Conference Paper

Influence of Structure and Wall Materials on Building Thermal Performance

Mahatma Sindu Suryo

Research Institute of Housing & Human Settlement, Ministry of Housing & Public Work, Bandung, Indonesia

Abstract

The passive cooling technique is a strategy to improve building thermal performance which is cost-effective, eco-friendly and best suited for the local climate. The building material is one of the elements in passive cooling techniques. The research aims to investigate the influence of building materials on building thermal performance by field measurements on test houses. Hobo data loggers were used to collect indoor air temperature and relative humidity data. FLIR Infrared Camera was used to collect surface temperature data. The National Standard for Ventilation and Air Conditioning system (SNI 03-6572-2001) used as a reference for thermal performance value. The scope of the research is investigating the influence of the structure and wall materials on building thermal performance. The structure materials for the experiment were steel material and concrete material. The wall materials for this experiment were clay brick, light concrete brick (AAC), GRC-Rockwool panel and GRC-Styrofoam Panel. This research showed that steel structure influences the increasing indoor building air temperature. Clay brick material with higher thermal conductivity values has longer duration above the warm comfort zone rather than other wall materials in this experiment.

Keywords: passive cooling, building materials, thermal performance

Corresponding Author:
Mahatma Sindu Suryo

Received: 24 May 2019
Accepted: 25 July 2019
Published: 4 August 2019

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ISTEcS 2019 Conference Committee.

1. Introduction

Building thermal comfort is related to the respond of the design to the microclimate. Thermal comfort defined as a condition of mind that expresses satisfaction with the thermal environment and assessed by subjective evaluation [1]. The variables that affect thermal comfort consist of three sets: environmental, personal and contributing factors. The environmental factors are air temperature, air movement, humidity and radiation [2]. Thermal comfort is determined by the relationship between air temperature, air humidity and wind flow [3]. According to Szokolay, thermal comfort index can be obtained empirically through social surveys and analytically based on the principles of heat flow physics. For thermal comfort, the building must act as a barrier, transforming the outside climate to conditions suitable for inside activities [4].

How to cite this article: Mahatma Sindu Suryo, (2019), "Influence of Structure and Wall Materials on Building Thermal Performance" in *Equity, Equality, And Justice In Urban Housing Development*, KnE Social Sciences, pages 521–534. DOI 10.18502/kss.v3i21.4992

The passive design strategy is a universal concept used in responding to climatic conditions to create thermal comfort in buildings. Distinguished between three stages in climatic design [5]:

1. Forward analysis, which includes data collection and ends with a sketch design.
2. Plan development consists of the design of solar controls, overall insulation properties, ventilation principles, and activity adaptation.
3. Element design comprises closer examination and optimization of all individual building elements within the frames of the agreed overall design concept.

According to Roselund, the good reasons to adopt passive techniques, not only economic but also to promote environmental sustainability at both local and global levels. The components of a passive design technique are building orientation, material use, natural lighting, vegetation layout, openings, and cross ventilation. Principles of passive cooling: sun-shading, reflection, insulation, reduction of internal gains, ventilation, fans, and tightness of buildings [4].

This study is a part of Passive Cooling Technique on Landed House Research Project. The research project will investigate the effect of design variables on thermal performance such as building materials, insulation, roof ventilation, ceiling, orientation, water, and ground cooling technique in a warm, humid tropical climate. The use of building materials can be categorized into materials for structures, walls and roof materials. This first phase of this research is investigating the influence of structure and wall material on building thermal performance. Currently, the most common materials used for building structures are steel (Wide Flange steel and H-beam steels) and reinforced concrete.

Clay brick was widely used for wall materials for centuries. Recently, in Indonesia, the use of lightweight concrete brick is growing up in building construction. Lightweight concrete brick can either be lightweight aggregate concrete, foamed concrete or Autoclaved Aerated Concrete (AAC.) The alternative wall materials in the building construction are precast Glassfiber Reinforced Cement (GRC) wall panels and GRC-Styrofoam Concrete Panel. GRC wall panel is commonly applied on a metal frame or wood frame structure.

2. Reference

The heat exchange on the surface of the building also affected by the reflection factor and heat absorption of the building material. The material resistance to heat that affects buildings is called thermal properties. All building materials possess both thermal resistance and thermal capacity in different proportions. Roselund stated that three factors are influencing these properties:

1. The density (ρ, kg/m3) plays a great role for the thermal properties: the lighter the material, the more insulating and the heavier, the more heat storing.
2. The conductivity (λ, W/mK) describes the ability to conduct heat. Insulating materials have low conductivity value.
3. The specific heat (c_p, Wh/kgK) indicates how much energy can be stored in the material. High specific heat means good thermal, that is heat storing, capacity. [4].

