# Modelling and Calibration of a building through simulation software, hand calculations and on-site measurements

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## 1. Abstract

Nowadays, it is becoming more crucial than ever to develop systems that not only improve the quality of indoor comfort, but also have low energy consumption. In the township of Auroville in India, an educational building was designed with the intent to ensure passive cooling and dehumidification by a desiccant- tower system linked to an earth duct that leads to inlet shafts connected to the rooms. For exhaust, these rooms have solar chimneys, creating a buoyancy effect for hot air to exit. The construction of the system was not finished.
The purpose of this paper is to explain the process of the simulation of the actual construction as a "base-case scenario", and how its calibration was done with real measurements taken on-site in order to make sure that it is the closest possible model to the real building. Setting this model is very important to be able to test proposals of improvements as a next step.

**Key words:** thermal simulation, passive design, calibration, on-site measurements, earth duct

## 2. Description of the location and building architecture

The building is in Auroville, a town located in the state of Tamil Nadu, India. The climate is hot and humid, with an average outside temperature of 28.5 °C, and humidity levels above 14.5 g/kg for most of the year. The rainy period of the year lasts for 9.6 months, from April to January.
Initially, the building was designed as a three-storey building, with a central courtyard surrounded by offices, classrooms, and other general services. The intent of the design was to have a passive building that could maintain comfort with minimal energy consumption. To achieve this, a natural ventilation system was designed as depicted in Figure 1, which included inlet towers with desiccant trays and fans, earth ducts and exhaust solar chimneys.
However, the building today is only built up to two-storeys. The inlet towers are only two meters high, and the desiccant trays are not installed. The inlet shafts to the rooms and exhaust solar chimneys are not built in, while there are openings in the slabs and walls to allow for their implementation.

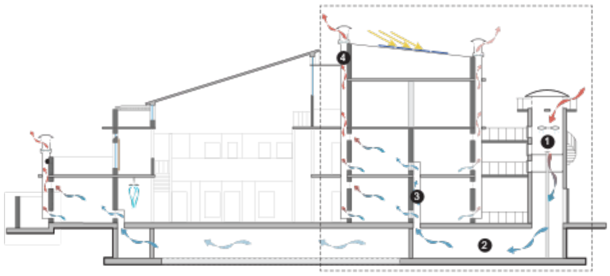

*Figure 1: Building design intent. (1) Inlet wind tower with desiccant trays, (2) Earth duct, (3) Inlet shafts to rooms, (4) Exhaust solar chimneys.*

## 3. Description of the model

In order to do the simulation, the information required to input is the weather, the building architecture and the building operation, and with this, the expected output would be the current operation and performance of the building. Once the model is set up, a validation with the real performance of the building will be made by comparing measured data on-site with results obtained from the simulation.

For the modelling, one classroom was selected in order to evaluate what happens in one zone which is representative for the rest of the building. The selected classroom was “Indian class” located in ground floor, in the north east side of the building. The total area is 58 m2. (Figure 2).

It is important to mention that the building modelled in the software is the “as-built”, as the desired output is the performance of the actual building. In this case, it includes the classroom and the earth duct, and it does not include the inlet tower and exhaust chimneys as they are still not built. The software used for the simulation was TRNSYS 18 (Transsolar Energietechnik GmbH,2009).

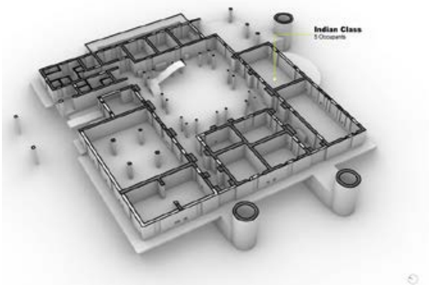


*Figure 2: Location of Indian class, room selected for the simulation*

### 3.1 Boundary Conditions

### a) Building Architecture

The building was constructed mainly with brick and lime mortar in the walls, and concrete and lime mortar in slabs. The windows are single float glass with wood frames, and bamboo carpets as external shading. The detailed boundary conditions of the construction are described in Table 1.

