

A Review on Coconut Coir as Thermal Insulation Material in Building Application

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Abstract: Over the previous few centuries, there has been a worldwide growth in energy consumption for cooling and heating in buildings. Therefore, researchers and building professionals have proposed the solution to use renewable resources from agricultural waste where it can develop to keep the building at the right temperature for a long period. The agriculture waste that is focused in this study for the thermal insulation building is coconut coir. The objective of the study is to review the availability potential of coconut coir that use in the building application and to study the effectiveness of the thermal properties of coconut coir in building application. The thermal insulation that will be cover in this study is thermal conductivity (U), thermal resistance (R), and thermal transmittance (U). Four parameters cover the thermal conductivity which are coir content, coir length, bulk density, and size of sand. To reach the study's goal, about 50 literature papers from previous research were examined and compared to meet the study's purpose. It was found that the optimum coir content is about 10% w/w which gives the lowest thermal conductivity, 0.24 W/mK. Using < 2mm length of the coconut coir gives the lowest value thermal conductivity value is 0.20 W/mK. The highest bulk density which is 1350 kg/m³ gives the highest thermal conductivity value, 0.6736 W/mK. For the size of sand, using <0.71 mm with the length of coir <2 mm will give the lowest thermal conductivity which is 0.195. The density of 65 kg/m³ will make the R-value higher; 2.52 m²C/W and the thickness of 0.08 m give the U-value 0.21 W/m²K. Hence, coconut coir fiber is recommended to use in the building application because of its lower thermal conductivity, thermal transmittance, and higher thermal resistance.

Keywords: Coconut Coir, Thermal Insulation, Thermal Conductivity, Thermal Resistance, Thermal Transmittance

1. Introduction

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In the next 10 years, International Energy Agency (IEA) assumes that global energy consumption would rise by 53%, owing to a large increase in industrial and urban activity as a result of rapid country development and a substantial increase in population size in recent years [1]. Alternative approaches for reducing yearly energy use by applying thermal insulation materials in buildings have been suggested, created, and executed in preliminary research [2]. Other than that, according to the MOA (2009), the statistics of the overall coconut palm output grew from 512,699 metric tonnes in 2006 to 555,120 metric tonnes in 2008, in Malaysia. From there, it might produce high waste material from coconut palm production. Therefore due to the excessive coconut coir waste problem and the poor thermal performance in the building, the alternative way can be taken to minimize both of them is by producing building material from the coconut waste which in this study is coconut coir. There is a large number of studies on the possibilities of coconut coir to replace the material as a building element in various products. Coconut is one of the most famous fruit due to the tropical climate in Malaysia which is common for food, industrial crops, and also one of the most eligible natural fibers to use as a composite material in construction [3]. Based on the properties of coconut coir, it is suitable to be a replacement for non-conventional local construction materials as it is a good thermal insulator when used in a building application. The development of this composite material is an interesting alternative because they have a low thermal conductivity which would lead to the solving problem in simultaneously energy, environment, and thermal comfort.

The objective of the study is to review the availability potential of coconut coir that use in the building application and to study the effectiveness of the thermal properties of coconut coir in building application. This study is focusing on the performance of coconut coir fiber in the building application. The study analyzes the thermal insulation material using coconut coir in the building application. For the thermal insulation properties, the review study was focused on thermal conductivity, thermal transmittance, and thermal resistivity. Other than that, it focused on the application as building insulation and the effectiveness of the coconut coir as composites material in the building application. To reach the study's goal, about 50 literature papers from previous research were examined and compared to meet the study's purpose.

2. Literature Review

2.1 Properties and Performance of Insulation Materials

Insulating materials are usually classified into three classes based on their characteristics. Physical properties are the first material behavior that would be described as insulation material. These physical properties include the mechanical strength, fire resistance, density, acoustics absorption, moisture, and also thermal insulation ability of the material. The next classes in dealing with the influence of insulating materials on the environment which is less generally acknowledged by people. This group includes properties such as primary embodied energy, gas emissions for the material's production, the use of additives against biological impacts, the classification of their treatment as waste, their reusability, and recyclability, as well as the material's environmental impact, based on the Life Cycle Analysis approach according to ISO 14025-00. Lastly, the characteristics of groups that deal with public health throughout material manufacture, use, and disposal. This category covers characteristics such as dust, fiber emissions, and toxicity.

