

Study on Thermal Comfort in Istiqlal Mosque

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Abstract

Most mosques in Indonesia, whether small or large mosques, use natural ventilation to control the thermal condition inside the prayer room. The mosque commonly has high ceilings and large openings on the three side walls, except the mihrab. The room plan of the prayer room is square or semi-square and surrounded by open corridors. Full occupancy normally occurs during the Friday praying time.

The Istiqlal mosque is being the largest mosque in Indonesia. The area of the inside praying hall is 75m x 75m, ceiling height is 19m and the height of the top dome ceiling is 47m. On the three side of the prayer walls there are four storey balconies with large openings and the prayer hall is surrounded by wide terraces.

The study on the thermal comfort inside the mosque was conducted during the Friday praying time by measuring air temperature, relative humidity and air velocity as well as by conducting simulation using *EnergyPlus* software. The measured data were then analyzed using the thermal comfort criteria of *FangerPMV*, *PierceTSENS* and *KsuTSV*.

From this study it can be concluded that during the Friday praying time with full occupancy in the praying hall, thermal condition inside was still within the comfort zone of slightly warm.

Keywords: mosque, natural ventilation, thermal comfort

1. Introduction

Most mosques in Indonesia, whether small or large mosques, use natural ventilation to control the thermal condition inside the praying room. This study chose the Istiqlal mosque in Jakarta as a study case. Although Jakarta has a hot climate, the mosque uses natural ventilation to obtain internal thermal comfort.

The Istiqlal mosque has a high ceiling and large openings on the three side walls, except the mihrab. The room plan of the praying room is square or semi-square and surrounded by open corridors. Full occupancy normally occurs during the Friday praying time.

The high ceiling, large openings and a big building mass are able to create thermal comfort.

The study was conducted during the Friday praying time by measuring air temperature, relative humidity and air velocity as well as by conducting simulation using *EnergyPlus* software. The measured data were then analyzed using the thermal comfort criteria of *FangerPMV*, *PierceTSENS* and *KsuTSV*.

2. Thermal Comfort

There are three mathematical models for thermal comfort namely: Fanger Comfort Model, Pierce Two Node-Model and KSU Two Node-Model^[1].

The Fanger model was firstly developed by P.O. Fanger in Kansas State University and Technical University of Denmark in 1967 and published in 1972. In this model, the calculation is strongly affected by heat loss from human bodies, namely heat loss from convection and radiation through outside surface of clothings, heat loss from water vapour through skin surface, loss from sweat evaporation from skin surface and heat transfer from the skin to outer part surface of the clothing.

In this model, “*predicted mean vote*” (PMV) is used as a scale to show thermal comfort.

PMV is then divided in 7 scales to determine thermal comfort levels where ‘0’ represents comfort relative against environmental condition, ‘positive scales’ for warm and ‘negative scales’ for cool conditions.

The Pierce Two-Node Model was developed by John B. Pierce Foundation in Yale University in 1970. In this model, human body consists of internal body and its skin. *Thermal sensation* (TSENS) is used to determine the thermal comfort scale. The thermal comfort is influenced by passive heat conduction from the body to the skin and temperature deviation between skin temperature and set-point temperature.

KSU Two-Node Model was developed by Kansas State University and firstly published in 1974. Variation of thermal conductivity between inner part of the body and the skin in cool environments and variation of skin humidity at warm environments, are main factors which affect this model. This model uses *thermal sensation vote* (TSV) scale to show the thermal comfort.

Effective Temperature (ET) is the temperature of saturated nearly or stagnant air without heat radiation to give equal thermal comfort with real air conditions^[2]. Therefore the thermal comfort can be equally given by combination of air temperature (DBT and WBT), humidity and air velocity. In this work, Effective Temperatures were simply determined by using ET nomogram.

Thermal comfort scale for Indonesian in effective temperature is as follows^[3]:

Comfortably cool, ET between 20,5 °C – 22,8 °C;

Comfortably optimal, ET between 22,8 °C – 25,8 °C;

Comfortably warm, ET between 25,8 °C – 27,1 °C.