Table 1: Thermal Conductivity of Building Material.

No	Building Material	Density (kg/m3)	K (W/m.K)
1	Concrete	2.400	1,448
2	Aerated Concrete	960	0,303
3	Plastered Clay Brick	1.760	0,807
4	Exposed Clay Brick		1,154
5	Glass	2.512	1,053
6	Gypsum board	880	0,170
7	Steel	7.840	47,6
8	Granite	2.640	2,927
9	Marble/Ceramic/Terazzo	2.640	1,298
Source: SNI 03- 6389- 2000			

The combination of thermal properties influences the time lag and the attenuation of building elements. Roselund described time lag as the time from outside to inside maximum surface temperature, and the attenuation is the proportion of inside to outside temperature amplitude (swing temperature). These properties strongly affect the indoor climate [4]. Thermal properties of building materials are related to heat storage, heat isolation, and the temperature of the building materials [6]. **Table 1** shows the thermal conductivity value of each building material [9]. Clay brick and Autoclaved Aerated Concrete brick (AAC) are most widely used in a low-rise building with an exposed or plastered application. Thermal conductivity value of plastered clay brick is 0,807 W/m.K which is higher rather than aerated concrete brick (0,303 W/m.K).

Research related to the thermal properties of building materials were:

1. Noerwarsito and Santosa (2006) conducted research on clay brick and concrete brick materials related to building thermal comfort [6]. The object of this study was house buildings in Surabaya. The result of field measurement is compared

with a simulation result. The simulation was conducted with Archipac 5.2 software. According to Santosa, thermal comfort in Surabaya is in 25,5˚C – 28,7˚C range. His research found that clay brick building has lower indoor temperature rather than concrete brick. The clay brick building also has less duration for an overheated condition.

2. Purnama et al. (2016) identify the effect of bamboo and clay brick materials on an indoor temperature in Mojokerto, East Java [10]. The average outdoor temperature in Mojokerto is 28˚C. This study measured indoor temperature on two office buildings with different wall materials which are MUTOS office building and Less office Building. The MUTOS office building has a clay brick wall, and Less office building has a bamboo wall. The result of field measurement is compared with the Ecotec simulation result. This research found that based on the field measurement the bamboo wall material has better thermal performance rather than clay brick wall. Based on field measurement, the average decreasing indoor temperature of clay brick office is 2,9˚C -3,24 ˚C. The average decreasing indoor temperature of bamboo wall office is 3,48˚C -3,52 ˚C. Based on the simulation, the average decreasing indoor temperature during day time on clay brick building is 5,58˚C and 4,57 ˚C on the bamboo building.

3. Gourav et al. (2017), found that the structural and thermal properties of masonry units influence the thermal behavior of masonry [11]. The research investigated the characteristic of Fly ash-Lime-Gypsum (Fal-G) bricks and compared them with conventional table moulded bricks. The investigation collected the data measurement of thermal conductivity values, specific heat capacity values, and material density values. Based on the analysis of the thermal properties the research found that Fal-G brick performs better for building envelopes in tropical conditions.

3. Methode

The objects studied from the previous research have different variables such as microclimate, orientation, and design. Test houses construction aims at controlling variables in a passive cooling technique. Each model has the same dimension of 3m x 3m x 3m (Fig.1 & Fig.4). All the test house models were constructed with prefab concrete panels except for Test House 1. Test House 1 were constructed as a stage steel structure. Buildings layout was designed to avoid the influence of shade among the test houses. This study was conducted in Cileunyi, Kabupaten Bandung (6,9˚ S, 109˚ W).