2.1.1 Thermal Insulation Performance Characterization

Thermal insulation is the most efficient technique to save energy in a building for cooling and heating [4]. Three properties of insulation material are mainly focused which is thermal conductivity, thermal transmittance, and thermal resistance. This thermal insulation aim into lowering the heat flow's transmission and thermal conductivity also thermal resistance is frequently used to evaluate it [2].

2.1.1.1 Thermal Conductivity (K-Value)

The amount of heat per unit time per unit area that can be transmitted through a plate of unit thickness of a particular material, with the faces of the plate varying by one unit of temperature, is known as thermal conductivity. It occurs when heat moves along a temperature gradient from a high temperature

which has a high-molecular-energy region to a lower temperature which has a low-molecular-energy region. These energies will transfer from high temperature to low temperature when these two molecules collide. Thermal conductivity is measured in compliance with EN12664 (low thermal resistance), EN 12667 (high thermal resistance), EN 12939 (thick product of high medium thermal resistance), or also ASTM C518. The thermal conductivity (K) value can be calculated based on the heat flow (Q), length or thickness of the material (L), the temperature differential (ΔT), and surface area of the material (A). The unit is expressed in W/mK.

$$K = \frac{QL}{A\Delta T} \quad 2.1$$

2.1.1.2 Thermal Resistance (R-Value)

The ratio of the temperature difference between two sides of a material to the rate of heat transfer per unit area is known as thermal resistance [5]. The SI unit for thermal resistance is $m^2.K/W$. The higher the R-value in building material, the greater it is insulation effectiveness [5]. It is measured by ASTM C168. The thermal resistance (R) value can be calculated based on the temperature differential (ΔT) and heat flux (q).

$$R = \frac{\Delta T}{q} \quad 2.2$$

2.1.1.3 Thermal Transmittance (U-Value)

Thermal transmittance, U-value is the steady-state heat flow passing through a unit surface area include divided by differences in temperature across the structure. The thermal transmittance is measured with the hot box method or using ISO 6946 calculation method and it is expressed in W/m^2K . [6]. U-values are applied in the whole building stock to estimate fuel consumption and standards for U-values for new construction projects [7]. The improvement of the thermal performance will improve if there is a reduction in the U-value. Therefore, the new housing will become significantly more energy efficient [7]. The thermal transmittance (U) value can be calculated based on total thermal resistance (R_T).

$$U = \frac{1}{R_T} \quad 2.3$$

2.2 Application of the coconut coir in the building

Wood or bricks are commonly used to build walls, and they transmit heat less efficiently than glass or metal, which is desirable [8]. Since walls are the largest contributor to a building, the implementation of thermal insulation is effective to make the heat loss on the overall building [9]. Therefore, by using the insulation materials, the building's heat transfer can affect the thermal performance of the building [10]. In addition, by inserting insulating material close to the source of heat input or outflow, will provide the best thermal performance in the building.

The floor is a rigid building assembly that divides space into storey horizontally. It forms the bottom of a room. Therefore, it is the building part that is advised to implement the insulation materials. The insulation will be applied along the base of the footings slab. However, because heat transmission towards the earth at the lower depths of basement floors is fairly modest, basement floor concrete slabs need to be insulated regarded to be of limited [10]. The poor heat flow is due to the low temperature difference between the ground beneath the floor, as well as the air above it .

One of the most significant aspects is reducing the energy use of a building envelope is the roof [11]. Roof is a top of the building that gives the occupants protection against the rain, sunlight, snow, and extreme temperature. During the day, a direct beam of sunlight leads the roof to absorb a large quantity of radiative heat from the sun [10]. Roofs may occur approximately to 32% of the horizontal surface area of built-up regions and provide significantly heat gain in structures. Reflective insulation is commonly used on the roof as a radiant barrier. This form can help to minimize heat transmission by conduction and convection.

2.3 Previous Test on Thermal Conductivity

2.3.1 Coconut Coir Content

One of the parameters that affect the thermal conductivity is the coconut coir content. Most of the previous study were using different percentages of the coir content to investigate their impact on the thermal conductivity. Most of them used the coir content in the range of 0.4%, 5%, 10%, 15%, 20%, 25% and the maximum coir content is 30%. JIS R 2618 was used to determine the thermal conductivity of these samples.

