Research paper

Archimane, 2024, Vol. 2, No. 1, 39–50
DOI: 10.59810/archimane/v2i1.57
ISSN 2987-1131 (online); 2987-4033 (print)

The Impact of Bamboo Cavities on Thermal Comfort in Building Construction

Jovanny Yves Modiano
Phoebe Anthonieta Danny Wijaya
Heristama Anugerah Putra

Department of Architecture, Faculty of Engineering, Universitas Katolik Darma Cendika, Indonesia

Abstract

In tropical countries like Indonesia, bamboo stands out as a sturdy and readily available building material due to its rapid growth. It's widely utilized in forming structural and architectural elements of buildings. However, due to the complexity of connections, bamboo has seen some replacement by newer materials like brick, steel, and concrete. Yet, the resurgence of bamboo usage aligns with the emergence of the green building concept, prioritizing environmentally friendly materials sourced from the local environment. Bamboo finds extensive application in tropical housing, serving as columns, roofs, and walls, often woven. This material effectively reduces indoor temperatures, providing occupants with thermal comfort. However, there's a gap in understanding regarding the use of bamboo as log-shaped walls or the role of cavities in bamboo stems in enhancing thermal comfort. This study adopts a quantitative approach, primarily through literature review, employing a descriptive presentation method. Bamboo plays a significant role in lowering room temperatures, particularly due to its cavity structure, which facilitates heat dissipation. This makes it suitable for use in tropical areas as a material for residential houses and other buildings.

Keywords: Bamboo, comfort, home, thermal, tropical

Article history:
Received July 19, 2023
Received in revised form August 01, 2023
Accepted Sept. 15, 2023
Available online April 01, 2024

Correspondence address:
Heristama Anugerah Putra, Architecture of Program Study, Faculty of Engineering, Universitas Katolik Darma Cendika, Jalan Dr. Ir. Soekarno No. 201, Surabaya, Indonesia
Email: heristama.putra@ukdc.ac.id

Introduction

Indonesia is situated geographically near the equator. Twice a year, on March 23 and September 22, the sun passes directly over the equator, resulting in two distinct seasons in Indonesia: the dry season and the rainy season. The hot regions of Indonesia experience heavy rainfall, commonly referred to as tropical rain.

Enhancing public awareness of the significant climate transformation in Indonesia and its impacts on the environment is imperative. Furthermore, various aspects of architecture have seen a sharp increase in attention in recent years. A greening movement has emerged with the dual purpose of environmental care and preservation, as well as energy conservation and reduction of environmental damage. Despite ongoing efforts by the Indonesian government to raise awareness about extreme climate change, not all individuals fully comprehend its implications.

Sick Building Syndrome is a condition characterized by discomfort caused by poor air quality and pollution within an inhabited building, leading to reduced productivity and health issues among its occupants. These issues stem from factors such as inadequate air ventilation, insufficient natural lighting, and the use of furniture emitting ozone. The solution to these problems lies in the implementation of green architecture or green buildings. Green architecture aims to minimize various environmental impacts and provides a positive contribution to addressing environmental issues, particularly global warming (Rachmayanti and Roesli 2014).

Bamboo is a construction material renowned for its strength, although its utilization has been supplanted by brick, concrete, iron, or plastic. However, bamboo is experiencing a resurgence in popularity alongside the concepts of sustainable and green building. Bamboo is recognized as an environmentally friendly material with the potential to contribute positively to the environment, as development remains integral to human civilization's progress.

Bamboo belongs to the bamboosoideae subfamily within the Poaceae or Gramineae family and is categorized into two types: monopodial (found in China, Japan, and Korea) and sympodial (found in Southeast Asia and South America) (Nurdiah 2016). There are approximately 1200-1300 species of bamboo worldwide. In Indonesia, there are documented 143 species of bamboo based on field and laboratory data. In Java, it is estimated that there are 60 species of bamboo, with 14 species found in the Bogor Botanical Gardens, and 9 endemics to Java. In the Lesser Sunda Islands (Lombok, Sumbawa, Sumba, Flores, Alor, Pantar, Timor, and Lomblen), there are 14 species of bamboo, while Sumba Island alone hosts 10 species. In the Manggarai area of Flores Island, there are 6 species of bamboo (Sary, Fahrizal, and Yani 2018).

