Journal of Architectural Research
and Education (JARE)
Vol. 1 (2) 129-138
@Erwin Yuniar Rahadian, Agung Prabowo Sulistiawan. 2019
DOI: 10.17509/jare.v1i2.22304

The Evaluation of Thermal Comfort using a BIM-based Thermal Bridge Simulation
(case Study : Itenas Mosque Building Bandung)

Erwin Yuniar Rahadian[1], Agung Prabowo Sulistiawan[2]
[1,2] Department of Architecture, Institut Teknologi Nasional, Bandung, Indonesia
[1,2] Jln. P.H.H. Musthopa No. 23 Bandung 40124, Indonesia
Corresponding Author: ears@itenas.ac.id
agung.prabowo@itenas.ac.id

Article History:
Received: 10 Oktober 2019 | Revised: 18 November 2019 | Accepted: 10 Desember 2019 | Available online: 31 Desember 2019

Abstract **-** Global warming has become an important issue today, caused by the increasing demand for energy and humans lifestyle. To reduce the impact, more architects started to respond regarding environmental issues. The concept of green architecture promotes to solving this problem. Natural ventilation is the one of the concept green architecture. This research tends to look at the aspect of Thermal Comfort in naturally ventilated mosque buildings through the Thermal Bridges strategy. Naturally ventilated building tend to have better indoor air quality (IAQ), but worse thermal comfort. Therefore, this research investigates the range of acceptable temperature and calculate by BIM thermal bridge simulation to achieve thermal comfort for naturally ventilated mosque building. The method of analysis conducted is quantitative based on direct measurement of weather data and existing comfort conditions in the field, calculations, and simulations using Building Information Modeling (BIM). Data was collected through a field survey in Itenas Mosque Building and were used to develop and validate then using the BIM thermal bridge model for simulation. The data collected from field survey and in situ environmental measurement such as air temperature, relative humidity, and wind velocity. The thermal comfort prediction model was developed from statistical analysis of the field survey data. Based on the result of thermal Bridge simulation using BIM software required exchange material of the existing building to achieve thermal comfort.

Keyword: Thermal comfort, Building Information Modelling, Thermal Bridge Simulation.

1. Introduction

The use of electrical energy that is non-renewable and increasing world population and the industrial revolution of science and technology will trigger an energy crisis. Thus, we need to change our mindset that emphasizes the conservation of the global environment, especially the preservation of energy sourced from non-renewable energy and encourages the use of renewable energy.

Increased consumption and exploitation of natural resources have negative impacts such as environmental damage and pollution and the depletion of the availability of non-renewable energy, materials and clean water in nature. For this reason, there needs to be aware that supports the conservation of the global environment, one form of which is the application of Green Architecture in building design.

The Itenas Mosque is a religious function building within the Itenas campus, where there is an optimized natural potential and anticipated wet tropical climate constraints, through the Green Architecture concept, so that all systems that work in buildings, in the long run, can save operational energy while supporting environmental preservation. This building deserves to be appointed as an object of research because it has a unique specific design. The scope of this research is focused on the Evaluation and Improvement of Building Design related to Ventilation and Air Conditioning Design related to the acquisition of thermal comfort in buildings.

2. Theory

a. Thermal Comfort

Fanger (1970) stated that thermal comfort for a person is defined that condition of mind which expresses satisfaction with the thermal environment. The reason for creating thermal comfort is to satisfy man's desire to feel thermally comfortable. The most important variables which influence the condition of thermal comfort are :

- Activity level (heat production in the body)
- Thermal resistance of the clothing (clo-value)
- Air temperature
- Meant radiant temperature
- Relative air velocity
- Water vapour pressure in ambient air

Many different combination of above variables can made thermal comfort. Therefore, they are also used many different fundamental technical system. For instance, the sensation of thermal comfort is closely connected with skin temperature and sweat secretion. Therefore, the values for mean skin temperature and sweat secretion can be used as basic conditions for thermal comfort.