2.3.2 Coconut Coir Length

About 5 previous studies do an investigation on the effect of the coconut coir length on the thermal conductivity. The length that was prepared in the experiment is about range 1 – 13 mm to be mixed with the different mixtures. They also investigated the impact of coir length and density and discovered that coir fiber length and thermal conductivity are inversely proportional. The longer the coir, the lighter the board and the lower the thermal conductivity.

2.3.3 Bulk Density

Most of the previous studies include the bulk density in their investigation on the thermal conductivity. The range that they used for the bulk density is about 329 – 1350 kg/m³. Their investigation shows the same result where the thermal conductivity is increase when the bulk density is increase.

2.3.4 Size of Sand

One of the previous studies found that the size of sand can give the effect on the thermal conductivity value. Only one worked on new lightweight composite construction materials with low thermal conductivity and the impact of sand size. There are two sizes of sand that were evaluated, below 0.71 mm and 0.855 ± 0.145 mm. It was found that the size of the sand is directly perpendicular to the thermal conductivity.

2.4 Previous Test on Thermal Resistance

The previous study does an investigation on the performance of indigenous fibrous materials including straw, hay, and coconut coir fiber as insulation compare to XPS sheet's performance and to figure out what these fibrous materials' R-values were. The straw, hay, and coconut coir fiber were put to the test at three different densities which are 30 kg/m³, 45kg/m³, and 65kg/m³ whereas the thickness of the XPS sheets and the number of sheets remained identical. The insulation was subsequently inserted into the wall cavity. Each experiment lasts for 72 hours.

2.5 Previous Test on Thermal Transmittance

The previous study investigates the behavior of coconut fiber insulation of green roofs in terms of thermal resistance according to UNI EN ISO 6946. Two types of structure have different insulation layers of material and thickness which is Concrete (CLS) and Cross Laminated Timber (CLT). Both of them have the same stratigraphy and also with and without air gap (AG) with thickness 0.018 m.

3. Result & Discussion

3.1 Thermal Conductivity of Coconut Coir

Figure 1 shows the thermal conductivity value against the percentage of coir content. The lowest value of thermal conductivity is from 0.240 W/mK with the 10% coconut coir content collected from a past study carried by [12]. Most previous studies used 5% and 10% of coconut coir content for the experiment and. However, [13] states that if the proportion of the coir content is higher than 15%, it may make the mixture uncontrollable due to the recognizable excess of coir to sums of cement and sand, then does not make the thermal conductivity low but higher. It can be observed that after the

thermal conductivity reaches 20%, it starts to rise. Therefore the optimum of coir content is about 10% w/w.