| **Element** | **Materials** | **Thickness (m)** | **Total Thickness** | **U-Value W/m$^2$K** | **G-Value** | **Tvis** |
|---|---|---|---|---|---|---|
| Walls | Lime Mortar | 0.025 | 0.6 | 0.801 | - | - |
| | Brick | 0.55 | | | | |
| | Lime Mortar | 0.025 | | | | |
| Ceiling | Lime Mortar | 0 025 | 0.258 | 2.882 | - | - |
| | Concrete | 0 15 | | | | |
| | Screed | 0 08 | | | | |
| | Bamboo Mat | 0 003 | | | | |
| Floor | Cut Stone | 0.1 | 0.44 | 1.796 | - | - |
| | Screed | 0.09 | | | | |
| | Concrete | 0.25 | | | | |
| Door | Wood Siding | 0.025 | 0.025 | 2.869 | - | - |
| Windows | Float | 0.05 | 0.05 | 5.72 | 0.837 | 0.866 |
| External Shading | Bamboo Screens | | | Thermal Resistance 1.944 hm2K/KJ | - | - |

*Table 1: Boundary Conditions of Construction*

### b) Building Operation

In order to understand the operation of the building, information was gathered from the operations and maintenance team such as the schedule of the classes and the internal loads which include: number of people that attended the courses, the equipment inside the room and lighting. Other two important aspects that influence the performance of the room are the infiltration and ventilation rates, for this it was important to know the number of windows and how often were they opened as well as the tightness of the enclosures. The gathered information is described in Table 2 and Figure 3.

| Number of Occupants | 8 |
|---|---|
| Equipment (Convective Gains) | 1044 W |
| Lights (Convective Gains) | 100 W |
| ACR (1/h) Windows | 8 ACH |
| Constant Infiltration | 2 ACH |

*Table 2: Building´s Operation Data*

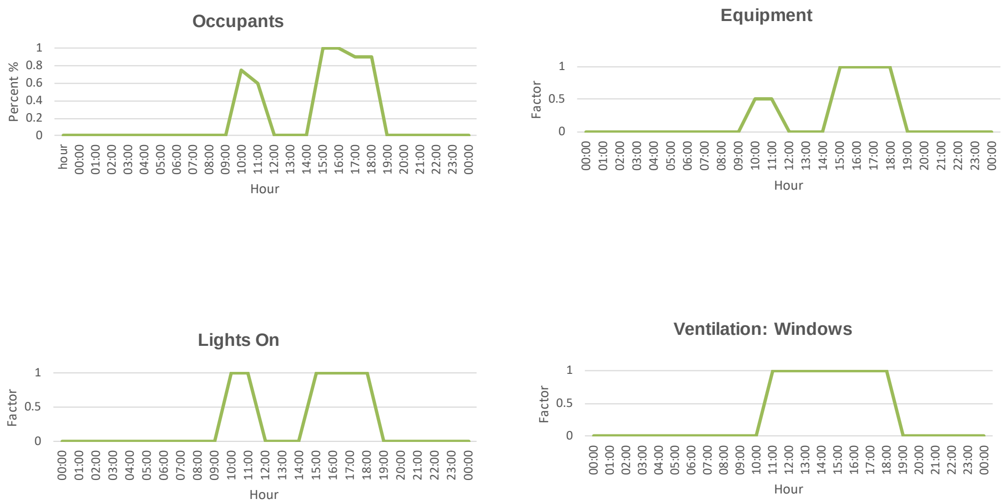


*Figure 3: Building´s Operation Schedules*

### 3.2 Components considered for the model

The gathered information was transferred into the Trnsys simulation software in the form of components to build the model. Figure 4 shows the assembly.