In order to create optimal thermal comfort occupants, it is possible to make the comfort equation for any activity level and any clothing, to calculate all combinations of air temperature, mean radiant temperature, relative velocity and air humidity (Fanger, 1970).

b. Building Information Modelling (BIM

The term Building Information Modeling first used in 2002 to describe the design, construction, and management of virtual facilities. Graphisoft in 1986 introduced the new ArchiCad software as a solution for virtual buildings. And allows the creation of three-dimensional (3D) project models.

The concept of BIM theoretically emerged and was developed at the Georgia Institute of Technology in the late 1970s and developed rapidly. Growth occurs because of the increased attention given to the construction team and companies that benefit from using BIM to integrate the construction process and its management (Rokooei, Saeed, 2015).

Furthermore, Her, et al (2019) stated that building Information Modelling (BIM) describes the production and management process in which construction procedures, as well as the physical and functional characteristics of buildings, are represented digitally before being physically implemented. BIM is usually used to predict and control construction procedures and building performance with the aim of minimizing costs, especially energy, materials, and labor (Herr, Christiane M., Thomas Fischer, 2019).

BIM allows architects to embed building components from 3D models not only with geometric information but also with appropriate constructive information. This produces a 3D model that includes building construction information. There is a significant thing in BIM namely collaboration between different specialties, analysis, and optimization processes during the design phase, and the construction stage (Caetano, Ines., António Leitão, 2019).

BIM has completely changed the data input process from the traditional coordinate system (x, y-axis) of Computer-Aided Design (CAD) to an approach with 3-dimensional object orientation, which has greater potential than before. BIM helps in achieving the objectives of the construction industry such as; increase productivity and efficiency and increase the value and quality of infrastructure. At the same time reduce; lead time, life cycle costs and duplication. Although BIM has been used for more than 20 years, awareness about the benefits of BIM especially in developing countries is still lacking especially for the construction, design, and operation of buildings that are more efficient and effective (Doumbouya, Lancine, Guoping Gao, Changsheng Guan, 2014).

Building Information Modeling presents huge opportunities and challenges for the construction industry. As BIM evolves and the construction process becomes increasingly automated, the role of construction professionals needs to adapt accordingly to provide more sophisticated services that combine 3D, time (4D), cost modeling (5D) and facility management (6D) as well as sharing information / data costs with project team as part of the BIM integrated project delivery approach (Smith, Peter, 2014).

Therefore, the use of BIM can offer many benefits including increased accuracy, time savings, more rigorous design, and analysis processes, as well as the ability to predict environmental performance and life cycles (Beazley, Scott; Emma Heffernan, Timothy J McCarthy, 2017).

c. Thermal Bridge Simulation

The thermal bridge is a part of a building envelope where uniform thermal barriers change significantly (in structural joints with roofs, ceilings, and other walls, or other building envelope details such as corners, window openings or doors), generating multi-dimensional heat flowing. The thermal bridge has a large effect on the thermal performance of the building envelope and significantly increases heat loss in winter and increases heat in summer. A better-insulated wall will cause a higher number of thermal bridges, so the heat loss in the building will also be higher. Differences in temperature gradients can cause condensation and mold growth thereby reducing indoor air quality (Larbi, A. Ben, 2005).

In addition, O'Grady (2018) stated that thermal bridges are part of the building envelope with higher thermal conductivity or different geometries. The thermal bridge is associated with a significantly higher heat loss than the plain components surrounding the thermal bridge. It is important to take into account this additional heat loss while assessing the thermal performance of the building envelope (O'Grady, Malgorzata, Agnieszka A. Lechowska, Annete M. Harte, 2018).