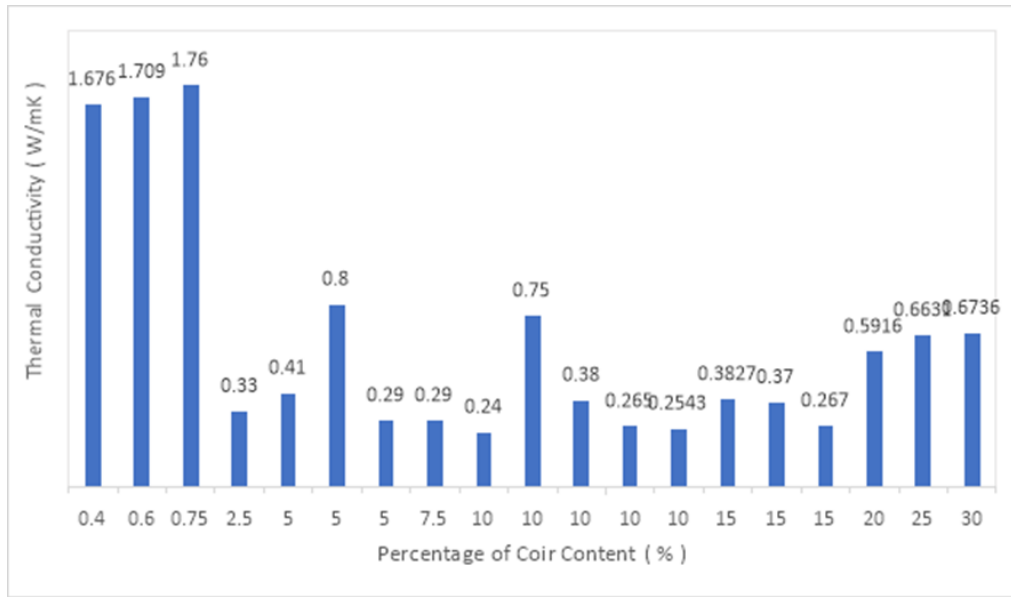


Figure 1: Thermal Conductivity based on the percentage of Coir Content

Figure 2 shows the effect of the percentage coir content with different coir lengths on thermal conductivity. It can be seen that the highest thermal conductivity value is 0.976 W/mK with 10% of coir content and 35 – 40 mm length was extracted from a former study carried out by [14]. The lowest value thermal conductivity value is 0.20 W/mK with 30% of coir content using < 2mm length which was obtained by [15]. These differences in thermal conductivity can be described by the fact that the short coconut coir fiber is harder to pack and align tightly compared to the longer coir fiber. The short coir fiber with the given coir content makes plenty of voids leading where it occurring from the packing of the coconut coir fiber then leads for a specimen to have a low thermal conductivity [15].

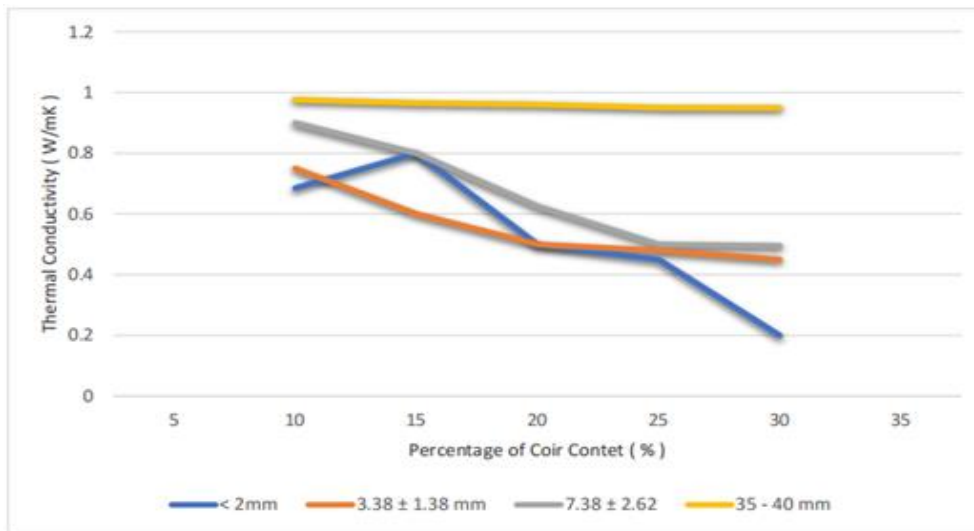


Figure 2: Thermal conductivity value against the percentage of coir content with different coir lengths

The effects of bulk density on thermal conductivity are seen in Figure 3. It can be observed that the maximum thermal conductivity value of 0.6736 W/mK with a density of 1350 kg/m³ was achieved from a past study done by using 30% coir content [15]. The result showed that when bulk density is directly proportional to the thermal conductivity. This is because when the bulk density is low, the porosity of the specimen becomes high then leads to higher thermal conductivity. Therefore, based on

the figure, the heat-insulating efficiency of a substance is inversely proportional to its density [16]. Some of the proportion was not mentioned in a handful of the studies of coconut coir content used in a specimen and had the lowest value of thermal conductivity of 0.054 W/mK.

