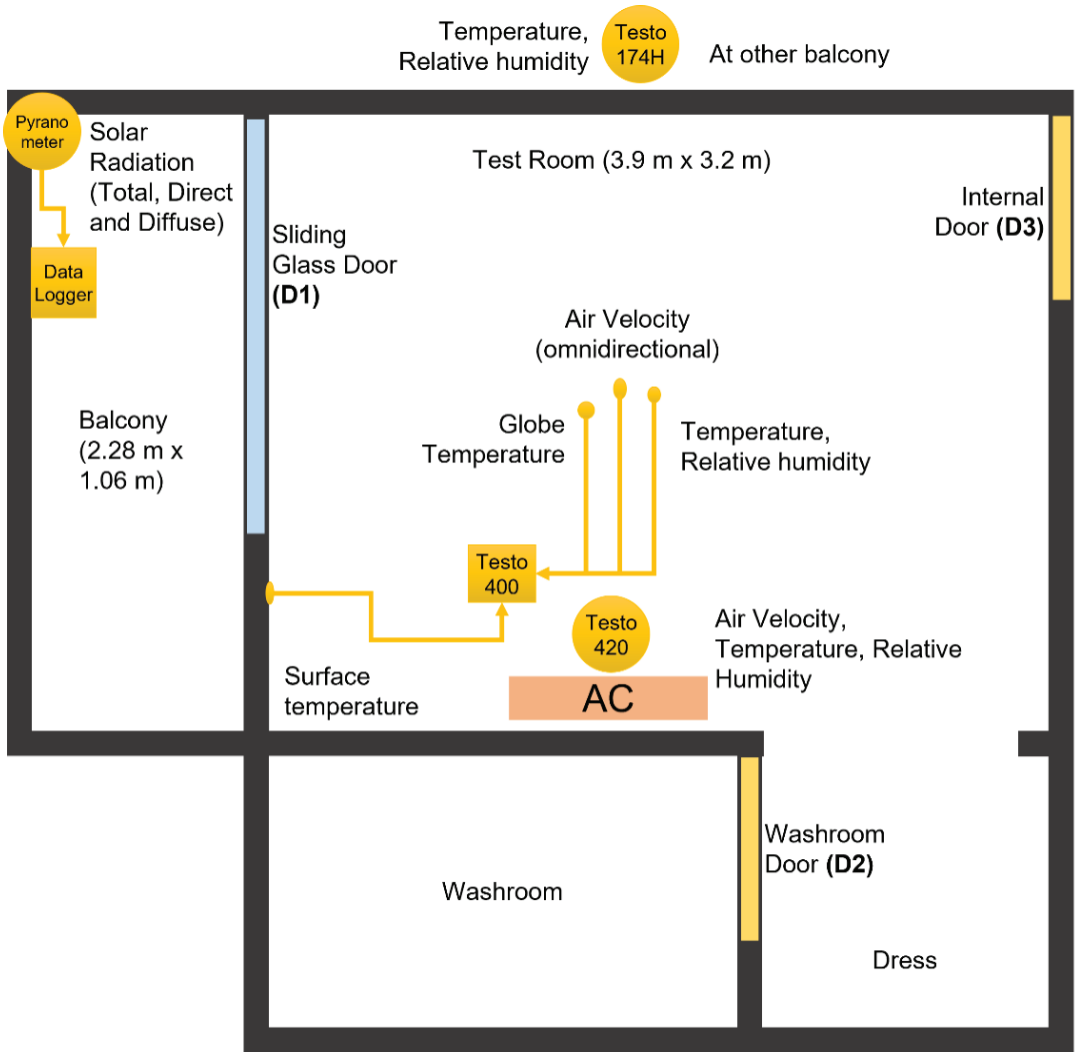


Figure 9. Placement of monitoring instruments for AC mode

5.4 Key Results of the Air-Conditioned Mode

The measurements were done for a duration of 8 days (1–8 April 2021). The set temperature of the AC during the monitoring is 24 °C. **Figure 10** shows the cumulative cooling delivered for both the test rooms, along with the solar radiation (direct and diffuse) data (for one day, i.e., 4 April 2021) and **Figure 11** shows the same for the entire duration of the monitoring. There is a loss of data on Day 2 of the experiment. The key observations made based on the results are as listed below.