Furthermore, Quinten (2016) stated that the thermal bridge would cause most of the heat loss in a building. A thermal bridge is a part of a building envelope in which uniform thermal resistance is significantly altered by full or partial penetration of the building envelope by materials with different thermal conductivity and/or changes in fabric thickness and/or differences between internal and external areas, as occurs at the intersection of walls /floors /ceilings, and some of them are almost inevitable (Quinten, Julien and Veronique Feldheim, 2016).

Hence, Baba (2018) explained that to avoid the formation of thermal bridges in the building envelope it is important to reduce energy consumption, of course not only increase the level of insulation and thermal mass required, but also the continuity of insulation. Thermal bridges in building envelopes are usually made by repetitive structural members and intersections between different building envelope components (Baba, Fuad, Hua Ge, 2016).

3. Method

a. Analysis Method

The method of analysis conducted is quantitative based on direct measurement of weather data and existing comfort conditions in the field, calculations, and simulations using Building Information Modeling thermal bridge simulation.

b. Theoretical Method & Inventory

Literature review to collect all the relevant information about :

- Thermal comfort
- Building Information Modelling (BIM)
- Thermal Bridge Simulation

The information will be taken from journals, papers, books, standards and website.

c. Computer Simulation Method

This simulation is to test and validate the model of Itenas Mosque Building. The processes are as follows :

- Development of simulation modeling for the base case.
- Test the base case using the real data for validation purposes.
- Applied the Thermal Bridge Simulation on ArchiCAD BIM software to test from real data.

4. Data

a. Location Data

- Location in Bandung, West Java, Indonesia.
- Buildings coordinate = -6.897652, 107.636841
- Elevation = 712 m above sea level.
- Site condition = on the Bandung urban area, inside of Itenas campus area, with surrounding building about 2 or 3 stories.
- Climate condition = wet tropical or humid tropical climate
- Weather condition = Based on data from Indonesian Meteorology Climatology and Geophysics Council, in the past thirty years : Temp min = 19.91 °C, Temp Max = 28.61 °C, Temp AVG = 23.76 °C, and RH = 45.39 % (http://data.bandung.go.id)