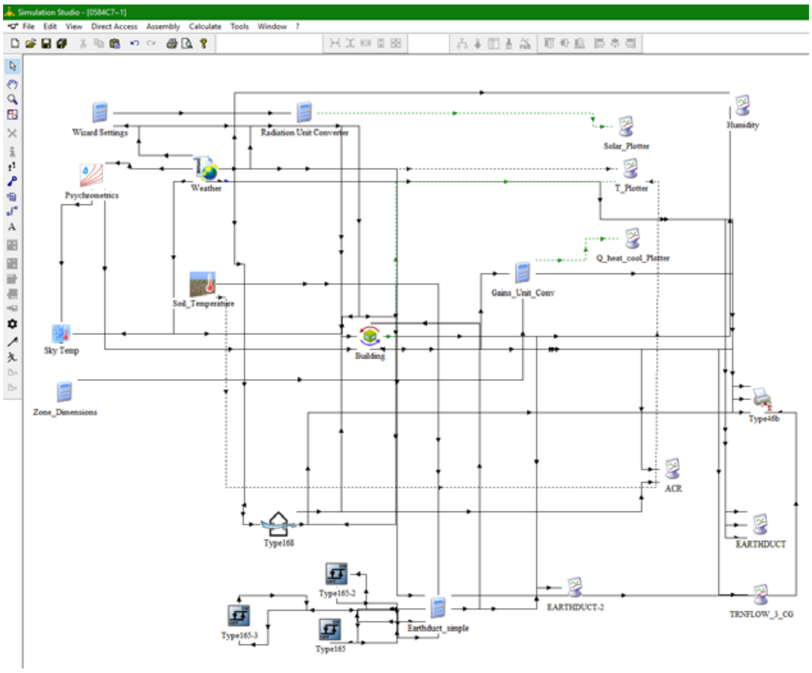


*Figure 4: Trnsys Studio Model*

1. Weather / Unit 15 – Type 99

   To input the weather file

2. Building/ Unit 56- Type 56

   Is the .b18 file, where all the information of the construction of the building and internal loads are inputted as well as infiltration, ventilation and/or any mechanical system

3. Psychrometrics/ Unit 13- Type 33e

   From the weather file it is inputted the "ambient temperature" and "relative humidity" into the psychometrics and outputted the "dew point temperature" into the "Sky temperature".

4. Soil Temperature/ Unit 77 – Type 77

   Input the "soil temperature" into the .b18

5. Sky Temperature

   Input the "ambient temperature", "beam radiation on horizontal" and "sky diffuse radiation on horizontal" to get as an output the "Fictive sky temperature" and input it into the .b18

6. Natural Ventilation/ Unit 18- Type 168

   Input the "ambient temperature" to get as an output the "ACH rate"

## 4. On-site measurements

Once the model was set up and simulations were run, it was needed to calibrate the model. For this, on- site measurements were taken for two weeks, from 13$^{th}$ to the 29$^{th}$ of September, of:

a) Exterior
   - Ambient temperature
   - Relative humidity
   - Absolute humidity

b) Inside Indian Class
   - Air temperature
   - Relative Humidity
   - Absolute Humidity

c) Surface temperature Indian Class
   - Inside wall
   - Outside wall
   - Floor
   - Ceiling

d) Earth duct
   - Temperature
   - Relative Humidity
   - Absolute Humidity

## 5. Calibration of the model

### 5.1 Room Calibration

The comparison between simulation results and on- site measurements showed difference in behavior of air temperature inside the room. The first week, the simulated air temperature inside the room was higher than the measured air temperature, and the second week it was lower. Results are shown in Figure 5.