a) Around 32% reduction in cumulative cooling delivered is observed in test room with EMSyS compared to the cooling delivered in the test room with IC.

b) The percentage reduction in cumulative cooling delivered, using EMSyS as compared to IC, is almost constant from the Day 3 onwards with less than 1% variation.

c) Figure 10 shows the opening and closing schedule of EMSyS and IC. The increased slope in cumulative cooling delivered is also observed in test room with IC during the day (due to higher solar heat gains through the glass) and can be seen in Figure 10.

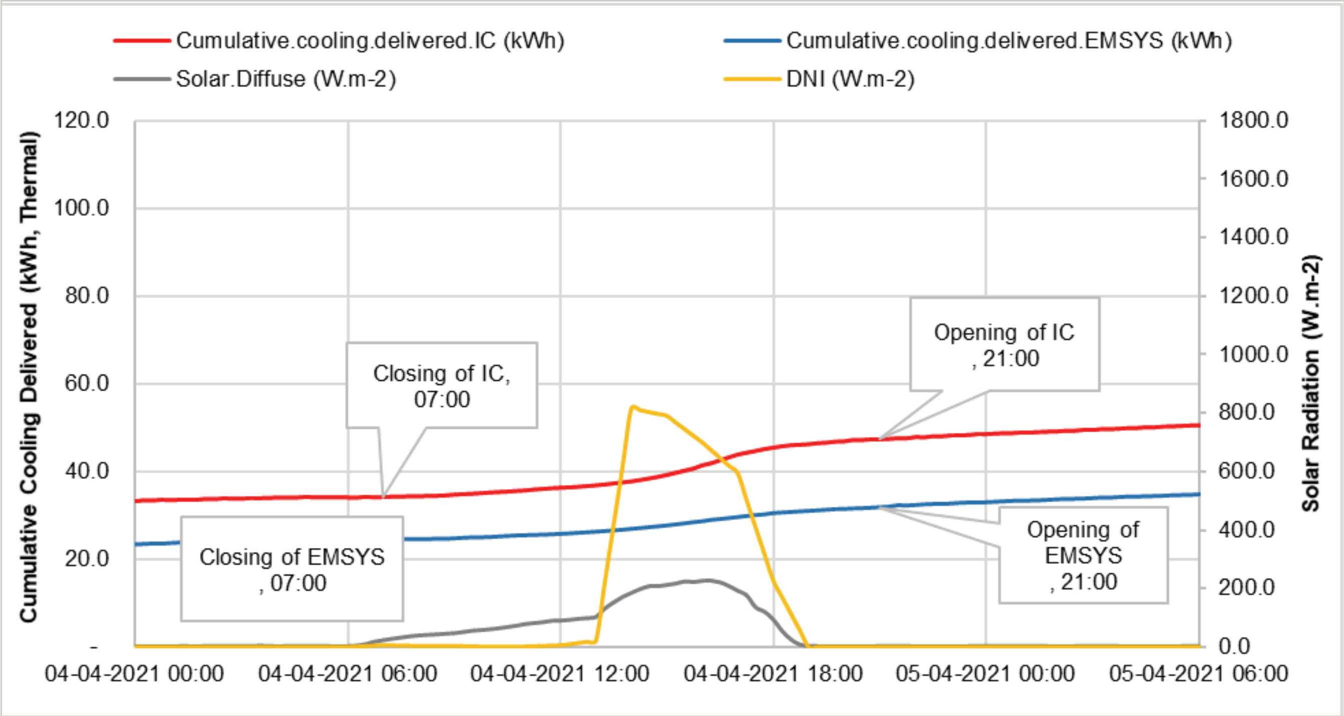


Figure 10. Cumulative cooling delivered for a day in April (4 April 2021) with opening/closing schedule of EMSyS, IC, and sliding door