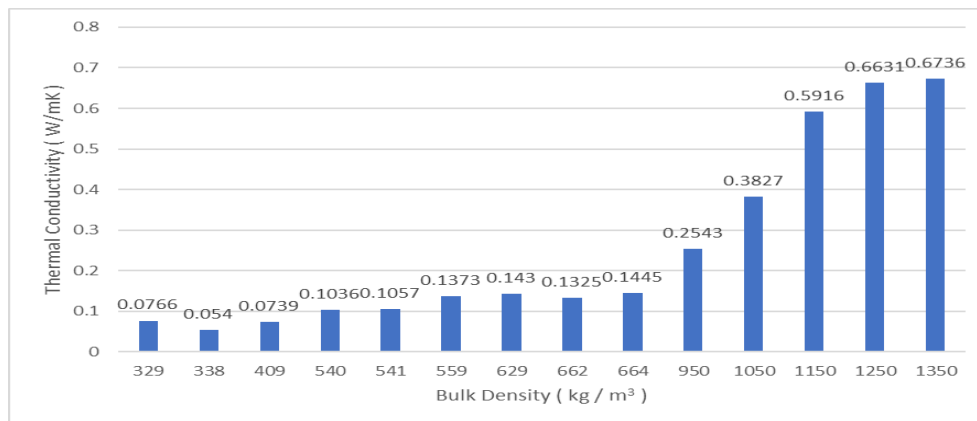


Figure 3: Thermal conductivity value against the bulk density

Figure 4 shows the effect of the coconut coir content on thermal conductivity for different lengths and sizes of sand. There are only a few studies that focus on thermal with the size of sand. Based on [15] studies where it used two sizes of sand which is <0.71 mm and 0.855±0.14 mm with the different length coconut coir. The results show that the size of sand is directly proportional to the thermal conductivity of the specimen. Therefore, the thermal conductivity of the specimen that have <0.71 mm sand size is much lower than the thermal conductivity specimen that has 0.855±0.14 mm sand size. In fact, by using the fine sand size or aggregate, it can make the sand insert between a matrix of coir fiber then make it more distant on each other where it will create the voids inside the specimen. Therefore, tend the density and thermal conductivity to become lower

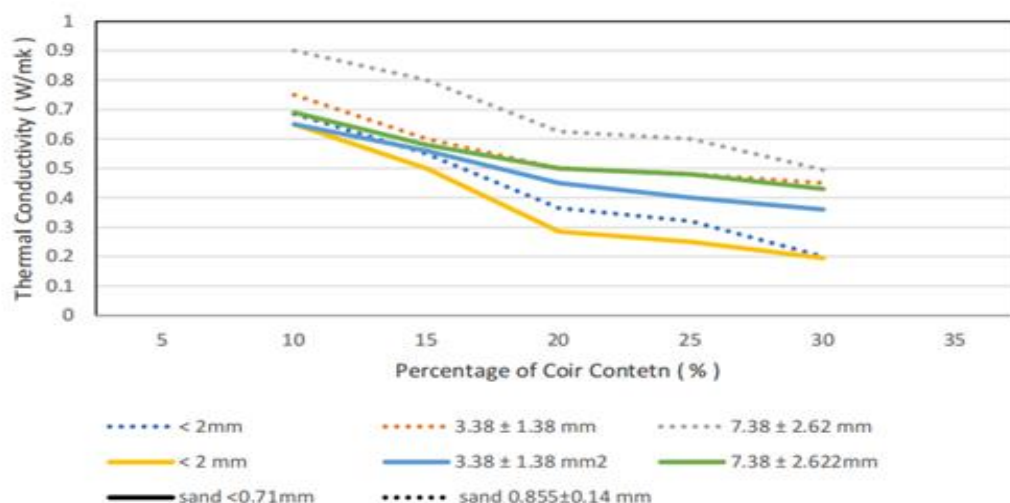


Figure 4: Thermal conductivity value against the coconut coir content for different lengths and sizes of sand

3.2 Thermal Resistance

Figure 5 shows the effect of the density against the thermal resistance. The graph shown that the highest thermal resistance is 2.52 m²°C / W where the densities are 65 kg/m³ and the lowest thermal resistance is 1.78 m²°C / W with the densities 30 kg/m³. It can be observed that the higher the densities of the material, the higher the thermal resistance. The thermal resistance properties are inverse with the

thermal conductivity. A building component that have a higher thermal resistance will have good insulating effectiveness for the building [17].