EnergyPlus software was used to simulate thermal load^[4]. This software was released in April 2001 by Berkeley Laboratory, which was developed from BLAST (*Building Loads Analysis and System Thermodynamics*) dan DOE-2 softwares. It can be used to model thermal comfort inside buildings. In this software, surface temperature is evaluated to determine the effect of radiation of the surface. Three mathematical models to determine thermal comfort have been integrated in this software (Fanger Comfort Model, Pierce Two Node-Model and KSU Two Node-Model).

3. Case study: Istiqlal mosque

Istiqlal mosque was built on 95,000 m² area which consists of a mosque building, parks, parking area, water fountain and surrounded by a river. The mosque building consists of main building, entrance hall, large terrace, tower and ground floor (Figure 1).

The main building consists of a 75 x 75 m² area for praying with capacity of 16,000 persons. At the left, right side and the back there is a 5 stories balcony with 10 m wide with its capacity is 61,000 persons.

The building has 12 pillars which support a large dome above the main building. These cylindrical pillars with 2.5 m cross section made of concrete which covered by stainless steel. The diameter of hemispherical dome is 45 m and the dome is constructed by polyhedrons frame covered by reinforced concrete. The inner side of the dome is covered by stainless steel plafond while the outer side of it covered by white ceramic tiles.

The building height is 47.3 m above the main floor area, its ceiling made from concrete. The ceiling height at the balcony is 3.8 m above the floor. At every side of the balcony there are 26 square pillars with 2 m equally spaced. Therefore the area of the opening in the main floor is 2 x 3.8 m², whereas at the balcony from 2nd to 5th floor, sun shading is used to cover all the space.

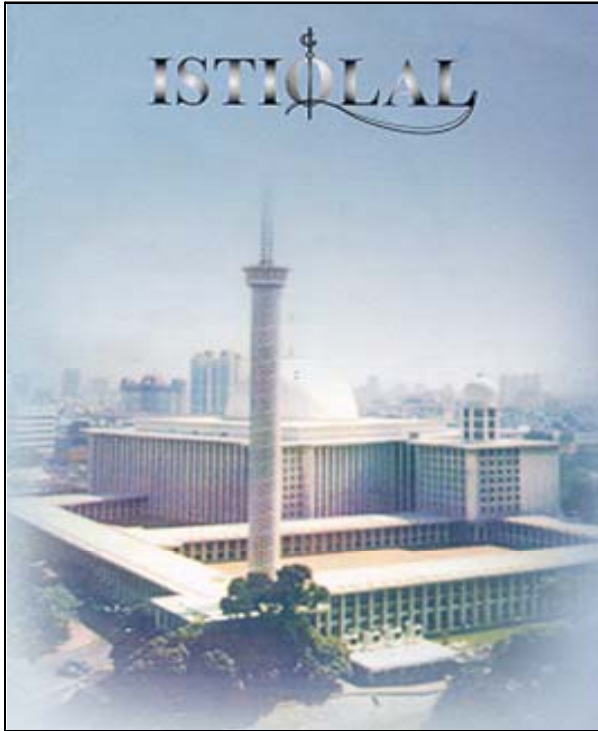


Figure 1. Istiqlal Mosque in Jakarta

4. Measurement and Simulation Results

Air temperature (DBT), air velocity (V) and relative humidity (RH) were measured during empty and fully occupied conditions. The 1st measurement was measured before the Friday praying time at 11:00, whereas the 2nd measurement was measured just after the praying finished at 12:30.

Measurements were carried out inside and outside the hall at 1.5 m high. 13 measurement points at the main hall 8 points at 2nd floor of the balcony were selected and representing the whole praying area and 4 measurement points outside the hall were also selected and these representing the north, east, south and west side conditions (Figures 2 and 3). The calculated ET at each measurement points is plotted in Table 1. For illustration, simulation results as temperature profiles and thermal comfort scale of central, north, north-2 and south-2 zones, are shown in Figure 4.