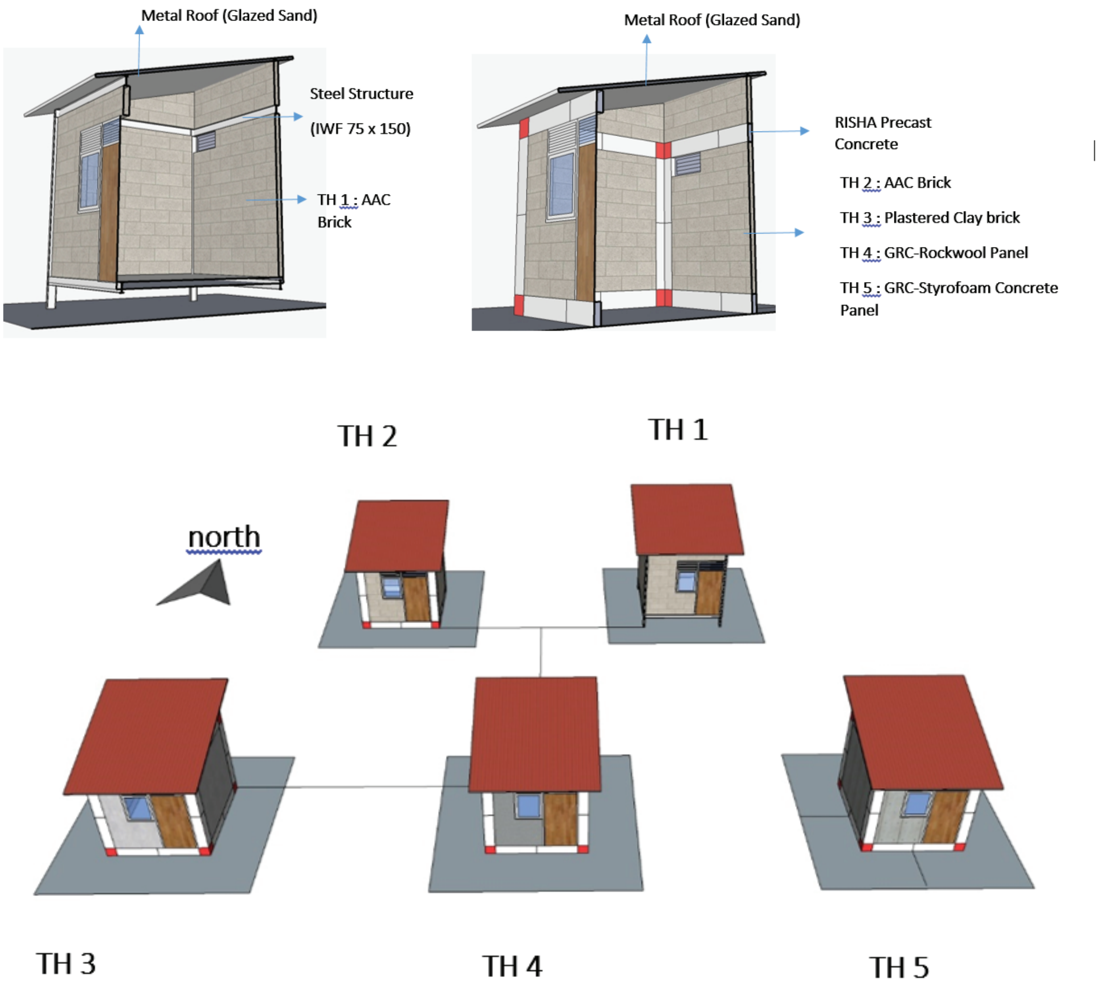


Figure 1: Test House Models & Layout.

The experimental scenarios described below:

1. Phase 1, measuring the effect of structural material on the thermal performance of the building. The objects of this experiment are prefab - concrete structure and steel - structure (Fig.2). Rumah Instant Sederhana Sehat (RISHA) structure is a frame structure that is assembled using prefabrication concrete panels. A steel plate connects these panels and bolts joint. The steel structure used Wide Flange Shape steel with 75 mm x 150 mm dimension. The controlled variables in this phase were wall material, roof material, roof shape, openings, and building orientation.

2. Phase 2, measuring the effect of wall material on the thermal performance of the building. **Fig.3** shows the objects of the experiment which are plastered clay brick (150mm thicks), AAC brick (75 mm thicks), GRC wall panel (75 mm thicks) and Ecolite Styrofoam Concrete wall panel (75 mm thicks). The controlled variables in

Figure 2: RISHA Concrete Structure (left). Wide Flange Shape Steel Structure (right).

this phase are the structure material, the roof material, the roof shape, and building orientation.

a. Clay brick b. AAC brick c. GRC insulated panel d. Styrofoam Concrete Panel

Figure 3: Wall Materials.

The inside-air temperature and humidity data collected by Hobo Data Logger. The Hobo Data Loggers were positioned 1-meter height above the floor in the middle of the room (**Fig.4**). The FLIR infrared camera used to measure the surface temperature of wall materials. A weather station built to collect the microclimate data such as outside air temperature, humidity, wind speed, and solar radiation.