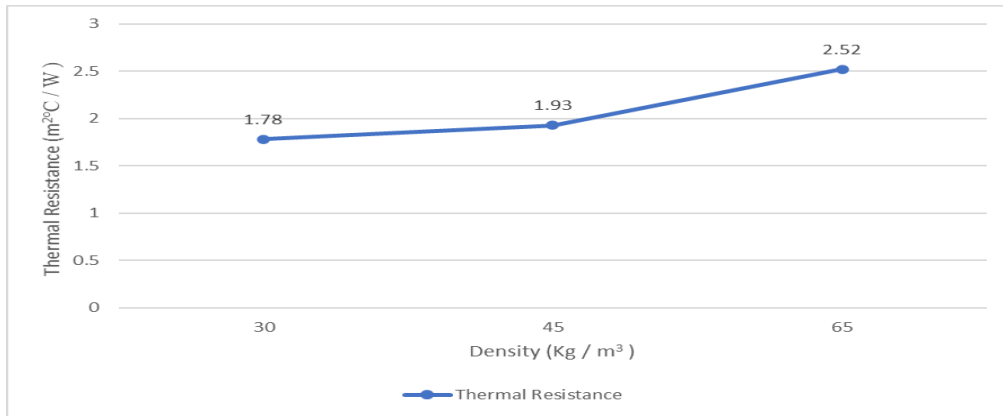


Figure 5: Thermal Resistance with the different densities

3.3 Thermal Transmittance

Figure 6 shows the thermal transmittance against the insulation material thickness [18]. used the coconut coir fiber with three different thicknesses of the material two different types of slab contain coconut coir which Concrete (CLS) and Cross Laminated Timber (CLT) with and without air gap (AG). It shows that the highest thermal transmittance is 0.21 W/m²K with 0.08m of the thickness of the CLS without air gap. The lowest thermal transmittance value is 0.12 W/m²K with a thickness 0.16 m of the CLT+AG. Based on the observation data, the slab which has the air gap has lower thermal transmittance than the slab that does not have an air gap. If the air gap is greater than 0.005 m, it can make the thermal transmittance of the thermal insulation layer increase up to 20% [19]. Therefore, there is an influence of the air gap on thermal transmittance. Also found that there is not much differences between the thickness of 0.12m and 0.16m. Conclude that the lower the U-value, the greatest the material holding up the heat in the building component.

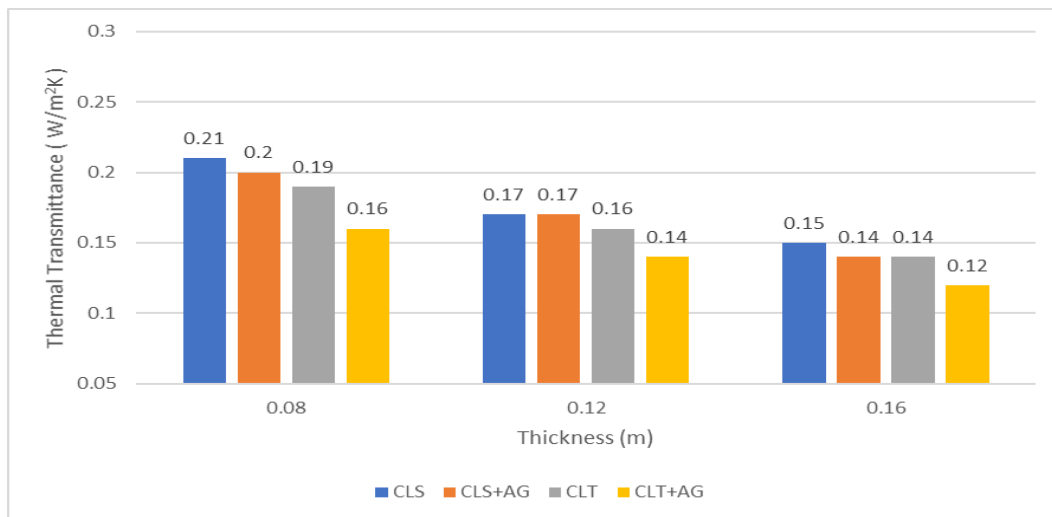


Figure 6: The Thermal transmittance against the thickness of the building materials

4. Conclusion

In the conclusion, the low thermal conductivity of the specimen can aid in preventing heat transmission into the building and as a result, it will save energy. Therefore, coconut coir has the potential to become an admixture in the building application. The result found that the coir content, length of coir, density, and size of sand can affect the thermal conductivity of the specimen. Good

building insulation will have a higher thermal resistance when the densities of the component is high. Meanwhile, good building insulation can be applied when thermal transmittance is low.

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