b. Building Data

Site / Location

Figure 1. Location at Itenas Campus Area

Figure 2. Building Orientation to North

Floor Plan

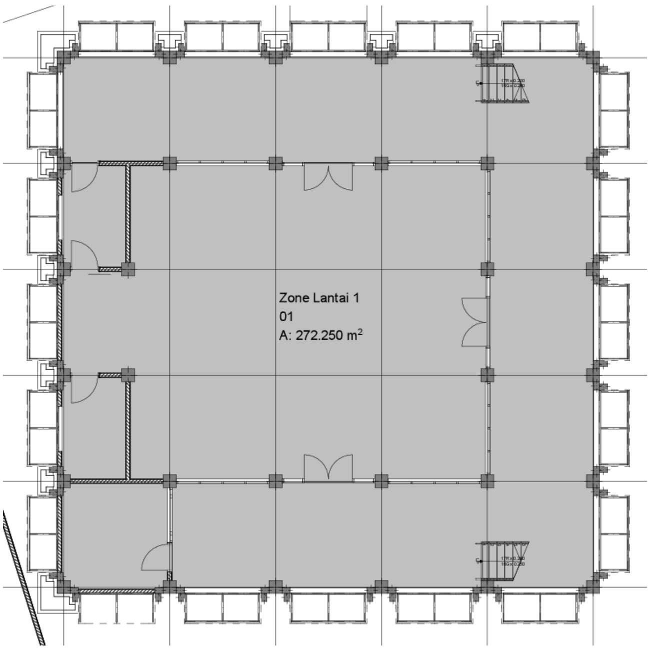

Figure 3. 1st Floor Plan

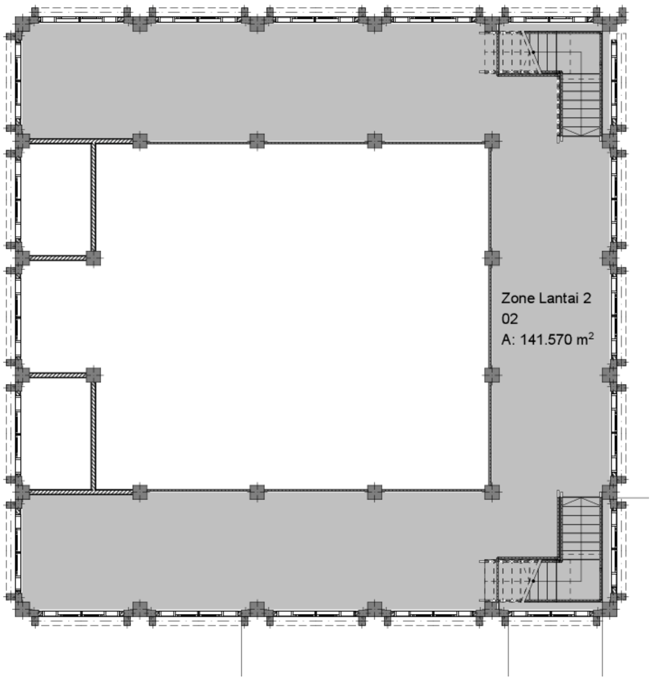

Fig.4. 2nd Floor Plan

Perspective View

Fig.5. Northwest Perspective

Fig.6. North Elevations

Fig.7. West Elevations

Fig. 8. East Elevations

Building materials especially for building Envelopes :

- Wall: Bricks + Plaster
- Windows 1: Alumunium Frames + Clear Glass 5mm
- Windows 2: Wood Frames + Clear Glass
- Door: Wood Frames + Clear Glass
- Floor: Granite Tile
- Ground: Concrete
- Roof 1: Bitumen Sheet
- Roof 2: Concrete Slab

Table-1. Building Material Properties for BIM Materials Data

No	Building elements	Materials	Thermal Conductivity (W/mK)	Density (kg/m2)	Heat Capacity (J/kgK)	Embodies Energy (MJ/kg)	Embodies Carbon (KgCO2/kg)
1	Wall	Bricks + Plaster	0.807	1760	840	3	0.24
		Plaster	0.533	1568	1000	1.34	0.213
2	Opening	Alumunium Frames	211.000	2672	880	155	9.1
		Wood Frames	0.138	702	1600	6.95	0.29
		Clear Glass	1.053	2512	750	0.85	0.02
3	Floor	Granite Tile	2.927	2640	1000	10.2	0.63
4	Ground	Paving	2.500	2400	1000	2.33	0.242
5	Roof	Bitumen Sheet	0.700	2100	1000	3.93	0.076
		Concrete Slab	2.500	2400	1000	2.33	0.242

5. Analysis

a. Thermal Comfort Validation Analysis

Based on the thermal measurement data that was carried out for 5 days, at outdoor and indoor building, the results obtained as the following table:

Table-2.Building Material Properties for BIM Materials Data

Days	Temp	Humidity	Velocity
Day 1	31.15	58.64	0.39
Day 2	28.39	59.25	0.20
Day 3	27.44	58.46	0.27
Day 4	26.64	57.78	0.06
Day 5	26.34	95.33	0.29
Average	**27.99**	**65.89**	**0.24**

From Table-2 above, it can be concluded that the space conditions in the Itenas mosque are very uncomfortable with an average temperature of 27.99 degrees Celsius. This condition spreads throughout the area of space within the Itenas mosque. Figure-9 showing the mapping indoor and outdoor temperature at Itenas Mosque.