The reference used for thermal comfort measurement is SNI 03-6572-2001 (The national standard for designing ventilation system and air conditioning in buildings). SNI 03-6572-2001 divides the thermal comfort area for Indonesia into:

1. cool comfort, the effective temperature is 20.5 °C ~ 22.8 °C

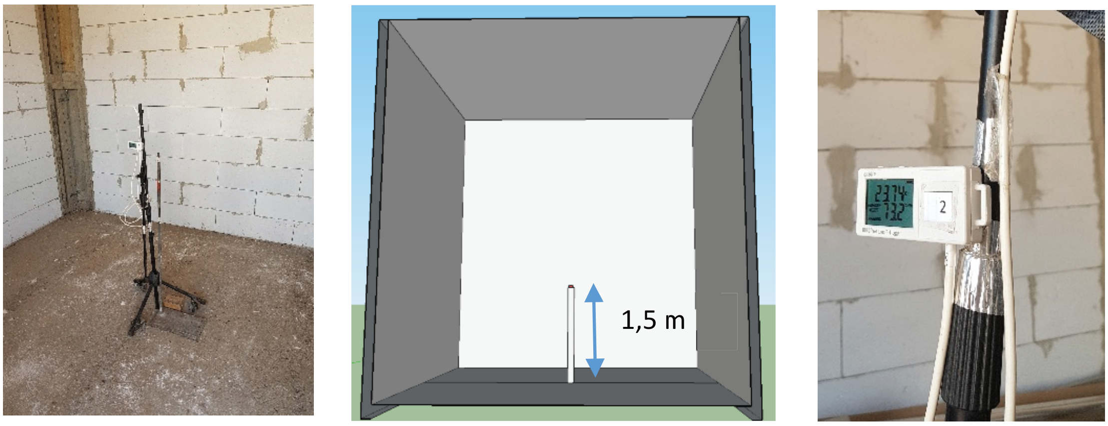


Figure 4: Datalogger position.

2. optimum comfort, the effective temperature is 22.8 °C ∼ 25.8 °C.

3. warm comfort, the effective temperature is 25.8 °C ∼ 27.1 ° C

The thermal comfort zone for Indonesian as mentioned in SNI 03-6572-2001, is about 25 ° C ± 1 ° C with relative air humidity around 55% ± 10%. [8]. **Fig.5** shows the constructed model of the Test houses. The data measurement was conducted on August 29^{th},2017 – August 31^{st}, 2017. The surface temperature measurements conducted during the daytime activities (9 am – 4 pm).

Figure 5: Test House models.

4. Result

4.1. Structure material

Based on measurements using infrared cameras, there is a significant difference between inside-surface-temperatures and outside-surface-temperatures of steel structures. **Fig. 6** shows that the average daytime temperature of the outside-surface-temperature of the steel structure is 69,5°C while the average of inside-surface-temperature is 86,1°C (difference of 9,6°C). While on prefab concrete structure (RISHA), the average daytime temperature of the outside-surface-temperature is 69,5°C while the average of inside-surface-temperature is 70,5°C (difference of 0,55°C). The difference between outside- surface-temperature and inside-surface-temperature is less than 1°C. This fact may be related to the thermal conductivity value between the steel and the concrete. The steel material has a higher thermal conductivity rather than concrete (Table 1).

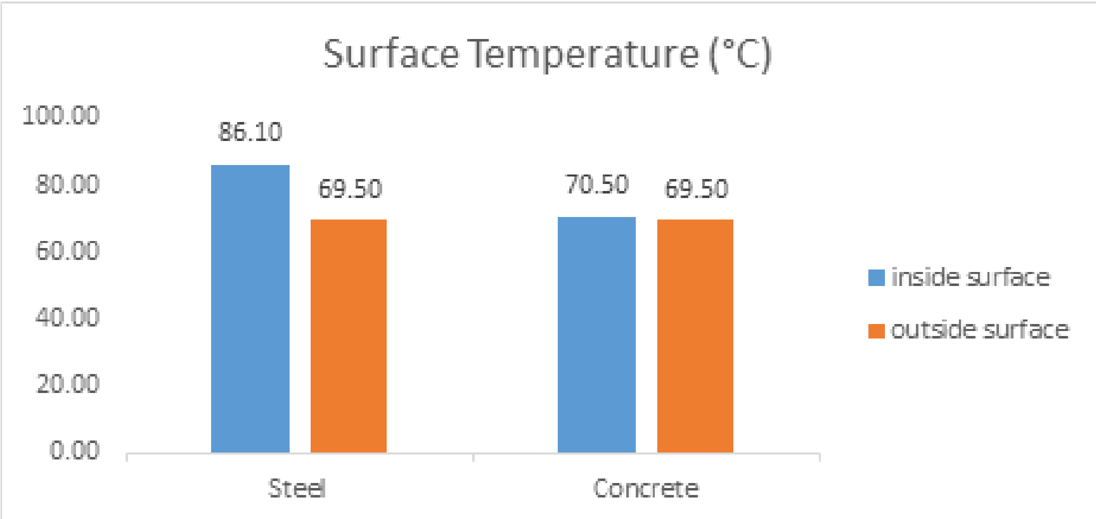


Figure 6: Average Surface Temperature of Structure Materials.