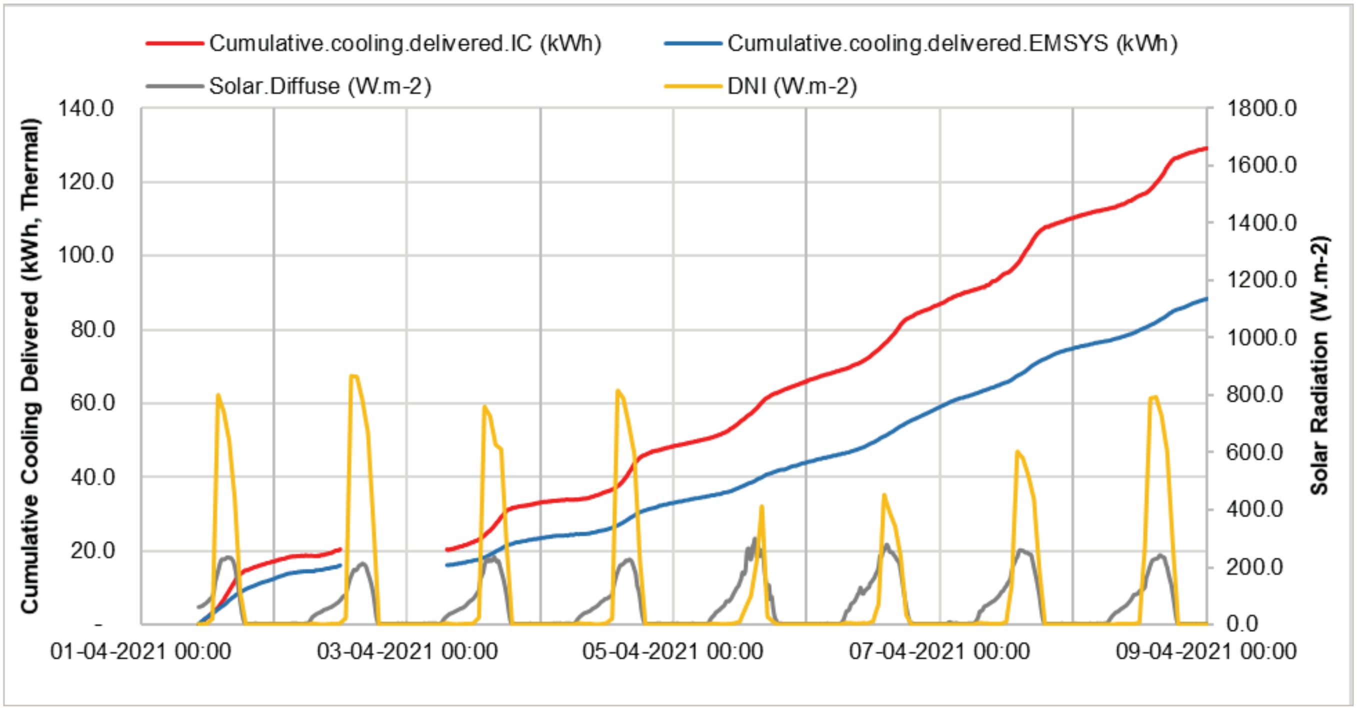


Figure 11. Cumulative cooling delivered of the test rooms in the air-conditioned mode (1–9 April 2021)

6. Performance Monitoring: Impact of EMSyS on Daylighting

Lux level measurement were done on 24 June 2021. The Lux meter readings were taken at marked points in the two rooms. These locations (locations 1, 2, 3, and 4) are shown in **Figure 12**. The other locations are outside of one of the test room's balconies (location 6) and at the centre of the first room (location 5) having no shading. The measurements were taken by a single person using a portable lux meter in the time frame of 10 minutes for all the locations. The readings were taken at four different times of the day (10.00 am, 1.00 pm, 3.30 pm, and 5.00 pm) (**Table 5**). It can be seen that the room with EMSyS receives good daylight and the lux level of the space with EMSyS is 12 times higher than the space with internal curtain at 10.00 am at location 2. It increases to 14 times at 5.00 pm at location 2. This also means that the room with EMSyS will not require any artificial lighting during daytime, while room with IC will require it.