Bamboo grows in clusters and is composed of 50% parenchyma, 40% fiber, and 10% connective cells. This versatile material finds applications in construction, biomass production, fiber and paper manufacturing, as well as in laminated panels and partition boards. Its rapid growth rate makes it superior to other plant materials commonly used in construction. Bamboo serves as a viable alternative to wood due to its similar properties, yet it is more environmentally friendly as it effectively absorbs carbon and mitigates the greenhouse effect.

Another advantage of bamboo material is its ease of processing, and its strength and flexibility surpass that of iron, steel, wood, and concrete. Bamboo density varies according to type, ranging from around 700 to 800 kg/m3 (Kaur 2018). Bamboo exhibits physical, mechanical, and chemical properties. The physical and mechanical properties of bamboo, which are influenced by factors such as age, height, thickness, diameter, and radial position, dictate its processing and resultant characteristics. Chemical properties of bamboo include cellulose content of 42.4%-53.6%, lignin content of around 19.8%-26.6%, pentosan content of 1.24%-3.77%, ash content of 1.24%-3.77%, silica content of 0.10%-1.78%, solubility in cold water of 4.5%-9.9%, solubility in hot water of 5.3%-11.8%, and solubility in alcohol benzene of 0.9%-6.9% (Seran 2017).

Attributes/characteristics	**Level/size**
Starch/flour	2 -4,5%
Density	0,2 – 0,85
Fracture modulus	610 – 1600 kg/cm^2
Flexural modulus	1,5 – 2,0 x 105 kg/cm^2
Compressive stress	794 – 864 kg/cm^2
Safety under pressure	105 kg/cm^2

Table 1
Additional properties or characteristics of bamboo
Source: Kaur 2018

Bamboo has long been utilized as a building material, particularly in residential construction. Thermal comfort is a crucial requirement for habitable houses or buildings, which can be achieved through the provision of openings, air gaps, or the use of a cavity system in walls. While bamboo has been widely used as wall coverings in woven form, which effectively increases thermal comfort due to the gaps between the matting, fewer people employ bamboo logs as wall coverings. The extensive utilization of bamboo in building materials today certainly entails both positive and negative impacts (Artiningsih 2012). Here are some of the advantages and disadvantages of bamboo as a building material:

a. Advantages: (1) Easy to cultivate and requires minimal maintenance; (2) Requires low investment for cultivation; (3) Exhibits rapid growth; (4) Demonstrates exceptional durability; (5) Exhibits high moisture tolerance; (6) Possesses elasticity; (7) Bamboo structures offer high resistance and are effective against earthquakes and wind.
b. Weaknesses: (1) Bamboo exhibits low durability; (2) Bamboo is susceptible to insect infestation; (3) Bamboo requires preservation for extended durability; (4) The strength of bamboo connections decreases when using nails, stakes, or palm fiber rope; (5) Bamboo is prone to breakage when nailed or pegged; (6) The connection between bamboo and rope should be periodically checked as the shape of bamboo changes over time.

Methods

The method employed is qualitative, involving data collection through literature studies and descriptive presentations. The data were obtained from journals containing previous research relevant to the discussed topic. Subsequently, the data were processed using a descriptive method, involving an overview and analysis of the literature sources, aiming to provide a comprehensive understanding. This study enables a detailed description of the factors and components of bamboo cavities, which serve the function of releasing heat or thermal energy in building construction.

Result and Discussion

Bamboo finds extensive use in various applications such as boards, furniture, construction and building, soil stabilization, paper and fiber industries, and more. The utilization of bamboo offers numerous benefits, as almost every part of it can be utilized, thereby minimizing waste generation during processing. For instance, bamboo shoots are edible, and the stems can be processed into various products as mentioned previously. In construction, bamboo can be employed for every aspect of a building, including walls, roofs, floors, and columns, owing to its strength and ability to withstand loads and tension (Sharma, Dhanwantri, and Metha 2014). Additionally, bamboo is recognized as an environmentally friendly material. Besides its minimal residue production during processing, bamboo plays a crucial role in controlling soil erosion, a problem exacerbated by development (Suriani 2017).

The numerous benefits of bamboo material are closely linked to proper bamboo care. Before use, bamboo undergoes preservation to protect it from destructive organisms such as fungi and insects. Bamboo preservation aims to extend its lifespan and enhance its resistance to such attacks. There are two main types of bamboo preservation: traditional and modern methods, both with the same goal but different techniques.