Fig.7 shows the hourly air temperature recorded inside Test House 1 and Test House 2. This graphic also represents the outside air temperature. The average inside air temperature in Test House 1 is 26,8°C with 67,69% of relative humidity, while Test House 2 has 27,15°C average inside air temperature with 66,16 % of relative humidity. The average outdoor temperature is 24,85°C with 70,90 % of relative humidity. The highest indoor temperature in Test House 1 is 38,39°C while Test House 2 has 36,88°C of indoor temperature. The highest outdoor temperature is 32,67°C.

Fig.7 shows that even though the Test House 1 has the highest inside air temperature, but Test House 2 has higher average inside air temperature. **Fig.8** shows that Test

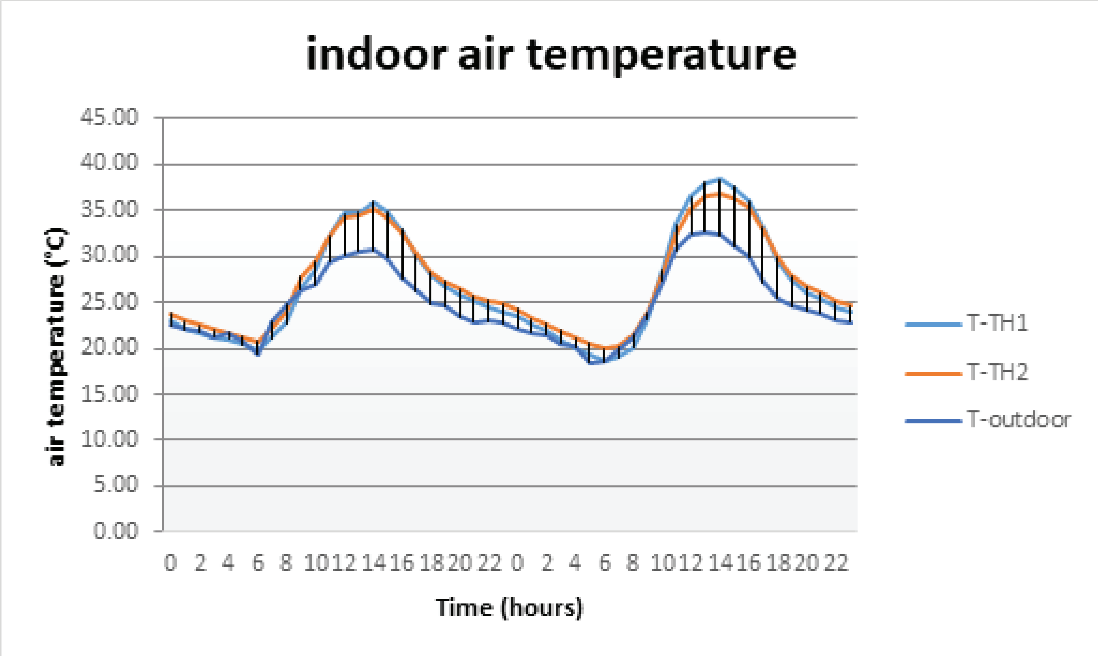


Figure 7: Indoor air temperature of Test Houses(below).

House 2 also has the longest duration outside the warm comfort zone (above 27,1°C) during the day time (refers to SNI 03-6572-2001). The steel material has a higher thermal conductivity value rather than concrete, so the stored heat in steel is re-released faster into the room and increasing the indoor air temperature.