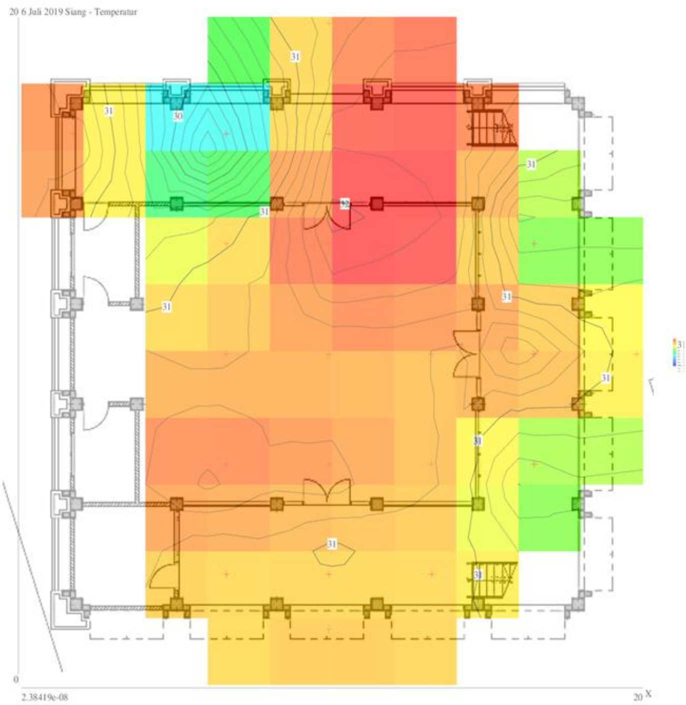

Fig. 9. Heat Map Indoor and Outdoor Temperature

b. Thermal Bridge Simulation Analysis

The temperature conditions on the four sides of the building look like in Table-3.

Table-3. Temperature Average at sourounding of building

Position	North	East	South	West
Outdoor AVG	27.17	27.82	27.73	28.20
Indoor AVG	28.19	27.67	27.47	27.85

According to figure 10 shows that the thermal Bridge at North side did not show significant results due to the absence of temperature differences between outdoor and indoor spaces.

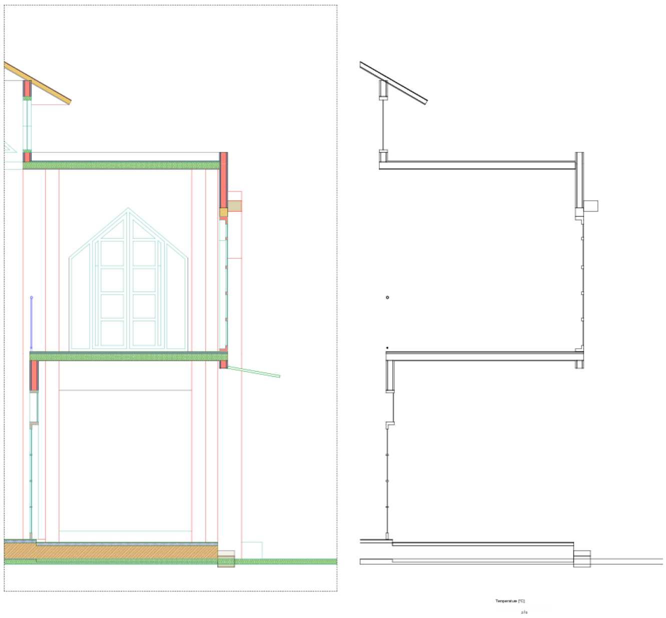

Fig. 10. Thermal Bridge at North Side

According to figure 11 shows that the thermal Bridge at East side shows the performance of the Thermal Bridge on the floor, walls and roof. On the floor the heat transfer is significant. In the concrete roof area the Thermal bridge does not show a minimal heat transfer while the walls show significant heat transfer.