Traditional bamboo preservation involves processes that are chemical-free and cost-effective, allowing individuals to perform them without special tools. These methods include smoking, curing, coating, soaking in water, and boiling, all aimed at removing starch and other substances from bamboo parts.

On the other hand, modern bamboo preservation, facilitated by the Information Center for Bamboo and Rattan Technology (ELSSPAT), utilizes chemical preservatives known to be toxic to destructive organisms. Some of these preservatives include BFCA, Koppers Formula 7, boric acid, borax, boron (CCB), NaOH, CCF, copper chromate, and others. When using chemical preservatives, it is essential to adhere to safety guidelines.

The success or failure of modern bamboo preservation depends on various factors such as bamboo specific gravity, physical condition, age, season, preservative type, bamboo size, and position. Key conditions for successful modern bamboo preservation include toxicity to destructive organisms, ease of penetration and permanence in bamboo, compatibility with other materials, cost-effectiveness, non-alteration of bamboo size or physical properties, resistance to burning, mechanical and chemical durability, and safety for humans and pets (Arsad 2015).

Bamboo is inherently a heat insulator, making bamboo material effective in releasing heat. As a building material, bamboo contributes to thermal comfort by allowing only a small amount of hot air to enter, while most of the heat is released. The hollow structure of bamboo cavities serves as a pathway for the release of incoming heat. As mentioned previously, cavities in walls with airflow facilitate heat release, thereby enhancing their effectiveness in reducing room temperature. Using bamboo as a woven plaster wall can effectively reduce temperature by 2.6°C, considering the presence of air gaps (Purnama, Nugroho, and Soebandono 2016).

Comparing buildings using vertical bamboo walls plastered with a 15 cm thickness and room dividers made of woven bamboo material plastered with a 7 cm thickness, as well as brick walls (Trianingsih and Hidayah, 2014), the research results indicate that bamboo material allows less external air temperature to enter compared to brick material. Specifically, the temperature decreases by 2.5°C for vertical bamboo and 2.6°C for woven bamboo with closed windows.

The room dividers made of brick material recorded the highest temperature in October at 31.8 °C and the lowest temperature in July at 29.3 °C. The brick material has a u-value of 1.52, significantly higher than the u-value of bamboo material, which is 0.84. This demonstrates that bamboo as a room barrier material exhibits superior heat isolation compared to brick material for room dividers.

It has been demonstrated that bamboo is more effective in heat insulation compared to brick walls, with vertical bamboo installation reducing temperatures by up to 2.5°C. Additionally, other factors influencing thermal comfort in buildings include the ventilation system, wall construction system, and presence of voids in the material (Chowdhury, Ahmed, and Hamada 2017).

Thermal comfort refers to the condition where individuals feel comfortable in their environment. Factors such as air temperature, radiation temperature, air humidity, wind speed, activity, and human factors contribute to the thermal comfort experienced by individuals. The room temperature plays a significant role in providing comfort to building occupants. Optimal room comfort in a building with thermal comfort should ideally range between 22.8˚C – 25.8˚C with a humidity level of 70%. However, in Indonesia, a tropical country, the air temperature can reach up to 35˚C with 80% humidity (Trianingsih and Hidayah 2014).

Bamboo boasts nearly 4,000 varieties worldwide. However, several types of bamboo are commonly available in the Indonesian market (Muhsin 2020), as follows:

1. Rope bamboo: This type of bamboo is characterized by its toughness or brittleness, with segment distances of up to 65 cm and stem lengths ranging from 6 to 13 meters. It is suitable for making rope materials. Rope Bamboo has a relatively low silica content of 0.37%, which makes it susceptible to drywood termites, classified as Class 4 bamboo (Febrianto et al. 2014).

Figure 1
Rope bamboo
Source: Febrianto et al. (2014)

2. Betung bamboo: This type of bamboo is characterized by its strength, short internodes, and thick walls. Stem lengths range from 10 to 20 meters. It has a relatively low silica content of 0.2%, making it susceptible to drywood termites and classified as Class 4 bamboo (Febrianto et al. 2014).

Figure 2
Betung bamboo
Source: Febrianto et al. (2014)

3. Duri bamboo: This type of bamboo shares almost identical characteristics with Petung Bamboo. The stem length ranges from 9 to 18 meters.