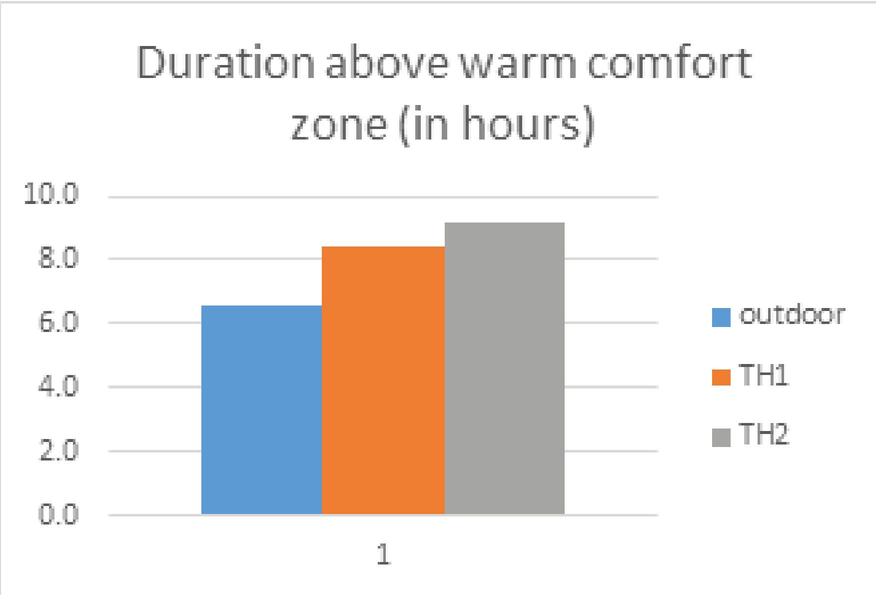


Figure 8: Average time duration of the condition above the warm comfort zone.

4.2. Wall material

Table 2 shows that plastered clay brick wall (Test House 3) has the lowest average value of inside-surface temperature which is 45,55 °C and the outside-surface temperature is 65,63 °C (20,08°C differences). The lowest difference between the outside-surface temperature and the inside-surface temperature belongs to the Test House 4 which is 7,14°C. The difference between the outside I surface temperature and the inside surface temperature of Test House 5 is 8,60°C. While on Test House 2, the difference is 8,90°C.

Table 2: Surface Temperature of Building Material.

	Test House 1		Test House 2		Test house 3		Test House 4		Test House 5	
	Structure:Steel		Structure: Precast Concrete		Structure: Precast Concrete		Structure: Precast Concrete		Structure: Precast Concrete	
	Wall: Lightweight Concrete		Wall: Lightweight Concrete		Wall: Plastered Clay Brick		Wall: Insulated Gypsum Board		Wall: Ecolite Styrofoam Concrete Panel	
Surface Temperature (°C)	**inside**	**outside**	**inside**	**outside**	**inside**	**outside**	**inside**	**outside**	**inside**	**outside**
North wall	59,0	68,40	59,95	76,05	48,35	79,00	63,65	85,45	59,55	69,25
East wall	57,65	63,30	58,30	66,80	50,35	66,00	63,95	77,10	56,85	67,00
South wall	55,95	53,75	55,55	56,15	41,25	50,15	59,75	59,10	50,60	54,05
West wall	56,95	63,90	57,90	68,30	42,25	67,35	62,65	56,90	53,90	65,00
structure	**86,10**	**69,50**	70,50	69,50	69,25	69,95	69,20	70,00	69,98	69,00
roof	115,00	0,00	105,90	0,00	103,40	0,00	107,50	0,00	111,00	0,00
Average Wall Temperature (°C)	57,38	62,34	57,93	66,83	45,55	65,63	62,50	69,64	55,23	63,83

Fig.9 represents the pattern of the surface temperature during the measurement in August, where the sun is above the north latitude. The graphic shows that the outside-surface-temperature of the west wall increased dramatically after midnight. The outside-surface-temperature of the north wall was relatively stable and started to decrease after midnight. The outside-surface-temperature of the east wall began to decline after 9 am, while the south wall was relatively stable.

Fig. 10 shows that the average outdoor air temperature during the measurement is 24,7°C. The highest outdoor air temperature is 32,9°C, and the minimum air temperature is 17,4 °C. Test House 2 has the highest average indoor air temperature which is 27.3 °C and the lowest average indoor air temperature belongs to Test House 5 which is 26.3 °C. The lowest maximum indoor air temperature belongs to Test House 3 which is 33,5 °C. The highest indoor air temperature in the room occurred in Test House 1 which is 39.4 °C.