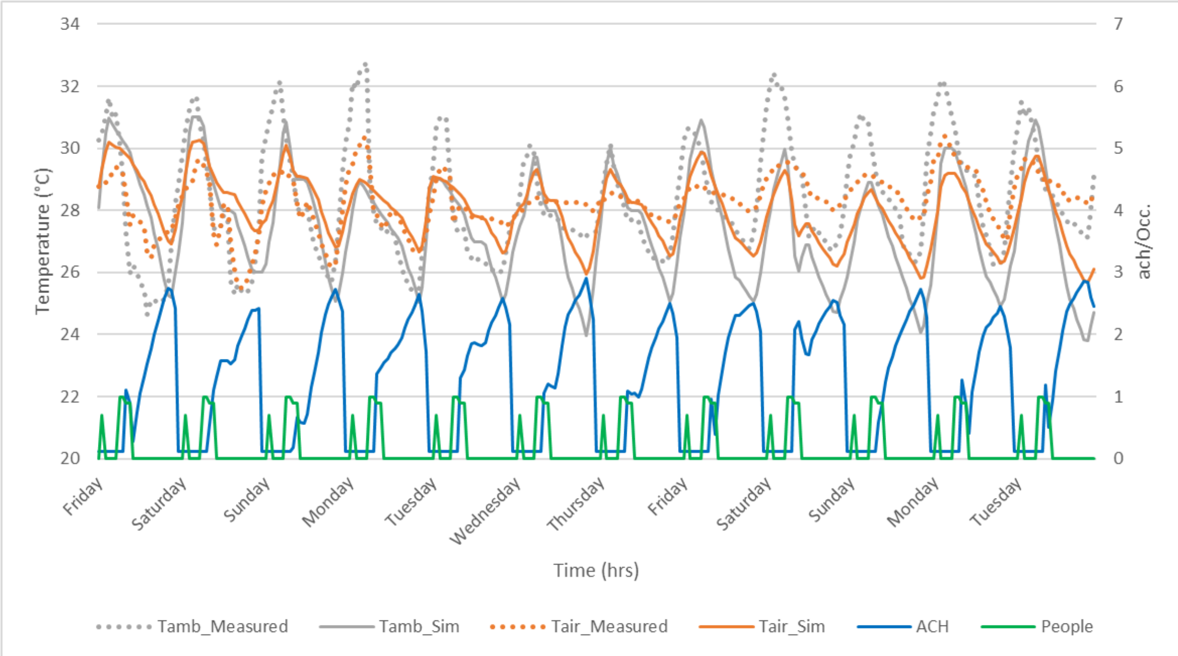


*Figure 5: Line graph showing the simulated and measured inside air temperatures of the room, and ambient air temperature, as measured from 13.09.2019 to 25.09.2019.*

Questions began to arise about the boundary conditions. In order to have more accurate information it was asked again to the operations and maintenance team to detail the number of persons and schedule for the same period the measurements were taken. It was also now taken into consideration the different operation´s schedule between weekdays and weekends, which was not considered before. The new boundary conditions are shown in Table 3 and Figure 6.

| | |
|---|---|
| Number of Occupants | 5 |
| Equipment (Convective Gains) | 1044 W |
| Lights (Convective Gains) | 100 W |
| ACR (1/h) Windows | 3.4 ACH |
| Constant Infiltration | 2 ACH |

*Table 3: New Building´s Operation Data*

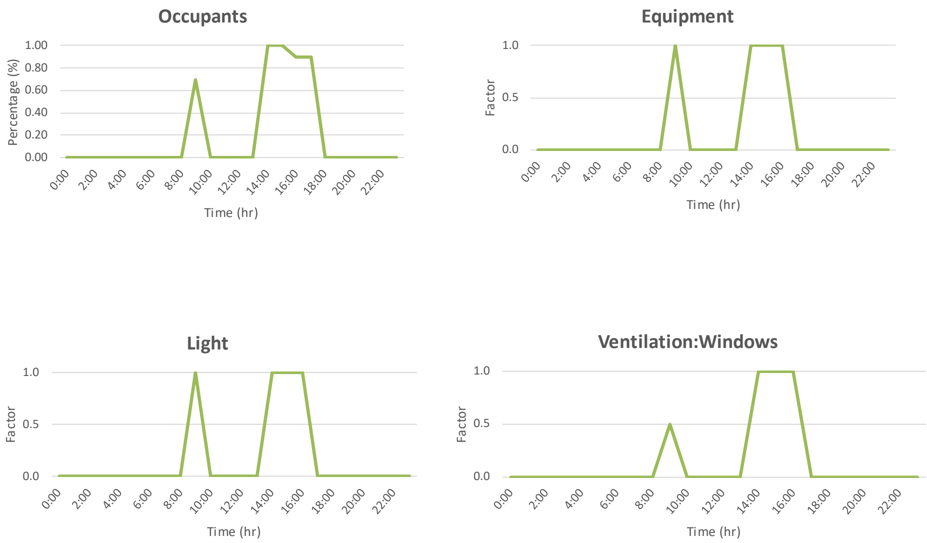


*Figure 6: New Building Operation´s Schedules*

It can be observed that air temperature inside the room follows the same pattern as ambient temperature, it increases during the day and decreases during the night, which means there is air movement between inside and outside, so ambient temperature is influencing inside temperature. This can be explained by the openings that are in the room which are supposed to be inlet and outlet shafts for the passive-cooling system, but as for the moment the shafts are not built, there is constant infiltration in the room.

Even though the same pattern between ambient and inside temperature is observed, it is shown that the temperature swing of inside temperature is not so great as the one of ambient temperature, this can be due to the impact of the thermal mass of the building.