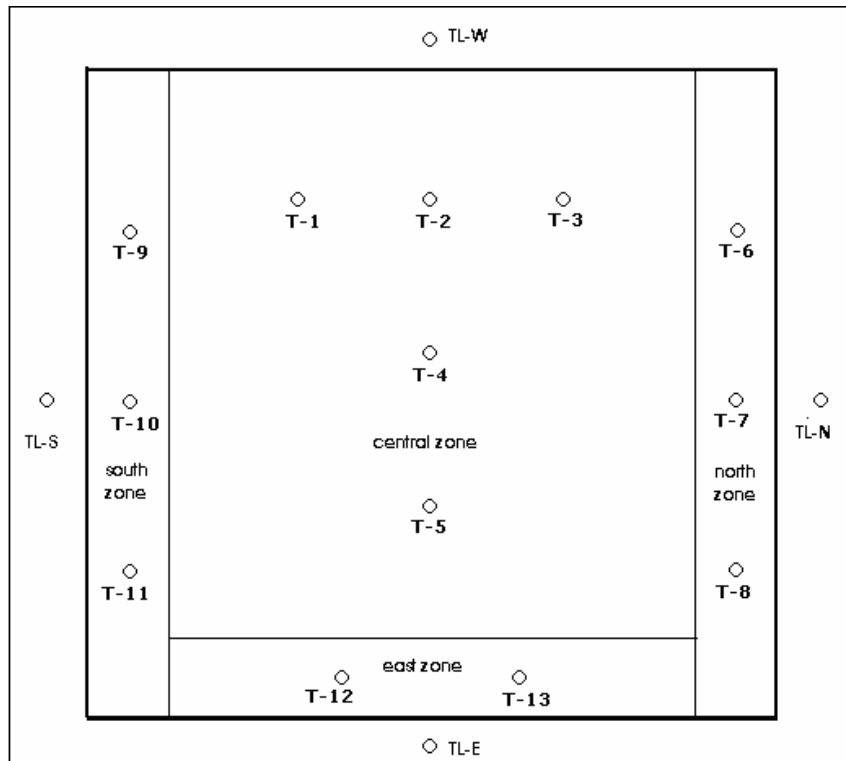


Figure 2. Measurement points at the main floor (hall)