Table 5. Illuminance measurement

Time	10th floor test room (internal curtain)				11th Floor test room (EMSyS)				First room 11th floor (no shading)	Outdoors: Outside 10th floor test room balcony
	1 (Lux)	2 (Lux)	3 (Lux)	4 (Lux)	1 (Lux)	2 (Lux)	3 (Lux)	4 (Lux)	5 (Lux)	6 (Lux)
10.00 am	16	20	16	17	180	255	206	434	820	7500
1.00 pm	35	40	37	34	285	390	312	654	1142	73000
3.30 pm	166	170	158	127	864	1176	950	1953	2900	45000
5.00 pm	126	148	138	108	1045	2084	1225	2909	15800	26000

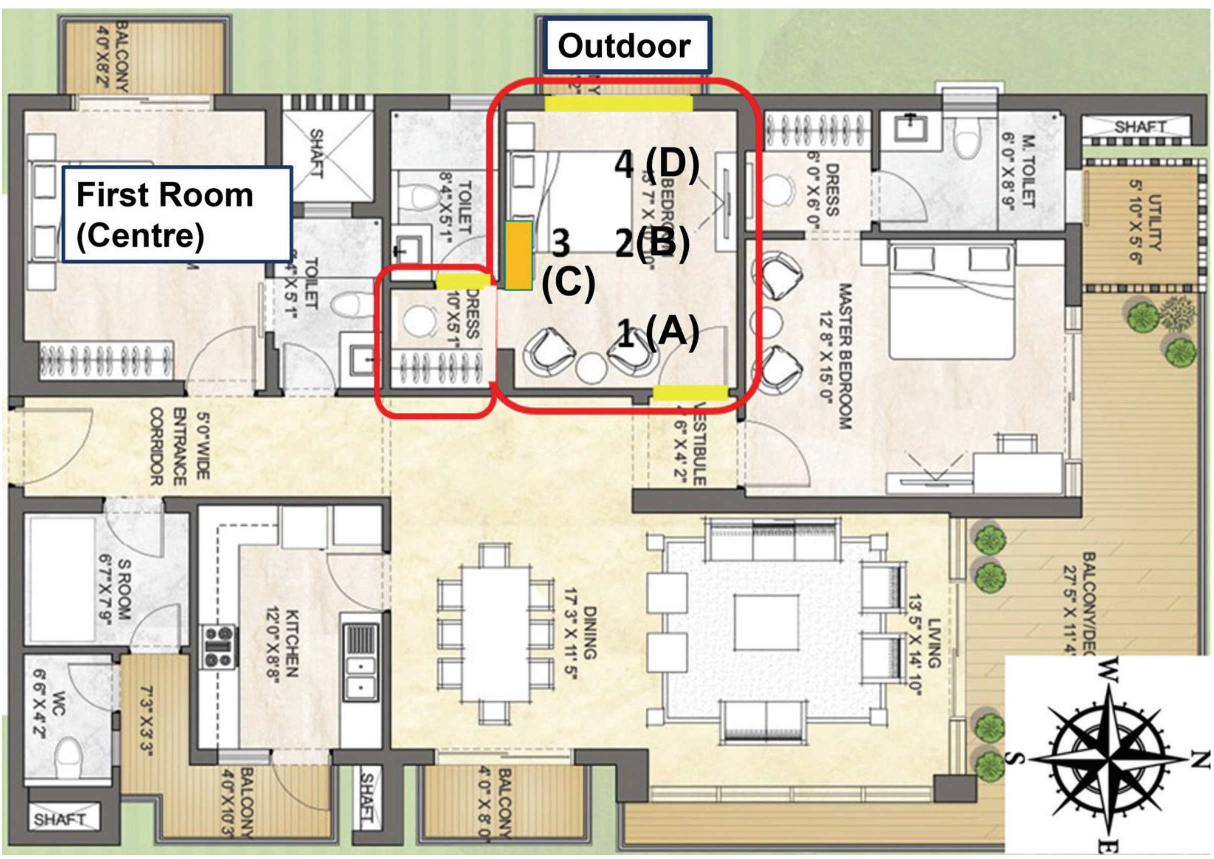


Figure 12. Luxmeter measurement location

7. Simulation Study

A simulation study was done to check how closely the simulation model can predict the thermal comfort (indicated by operative temperature) results as compared to the actual monitored results, while giving the key input parameters for simulation model as the actual. The simulation model was prepared using 'Design Builder' software. A 3-D simulation model was prepared as