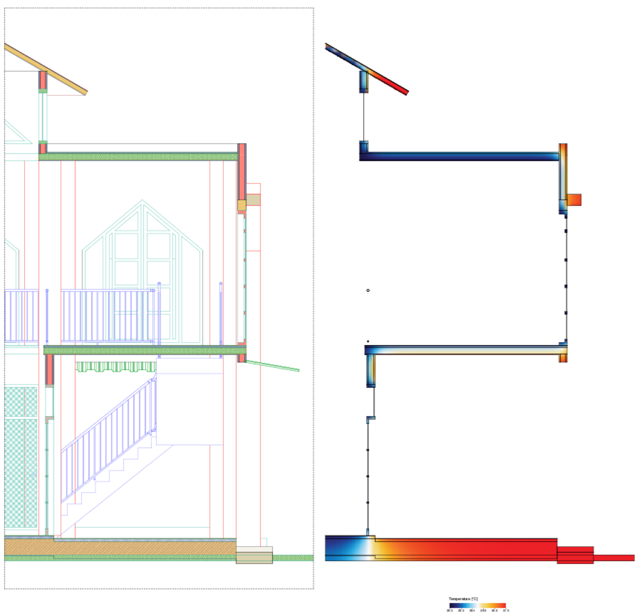

Fig. 11.Thermal Bridge at East Side

According to figure 12 shows that the thermal Bridge at Westside shows the performance of the Thermal Bridge on the floor, walls, and roof. The same as Eastside, on the floor the heat transfer is significant. Whilst, on the concrete roof, the heat transfer quite significant into the room. The wall elements show the minimum performance of the thermal bridge in inhibiting heat transfer into the building.

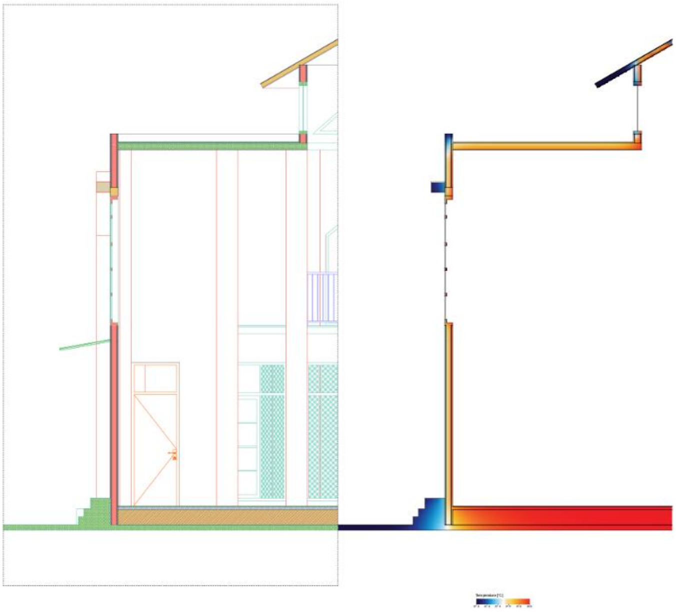

Fig. 12.Thermal Bridge at West Side

According to figure 13 shows that the thermal Bridge at Southside shows the performance of the Thermal Bridge on the floor, walls, and roof. The same as Eastside, on the floor, and wall, shows that heat transfer is significant. Whilst, on the concrete roof, the heat transfer quite significant into the room.