Figure 3
Duri bamboo
Source: Febrianto et al. (2014)

4. Wulung bamboo, also known as black bamboo, can grow up to 15 meters with a stem diameter ranging from 6 to 8 centimeters. It has the highest silica content among other types of bamboo, namely 2.93%, which grants it the highest resistance to drywood termites.

Figure 4
Wulung bamboo
Source: Febrianto et al. (2014)

5. Ampel bamboo typically reaches a height of 10-20 meters with a diameter ranging from 4-10 centimeters. It has a silica content of 1.78%, which classifies it as not resistant to attacks by drywood termites.

Figure 5
Ampel bamboo
Source: Febrianto et al. (2014)

6. Andong bamboo has a silica content of 0.52%, which is relatively low, making it susceptible to attacks by termites and insects.

Figure 6
Andong bamboo
Source: Febrianto et al. (2014)

The type of bamboo commonly used as a house divider is Betung Bamboo. For instance, the residents of Taba Terujam village in Central Bengkulu utilize bamboo to divide their houses. Particularly, the Dendrocalamus asper bamboo, or Betung bamboo, is commonly employed by the people of Taba Terujam village for house walls. The use of bamboo in Taba Terujam village is primarily for house borders, accounting for up to 70% (Yani and Anggraini 2018).

Bamboo is also used as a house divider by Indonesian architect Widhi Nugroho from WNA Studio. He created accommodations on the island of Bali, specifically in the Karangasem area, named Hideout Bali. These accommodations are predominantly made from bamboo, including both the exterior and interior of the buildings, as well as most of the furniture. The bamboo accommodations, also known as glamping (Glamour Camping), consist of 6 types: Hideout Classic, Hideout Lightroom, Hideout Beehive, Hideout Falcon, Hideout Horizon, and Hay House.

Figure 7
Hideout classic
Source: Dewi and Kristanti (2020)

Figure 8
Hideout lightroom
Source: Dewi and Kristanti (2020)

Figure 9
Hideout beehive
Source: Dewi and Kristanti (2020)

Each type of Glamping accommodation at Hideout Bali has its own unique shape and characteristics. However, a characteristic feature of these Glamping accommodations is the use of various types of bamboo as the primary material. Architect Widhi Nugroho chose bamboo material for the Glamping Hideout Bali accommodations due to its strong structure and ability to provide comfort for occupants through natural airflow. These buildings do not use air conditioning but rely solely on fans. Bamboo is selected to allow fresh air from outside to enter properly and regulate the room temperature according to the external climate. Additionally, the cavities in the bamboo structure allow natural light to enter the building, providing both natural lighting and comfort for occupants (Dewi 2020).

Figure 10
Hideout falcon
Source: Dewi and Kristanti (2020)

Figure 11
Hideout horizon
Source: Dewi and Kristanti (2020)

Figure 12
Hay house
Source: Dewi and Kristanti (2020)

Conclutions

Bamboo is a material with numerous benefits in people's daily lives, particularly in the field of building construction. One notable characteristic of bamboo is its cavity structure, which contributes to creating thermal comfort, especially in tropical areas. Cavity structures in construction, particularly in walls, can reduce direct exposure to heat radiation from outside the building, thus making bamboo material highly suitable for use as a room divider. The room divider serves as the first layer of protection for occupants against external disturbances.

This research focuses solely on the use of bamboo material as a room divider in one tropical country, namely Indonesia. It is hoped that future research will explore the use of bamboo material as a room divider in other tropical areas outside Indonesia.

Referensi

Arsad, Effendi. 2015. “Teknologi Pengolahan Dan Manfaat Bambu.” *Jurnal Riset Industri Hasil Hutan* 7 (1): 45. https://doi.org/10.24111/jrihh.v7i1.856.

Artiningsih, Ni Komang Ayu. 2012. “Pemanfaatan Bambu Pada Konstruksi Bangunan Berdampak Positif Bagi Lingkungan.” *METANA* 9 (1). https://doi.org/https://doi.org/10.14710/metana.v8i01.5117.

Chowdhury, Sajal, Khandaker Shabbir Ahmed, and Yasuhiro Hamada. 2017. “Thermal Performance Evaluation of Cavity Air-Gap for Tropical Factory’s Envelope.” *International Journal of Architecture, Engineering and Construction* 6 (4). https://doi.org/10.7492/IJAEC.2017.019.