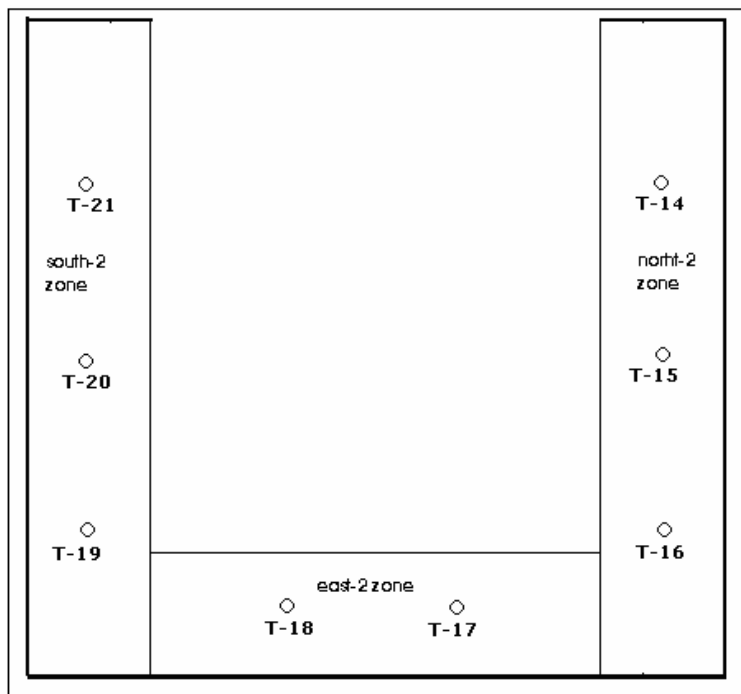


Figure 3. Measurement points at the 2nd floor of the balcony

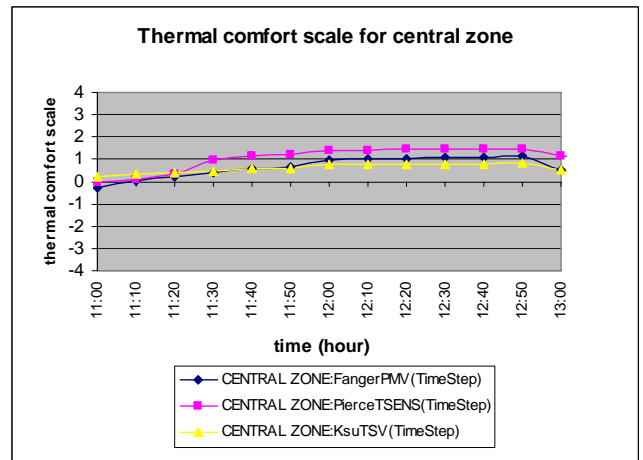
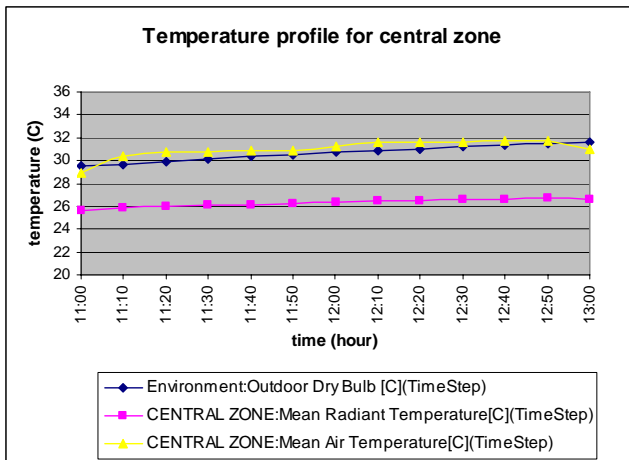
Table 1. Calculated Effective Temperature (ET) for the 1st and 2nd measurements.

TL-S ET 1=25.3 ET 2=25.4	TL-W ET 1 = 25.4 ET 2 = 25.8		TL-N ET 1=25 ET 2=26	
	SOUTH ZONE ET 1 = 25.2 ET 2 = 25.2	CENTRAL ZONE ET 1 = 25.1 ET 2= 25.7		NORTH ZONE ET 1 =25.3 ET 2 = 24.9
		EAST ZONE ET 1 = 25.5 ET 2 = 25.6		
TL-E ET 1 = 25.4 ET 2 = 25.5				

2nd floor of the balcony

SOUTH-2 ZONE ET 1 = 25.2 ET 2 = 24.8	EAST-2 ZONE ET 1 = 25.3 ET 2 = 24.8	NORTH-2 ZONE ET 1 = 25.3 ET 2 = 24.4

Notes: ET1 = Effective Temperature (°C) at 1st measurement
 ET2 = Effective Temperature (°C) at 2nd measurement