per the actual building geometry, zoning, walling material, window sizing, window material, shading system. The inputs for simulation model were matched with the actual monitored data. The schedule of opening and closing of Internal Curtain and EMSyS in the simulation was same as that of monitoring. The measured ambient parameters – e.g., total solar radiation, diffuse solar radiation, outdoor air temperature, and outdoor air relative humidity – were used in the simulation model. As the wind velocity was not measured, the values were taken from an external source.[2]

Figure 13 shows the comparison of measured air temperature and simulated air temperature of the test toom with IC in the month of March. **Figure 14** shows the similar comparison for test room with EMSyS.

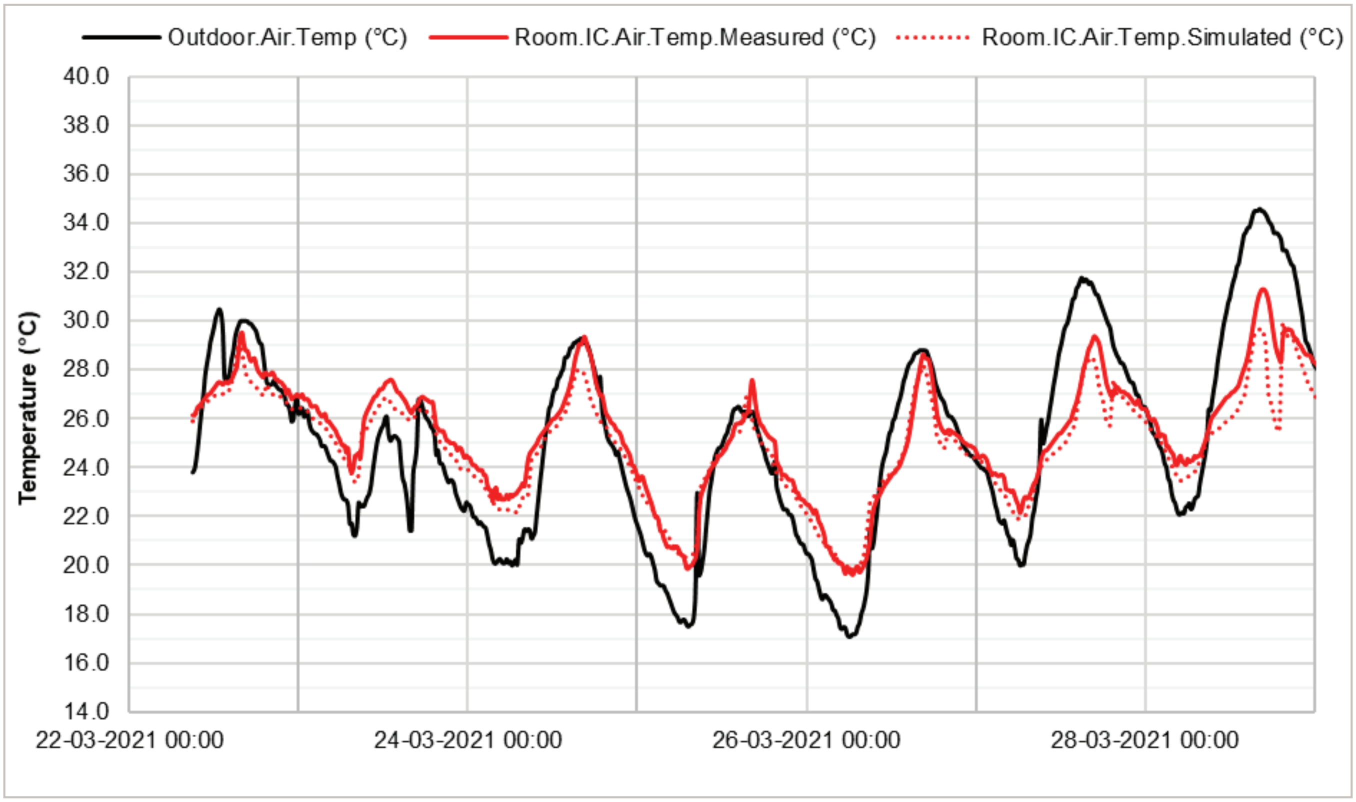


Figure 13. Comparison of measured and simulated air temperature for test room with IC in the month of March (naturally ventilated mode)