Dewi, Putu Surya Triana, and Ni Ketut Sherlia Riski Kristanti. 2020. “Effect of Bamboo Interior Design on Psychological Users of Hideout Bali.” *IMADE (International Conference on Multimedia, Architecture and Design)* 1. https://eprosiding.idbbali.ac.id/index.php/imade/article/view/379.

Febrianto, Fauzi, Adiyantara Gumilang, Sena Maulana, Imam Busyra, and Agustina Purwaningsih. 2014. “Natural Durability of Five Bamboo Species against Termites and Powder Post Beetle.” *Journal of Tropical Wood Science and Technology* 12 (2). https://doi.org/https://doi.org/10.51850/jitkt.v12i2.70.g67.

Hilmy, Mochamad, and Indrayadi. 2014. “Pengaruh Rongga Pada Dinding Batako Terhadap Suhu Ruang Dalam.” *Jurnal Teknik Sipil Perencanaan* 16 (1). https://doi.org/https://doi.org/10.15294/jtsp.v16i1.7225.

Kaur, Perminder Jit. 2018. “Bamboo Availability and Utilization Potential as a Building Material.” *Forestry Research and Engineering: International Journal* 2 (5): 240–42.

Langmans, Jelle, Margaux Indekeu, and Staf Roels. 2017. “The Impact of Workmanship on the Thermal Performance of Cavity Walls with Rigid Insulation Boards: Where Are We Today?” *Energy Procedia* 132 (October): 255–60. https://doi.org/10.1016/j.egypro.2017.09.711.

Nurdiah, Esti Asih. 2016. “The Potential of Bamboo as Building Material in Organic Shaped Buildings.” *Procedia - Social and Behavioral Sciences* 216 (January): 30–38. https://doi.org/10.1016/j.sbspro.2015.12.004.

Purnama, Damalia Enesty, Agung Murti Nugroho, and Bambang Yatnawijaya Soebandono. 2016. “Identifikasi Pengaruh Material Bangunan Terhadap Kenyamanan Termal (Studi Kasus Bangunan Dengan Material Bambu Dan Bata Merah Di Mojokerto).” Universitas Brawijaya.

Rachmayanti, Sri, and Christianto Roesli. 2014. “Green Design Dalam Desain Interior Dan Arsitektur.” *Humaniora* 5 (2): 930. https://doi.org/10.21512/humaniora.v5i2.3191.

Sary, Novia, Fahrizal, and Ahmad Yani. 2018. “Jenis Bambu Di Hutan Tembawang Desa Suka Maju Kecamatan Sungai Betung Kabupaten

Bengkayang." *Jurnal Hutan Lestari* 6 (3). https://doi.org/https://dx.doi.org/10.26418/jhl.v6i3.27075.

Seran, Regina. 2017. "Pengaruh Mangan Sebagai Unsur Hara Mikro Esensial Terhadap Kesuburan Tanah Dan Tanaman." *Jurnal BIO-EDU* 2 (1). http://jurnal.unimor.ac.id/JBE/article/view/518.

Sharma, P., K. Dhanwantri, and S. Metha. 2014. "Bamboo as a Building Material." *International Journal of Civil Engineering Research* 5 (3): 249–54.

Suriani, Efa. 2017. "Bambu Sebagai Alternatif Penerapan Material Ekologis: Potensi Dan Tantangannya." *EMARA Indonesian Journal of Architecture* 3 (1): 33–42.

Trianingsih, Lilis, and Retna Hidayah. 2014. "Studi Perbandingan Efektivitas Material Bambu Dan Batu Bata Sebagai Konstruksi Dinding." *Jurnal Teknik Sipil Dan Arsitektur* 10 (1). https://doi.org/10.21831/inersia.v10i1.4428.

Yani, Ariefa Primair, and Nike Anggraini. 2018. "Peranan Bambu Dalam Kehidupan Masyarakat Desa Taba Terunjam Bengkulu." *Prosiding Seminar Nasional Pendidikan Biologi*, 924–28.

Author(s) contribution

Jovanny Yves Modiano contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

Phoebe Anthonieta Danny Wijaya contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

Heristama Anugerah Putra contribute to methodology, supervision, and validation.