It can also be observed that measured temperature inside the room matches measured ambient temperature when the room is not occupied, and it shows a difference when the room is being occupied. This can mean that windows remained totally open when there was no one in the room and closed during the days it was used.

With the new boundary conditions the simulated air temperature inside the room shows the same behavior as the measured one, but it is around 2°C higher, so this can be considered as a conservative model.

It is shown that simulated inside air temperature constantly overlaps with simulated ambient temperature in the higher peaks while measured inside temperature keeps more distance with measured ambient temperature. This can mean that some boundary conditions in the model are still not quite accurate, and there is more space for improving the calibration. It was discovered that changes made in ventilation rate, ACR, have a big impact in air temperature inside the room, while changes in internal loads or gains have almost no impact. So, we can conclude that this difference between simulated and measured results are due to too much infiltration or ventilation ACR.

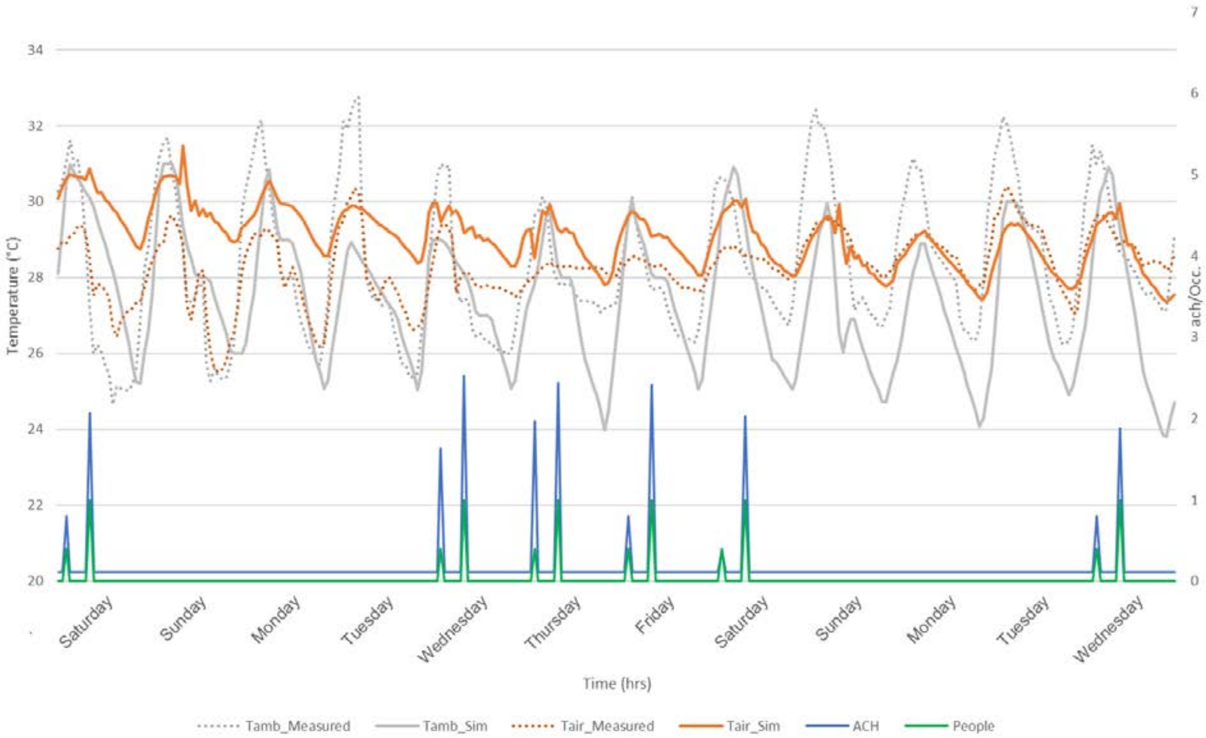


*Figure 7: Line graph showing simulated (with new boundary conditions) and measured inside air temperatures of the room, and ambient air temperature, as measured from 13.09.2019 to 25.09.2019.*

### 5.2 Earth Duct Calibration

As the earth duct was also measured but not simulated, hand calculations were used to see if results were similar and then they were calibrated. Two heat transfer formulas were solved to find out the exit temperature of the earth duct (Tout). These were as follows:

$Q_1$=VÁ$C_p$ ($T_{in}$-$T_{out}$) (1)

$Q_2$=$h_c$A ($T_{wall}$-($T_{in}$/2 + $T_{out}$/2)) (2)

Where
$Q_1$ –Heat loss in convective streams (W);
$Q_2$-Convective heat transfer between wall and air(W);
V-volume flow rate ($m^3$/h);
Á-fluid density (kg/$m^3$);
$C_p$-heat capacity of air (Wh/kgK);
$T_{in}$-inlet air temperature (K);
$T_{out}$-outlet temperature (K);
$T_{wall}$ -surface temperature (K);
$h_c$- heat transfer coefficient (W/$m^2$K);
A-surface area ($m^2$).

Inputs for these equations were based on preliminary assumptions and measurements from drawings.

*Image 1: Underground earth duct*

These were then added into an Excel sheet where surface temperature (Twall) and volume flow rate (V) were altered to calibrate the results of the hand calculations with the measured data collected on site. As the monitoring device used was "Elitech", it was important to account for average deviations in results to ±0.33°C. Findings are presented in Figure 8.

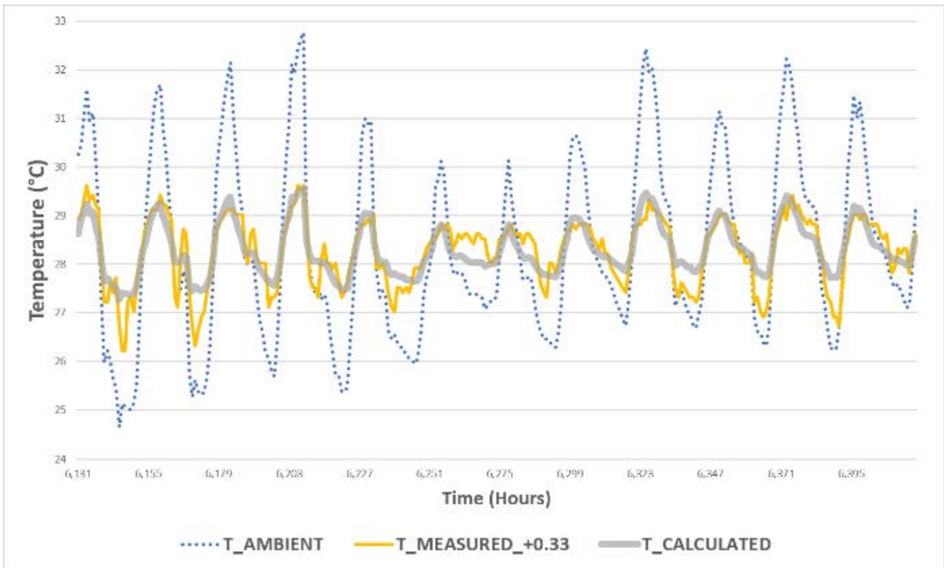

*Figure 8: Line graph showing the calculated and measured outlet temperatures of the earth duct, and the ambient air temperature, as measured from 13.09.2019 to 25.09.2019.*

The measured results show that the outlet temperature in the earth duct is lower by an average of 3°C than the measured ambient temperature in the mornings, but sometimes higher by a range of 0.5 to 1°C at night. This difference between the measured and calculated results at night is because the surface temperature was always kept constant at 28°C (the average annual theoretical surface temperature).

Evidently, there is an adequate air flow in the ducts to allow for conditioning air. Having these results helped in generating questions that can be answered more effectively via simulations. Moreover, these simulations are necessary for evaluation as the hand calculations can only be calibrated to represent either morning or night, and not both simultaneously. Therefore, simulation outputs would help in evaluating all the hours of the year.

## Conclusion

Simulations are useful to test variations of a building to get to the most efficient and climate-responsive solution, but these must be the closest as possible to reality. An important aspect to consider is to get the correct data of the building, which can be achieved through good communication with the users of the building. Making analysis of the first simulations and asking questions can help discover possible points to reconsider in the model. When simulating an existing building is possible to compare with on- site measurements as a way of ensuring the model´s accuracy.

For this project, the next step would be to simulate the proposed passive-cooling system to evaluate its performance and decide if it is worth it to build it as planned, or, if any variation must be made.

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