2 Weather History for New Delhi, Feb 2021 to September 2021, Weather Underground, The Weather Company, New Delhi, India Weather Conditions | Weather Underground (wunderground.com)

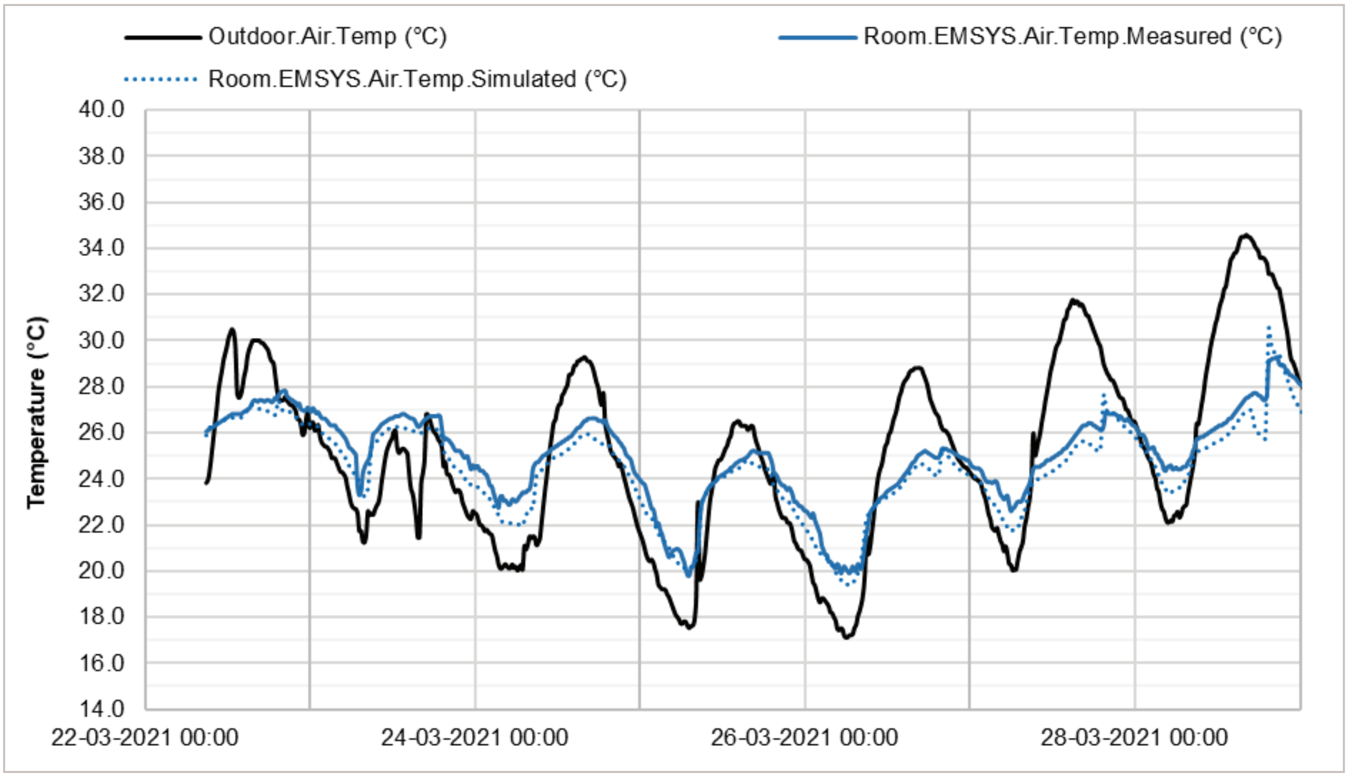


Figure 14. Comparison of measured and simulated air temperature for test room with EMSyS in the month of March (naturally ventilated mode)

In both cases, the measured air temperature and the simulated air temperature match very well as shown by key statistical indicators below.