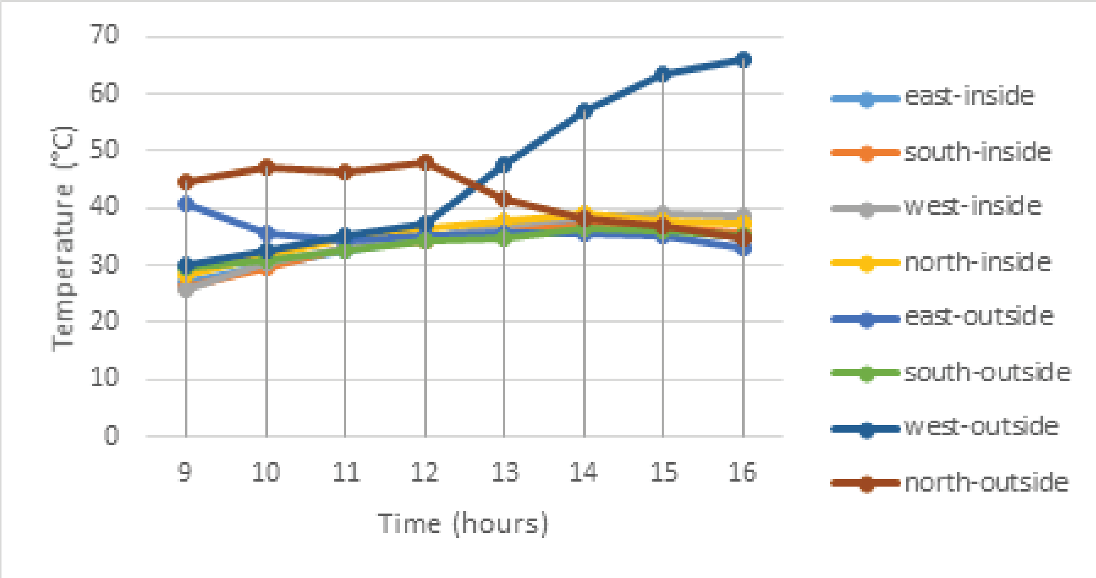
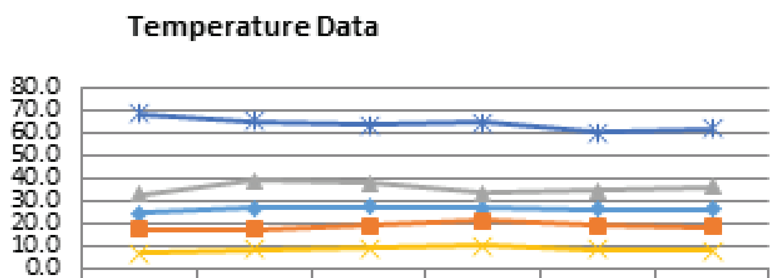


Figure 9: The pattern of surface temperature.



	weather station	Test House 1	Test House 2	Test House 3	Test House 4	Test House 5
average air temp.(°C)	24.7	26.9	27.3	27.1	26.4	26.3
Min air temp(°C).	17.4	17.7	19.1	21.5	19.0	18.8
Max air temp(°C).	32.9	39.4	37.9	33.5	34.8	36.1
Uncomfort zone duration(hours)	6.6	8.4	9.2	10.4	8.8	8
average RH(%)	68.6	65.2	63.6	64.6	60.2	61.8

Figure 10: Average Indoor air temperature.

Plastered clay brick has higher thermal conductivity value rather than other wall materials in this experiment (**Table 1**). Based on that, plastered clay brick wall will release its stored heat faster rather than other wall materials. **Fig.11** shows that Test House 3 has a different pattern on the thermal behavior compare to other test houses. The common thermal behavior of the test houses is that the indoor air temperature is always higher than outdoor air temperature during the daytime (9 am-5 pm) except in Test House 3. In Test House 3, the air temperature increased slower rather than other test houses so when it decreased. Test House 3 also has a lower air temperature rather than outdoor air temperature during 9 am-1 pm, but it has higher indoor air temperature rather than the outdoor air temperature and other test houses after 3 pm. Despite having the lowest maximum temperatures, Test House 3 has the longest duration in time above the warm comfort zone (>27,1°C).