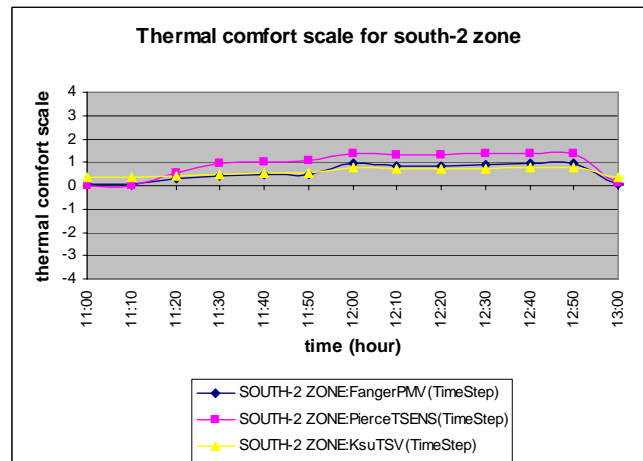
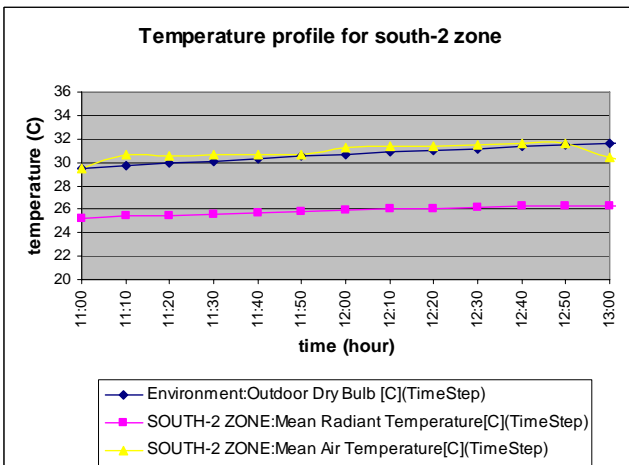
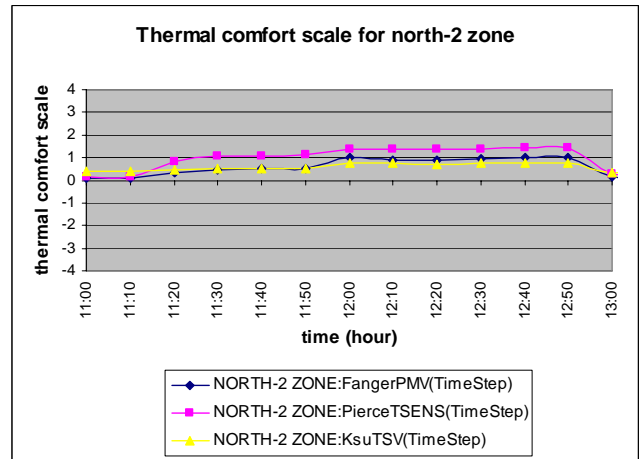
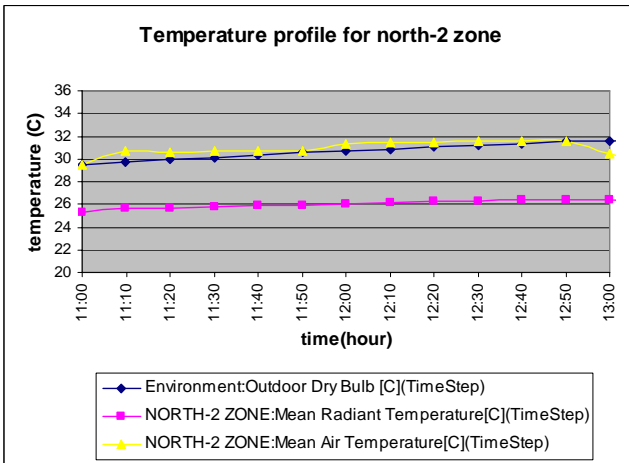
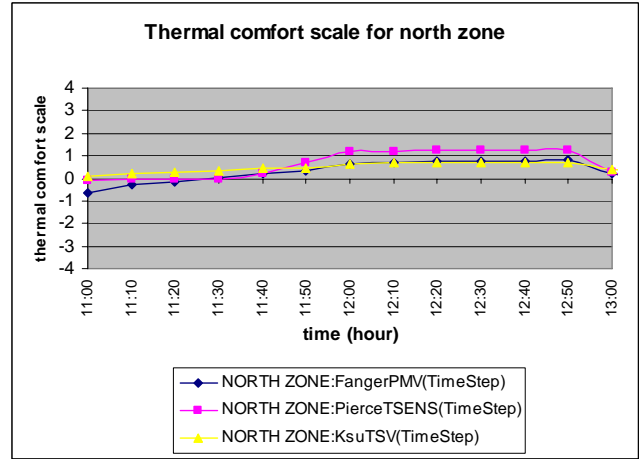
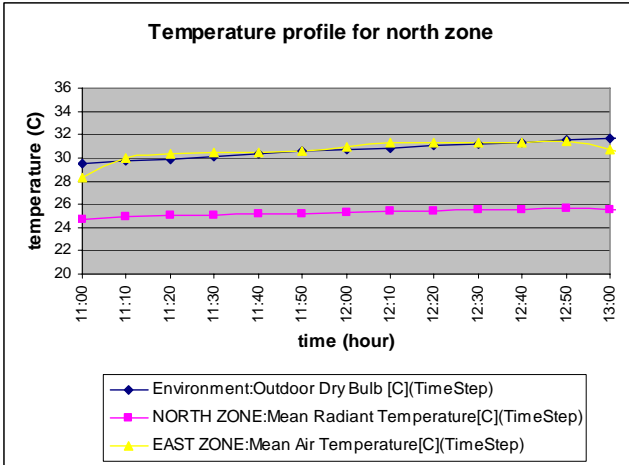