Parameters for comparison	R-squared	Coefficient of variation of root mean square error (CVRMSE)
Measured air temperature and simulated air temperature of the test toom with IC	95%	2.6%
Measured air temperature and simulated air temperature of the test toom with IC	96%	2.2%

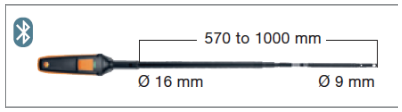
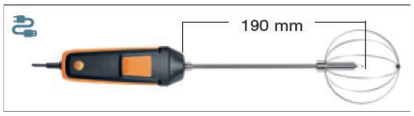
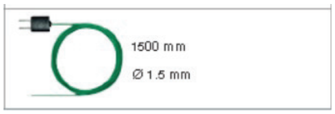
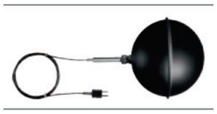
This suggests that the simulation model can very well predict the actual life scenario, by giving the correct set of inputs to the simulation model.

8. Conclusions

The key outputs of this study are as listed below.

- A customized methodology for conducting the performance monitoring of EMSyS for both naturally ventilated and air-conditioned residential buildings was developed.
- The monitored data quantified the reduction in operative temperature and cooling demand through the use of EMSyS. The key results were:
  - In the naturally ventilated mode, on a clear sunny day, the room with EMSyS had 3.0–3.5 °C lower peak operative temperature as compared to the room with internal curtains. This was observed in both sets of monitoring done with EMSyS Product 1 in the month of March and with EMSyS Product 2 in the month of June.
  - In air-conditioned (AC) mode, the room with EMSyS had ~32% less cumulative cooling demand (thermal) as compared to the room with IC. This was observed with monitoring done with EMSyS Product 1 in the month of March.
- The results of simulation model matched closely with the monitored results. The simulation model can be used to conduct parametric study to assess the impact of such parameters as orientation and location.

Annexure I. Specifications of the Instruments Used for Monitoring

Instrument	Make	Parameter measured	Picture	Type of measurement	Location and number of instruments
Hot Wire Probe	Testo	Velocity, temperature, relative humidity		Continous data logging at 15 minutes frequency	Indoor in each test room (2 nos)
Humidity / Temperature Probe	Testo	Relative humidity, temperature		Continous data logging at 15 minutes ferquency	Indoor in each test room (2 nos)
Turbulence Probe	Testo	Omni direction velocity		Continous data logging at 15 minutes frequency	Indoor in each test room (2 nos)
K-type Thermocouple	Testo	Wall surface temperature		Continous data logging at 15 minutes frequency	Indoor surface temperure of western wall in each test room (2 nos)
Globe Probe	Testo	Globe temperature		Continous data logging at 15 minutes frequency	Indoor in each test room (2 nos)
Temperature/ Humidity Sensor	Testo	Outdoor temperature and relative humidity		Continuous data logging at 15 minutes frequency	Outdoor in balcony (1 no.)
Pyranometer	Delta -T	Solar direct and diffuse radiation		Continuous data logging at 15 minutes frequency	Outdoor in balcony (1 no.)
Infrared Thermometer	Testo	Surface temperature		Spot measurements	Indoor wall surfaces (1 no.)
Lux Meter	Testo	Illuminance		Spot measurements	Indoor and outdoor (1 no.)

Instrument	Make	Parameter measured	Picture	Type of measurement	Location and number of instruments
Air Flow Capture Hood	Testo	Temperature, humidity, flow velocity, volume flow, pressure (absolute pressure), pressure (differential pressure)		Continous data logging at 1 second frequency	Indoor air conditoner unit of test room (2 nos)
Temperature Humidity Sensor	Testo	Temperature, humidity		Continous data logging at 15 minutes frequency	Indoor in each test room (2 nos)

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Confederazione Svizzera
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