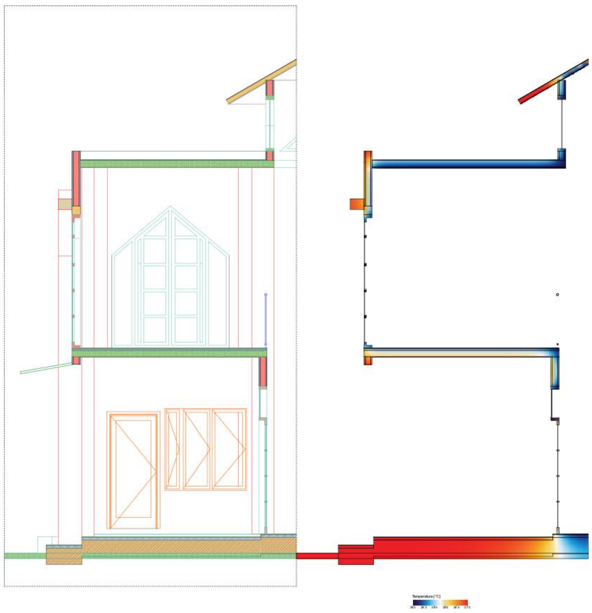

Fig. 13.Thermal Bridge at South Side

6. Conclusion

Evaluation of thermal comfort using BIM thermal bridge simulation shown :
Concrete roof elements on the East and South sides show heat transfer barriers into the building. While on the Westside, there is a significant heat transfer into the building. On the Northside shows whether or not heat transfer is due to the same temperature inside and outside the room.
Wall elements on the East and South sides show minimal heat transfer into the building. While the wall on the west side shows a significant heat transfer into the building. The wall on the north side

does not show the existence of Heat Transfer into the room, because of the same temperature inside and outside the room.

The ground floor elements on the East, South and West sides show significant Heat Transfers into the building. While on the Northside of the floor element there is no visible heat transfer due to the same temperature data inside and outside the financial when measuring temperature data.

Based on the above heat transfer conditions, it can be proposed that the replacement of building materials and the addition of building elements to increase heat transfer barriers into the building, so as to provide comfort in the thermal pad of the room in Itenas Mosque.

Related to the use of Building Information Modeling in the process of building design, especially those relating to Building Performance, it is very important to have physical material property data from each building material to be used as input data in the BIM building performance simulation process. So when an alternative design is completed, at the same time building performance can be known from the alternative design.

7. References

Baba, Fuad, Hua Ge. " Dynamic effect of balcony thermal bridges on the energy performance of a high-rise residential building in Canada,"Energy Buildings 116, , 2016, pp 78-88, 2016.

Beazley, Scott; Emma Heffernan, Timothy J McCarthy."Enhancing energy efficiency in residential buildings through the use of BIM: The case for embedding parameters during design," Science Direct, Energy Procedia 121 ,2017, pp 57–64

Caetano, Ines., António Leitão."Integration of an algorithmic BIM approach in a traditional architecture studio ; Journal of Computational Design and Engineering 6, 2019, pp.327–336

Doumbouya, Lancine, Guoping Gao, Changsheng Guan."Adoption of the Building Information Modeling (BIM) for Construction Project Effectiveness:The Review of BIM Benefits," American Journal of Civil Engineering and Architecture, Vol. 4, No. 3, 2016, 74-79.

Fanger, P.O. "Thermal Comfort, Analysis and Application in Environmental Engineering", McGraw-Hill Book Company, 1970

Herr, Christiane M., Thomas Fischer."BIM adoption across the Chinese AEC industries: An extended BIM adoption model," Journal of Computational Design and Engineering 6 , 2019,pp173–178

http://data.bandung.go.id/dataset/laporan-iklim-kota-bandung-tahun-1976-2017

Larbi, A. Ben. "Statistical modelling of heat transfer for thermal bridges of buildings", Energy and Building 37 2005, pp: 945-951,

O'Grady, Malgorzata, Agnieszka A. Lechowska, Annete M. Harte, " Application of infrared thermography technique to the thermal assessment of multiple thermal bridges and windows", Energy &Buildings 168, 2018, pp: 347-362

Quinten, Julien and Veronique Feldheim. " Dynamic modelling of multidimensional thermal bridges in building envelopes: review of existing methods, application and new mixed method," Energy and Buildings 110, 2016, pp: 284-293

Rokooei, Saeed. "Building Information Modeling in Project Management: Necessities,Challenges and Outcomes,"Procedia - Social and Behavioral Sciences 210, 2015, pp:87 – 95

Smith, Peter."BIM Implementation – global strategies," University of Technology Sidney, Science Direct, Procedia Engineering 85, 2014 pp. 482-492