Figure 4. Simulation results for central, north, north-2 and south-2 zones.

5. Analysis

The area of the mosque was then divided into zones, based on thermal condition of the space. The main floor was grouped into 4 zones namely central, north, east and south zones respectively. Direct sunlight did not enter the central zone whereas north, east and south zones received direct sunlight and external climate conditions. 2nd floor of the balcony was grouped into 3 zones namely north-2, east-2 and south-2 zones.

Based on ET calculation, all zones have 'comfortably optimal' thermal condition (range 22.8-25.8°C). On average, DBT and RH in all zones were nearly equal and the average RH was 53%. At the 1st measurement, the highest wind speed was 0.6 m/s at north zone, while the lowest was 0.2 m/s at east zone. At the 2nd measurement, the measured wind speed was higher than the 1st measurement. The highest wind speed was at the north zone with 1.4 m/s and the lowest was at the central and east zones with around 0.5 m/s. Similar results were found also at the 2nd floor of the balcony.

It was found that during the Friday praying time, full occupancy at the main floor and 2nd floor of the balcony did not affect much on thermal comfort inside the mosque, and it was still within the 'comfortably optimal' range. This was due the increasing wind speed at afternoon (although increasing also in DBT) and the direction of the incoming wind into the mosque was in line with congregational prayer's direction.

The output from the simulation were outside air temperature (DBT), inside air temperature in each zone (DBT), Mean Radiant Temperature (MRT) and Thermal comfort scales based on FangerPMV, PierceTSENS and KsuTSV methods.

It was found that air temperatures in each zone were almost the same. The inside air temperature increased with increasing the number of people entering the mosque. The maximum inside air temperature reached at 12:50 due to heat load from the people. After praying, the air temperature decreased. The highest inside air temperature was found in the central zone, which was fully occupied by attendants.

Prediction of the thermal comfort in all zones gave similar results. At empty condition, all zones were at 'comfortably optimal' (around zero) for the three thermal comfort methods. The highest thermal comfort scale was achieved at 12:50, the time at the maximum inside air temperature. At this condition, the three methods showed 'comfortably warm' scale. Therefore thermal comfort inside the Istiqlal mosque was still in the comfort zone during Friday praying times.

6. Conclusions

- Measurement results taken before the Friday praying time showed that the Effective Temperature ranged from 25,1°C to 25,5°C. This shows that thermal comfort inside the Istiqlal mosque was still within the 'comfortably optimal' scale of 22,8 °C – 25,8 °C ET. After the Friday praying time, the Effective Temperature ranged from 24,9 °C to 25,7 °C, which was still within the same scale.
- Simulation results using EnergyPlus showed that all zones were within the comfort zone. At empty condition, the hall was in 'comfortably optimal' scale and this shifted to 'comfortably warm' with increasing the attendants and air temperature.
- The highest thermal comfort scale, 'comfortably warm', happened at 12:50. This was given by the three thermal comfort models.

References

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