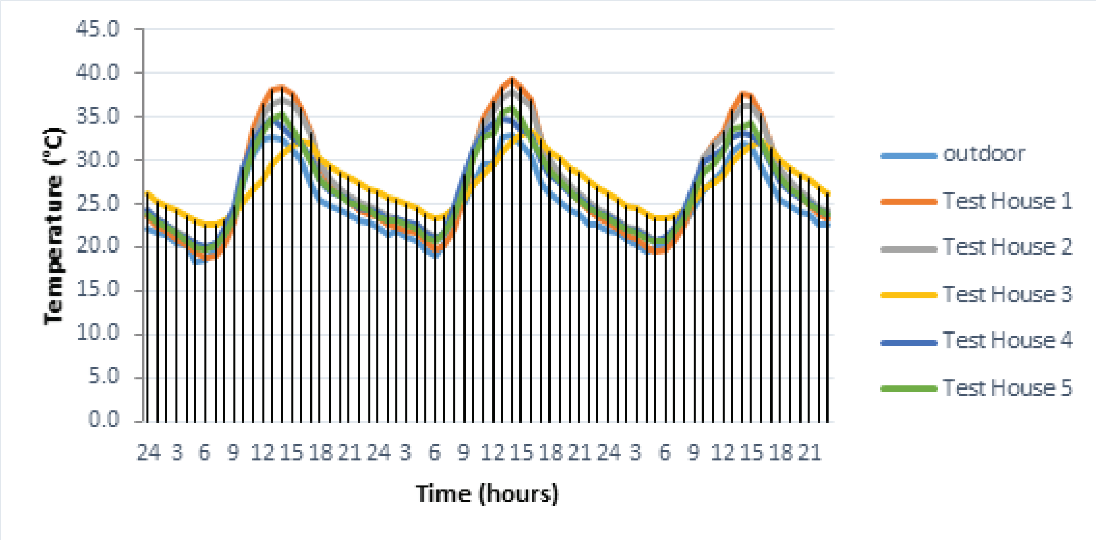


Figure 11: Indoor air temperature (August 29th-31st,2017).

In terms of heat transfer, IFC report stated that plastered clay brick and AAC brick already have excellent performance in preventing heat transmission. There is no significant difference between outdoor – indoor air temperature of plastered clay brick and AAC brick [7]. It is true that the average indoor air temperature is not significantly different between plastered clay brick house and AAC brick house (**Fig.10**). The experimental results also highlighted a significant difference in maximum indoor air temperature and the time lag between plastered clay brick and AAC brick walls.

5. Conclusion

The impact of building materials on the thermal performance of a building is investigated using experimental measuring on Test Houses models. In Phase 1, the experimental result shows a significant impact of structure materials on the thermal performance of buildings. The thermal conductivity value of steel is higher than the concrete, during the day time, steel material will transmit more heat into the room and increasing the indoor air temperature rather than the concrete material. Even though the steel - structure building has the highest inside air temperature, but it has lower average indoor air temperature rather than concrete structure building. The steel structure building also has a shorter duration of time above the warm comfort zone rather than the concrete structure building. The inside-air temperature of steel-structure building decreased faster following the decreasing of outdoor air temperature rather than building with concrete structure material.

In Phase 2, the experimental result shows that clay brick material has transmitted heat slower rather than other wall materials event though it has higher thermal conductivity value rather than materials with lower thermal conductivity value. The test houses which have wall materials with lower thermal conductivity value (AAC brick, GRC-Rockwool Sandwich Panel, GRC-Styrofoam Concrete Panel) showed the same temperature behavior. For further analysis, the result of this research can be compared with software simulation. Twenty-four hours - measurement on surface temperature is needed to investigate the material behavior in heat transmission.

References

[1] ANSI/ASHRAE Standard 55-2010 (2010) *Thermal Environmental Conditions for Human Occupancy*, ASHRAE, Inc., Atlanta.

[2] Auliciems, A. and Szokolay,S.V. (1997) *THERMAL COMFORT*, PLEA: Passive and Low Energy Architecture International in association with Department of Architecture, The University of Queensland, Brisbane.

[3] Frick, H & Mulyani (2006) *Arsitektur Ekologis,* Kanisius, Yogyakarta

[4] Rosenlund, H. (2000) Climatic Design of Buildings using Passive Techniques, Building Issues Vol.10 No.1, Lund University

[5] Koenigsberger, et al. (1974) *Manual of Tropical Housing and Building*, Longman,London.

[6] Noerwasito,T & Santosa,M. (2006*) PENGARUH "THERMAL PROPERTIES" MATERIAL BATA MERAH DAN BATAKO SEBAGAI DINDING, TERHADAP EFISIEN ENERJI DALAM RUANG DI SURABAYA*, DIMENSI TEKNIK ARSITEKTUR Vol. 34, No. 2, Desember 2006: 147 – 153

[7] IFC – Pemerintah Provinsi DKI Jakarta (2012) *Panduan Pengguna Bangunan Gedung Hijau Jakarta Vol. 1 Selubung Bangunan,* Jakarta

[8] SNI 03-6572-2001 *Tata cara perancangan sistem ventilasi dan pengkondisian udara pada bangunan gedung.*

[9] SNI 03- 6389- 2000 *Konservasi energi selubung bangunan pada bangunan gedung.*

[10] Purnama et al (2016), *Identifikasi Pengaruh Material Bangunan Terhadap Kenyamanan Termal (Studi kasus bangunan dengan material bambu dan bata merah di Mojokerto*, Jurnal Mahasiswa Jurusan Arsitektur, Volume 4 no 1

[11] Gourav et al (2017), *Studies into structural and thermal properties of building envelope materials*, International Conference – Future Buildings & Districts – Energy Efficiency from Nano to Urban Scale, CISBAT 2017 6-8 September 2017, Lausanne, Switzerland