Building Material in The Perspective of Energy Efficiency and Thermal Environment in TOD Area

Fadhil Muhammad¹, Surjamanto Wonorahardjo²

¹Architecture Department Master Program, SAPPK Institut Teknologi Bangunan, INDONESIA  
²Building Technology Research Group, Department of Architecture, SAPPK Institut Teknologi Bandung, INDONESIA

Abstract. The development of urban area such as a Transit Oriented Development (TOD) involves a lot of building materials that are forming the physical environment which rises problems of urban heat island (UHI) and energy consumption. The TOD forming urban corridors that rise urban canyon issues with high air temperature, poor air quality, high energy consumption for air cooling and purifying (HVAC). The common heavyweight building materials that dominate the physical environment of TOD and other urban areas have low specific heat and high heat capacity. Another thermal property of concrete and brick storing the heat energy influence the air temperature during the night. The lightweight modern building materials that are cheap in construction cost show the worse phenomenon in the UHI perspective due to its lower specific heat. This review paper discusses the role of building material in the urban thermal environment such as the TOD area in the energy and environment perspective. The early result shows that both heavyweight and lightweight modern building material have a bad performance for the environment and should be mitigated otherwise our future will become worse. The energy consumption that rises uncontrollably due to bad air quality and high temperature will decrease the liveability level of the urban area.

1. Introduction
The phenomenon of Urban Heat Island (UHI) is indicated by the higher air temperature in an urban area than its neighbouring microclimates that it can be perceived [1]. The increasing temperature in the urban area caused by several factors, causing the UHI phenomenon to occur in the urban area. One of the causes of the increase in temperature of microclimates in an area is due to the physical development of urban areas. Urban areas characteristic are commonly indicated by the low percentage of green area, high density of buildings, and high transportation pollution of anthropogenic heat emission [2]. The physical development of urban areas never separated from the use of building materials both heavyweight materials and lightweight materials. One of the reasons causing the Urban heat islands phenomenon is the excessive application of artificial construction materials [3]. The concrete pavement area between buildings causes air temperature rising during the day and night in an urban area. [1]. Building material that has a high value of heat storage absorbs heat from sunlight radiation during the day and emits the heat it absorbs into the surrounding environment. Buildings with modern materials often consume high amounts of energy for cooling the room inside the building.
The building sector contributes to the largest energy consumption in the world. Almost 33\% of national energy consumed by the household sector in Indonesia and around 40\% in the European Union [4]. It is known that reducing building energy consumption is very important. The environmental deterioration such as the global warming caused by the population growth and physical development in an urban area and also the used of huge fossil energy [5]. The passive design approach as an effort to reduce building energy consumption is one of the right strategies which can be done in terms of architecture perspective [4]. For controlling the environmental deterioration, building sectors should reduce energy consumption. It is the most important keys in today's era [6].

To control the quality of thermal urban areas, architects must understand the role of the use of building materials in urban environments. Each building material has unique thermal behaviour different from others. The thermal behaviour of building material is defined its intrinsic thermal characteristics i.e.; 1) density of the material, 2) the specific heat, and 3) thermal conductivity.

Besides the surface properties of building materials used are very influential in the thermal quality of the environment. The influential surface thermal properties are 1) albedo or surface brightness level, and 2) surface texture. Two ambient characteristics should be considered in choosing appropriate building material in the tropic climates i.e.; 1) the peak temperature level and 2) the diurnal range of air temperature. The orientation and surface characteristic such as the colour of the wall is the significant aspects in absorbing the solar radiation. The relevant thermophysical properties that should be considered are thermal resistance and heat capacity [7]. The surface of an urban area that is formed by hard and heavyweight material shows the phenomenon of energy balance that affect by re-emission and heat storage. Emissivity and albedo are considered as the radiative properties of materials while heat capacity and thermal conductivity are considered as storage properties [8].

2. Method
This study aims to show the role of building materials that are forming the urban thermal environment. The role of building materials is seen from two perspectives, namely the level of energy consumption and the level of environmental damage. Based on these two parameters, we formulate the rules of using building materials that are appropriate for tropical urban environments.

We conducted a prospective study of energy consumption due to the use of materials in several articles about the impact of the use of building materials on building cooling loads. Environmental deterioration issue is used as the perspective of this study, that building envelope material gives a negative impact on the urban thermal environment. In this study, several articles studying energy and environmental performance of heavyweight materials and lightweight materials for building are reviewed. This study reviews the role of most popularly used materials for building in the urban area to the energy consumption and thermal environment.

3. Building Materials
Building materials that popularly used in urban environments include concrete, steel, ceramics, glass, PVC, plastic, aluminium, metal composites, and various other materials in the form of a single material, mixed material, and composite.

The material acts as a building envelope, building structure, pavement, aesthetic elements, and others. The building envelope has the role of separating the external and internal environment from different conditions following the function of the inner space. The building envelope is void and solid for light, sound, airflow, and heat flow from outside to inside or vice versa. The building envelope is void for light if the building material can transmit light into the room, such as glass or other transparent materials, and solid if it cannot transmit light. The building envelope is void for the heat flow if the building material can transfer the heat from the outside to the inside of the building and is solid if it cannot transfer the heat.

Furthermore, building materials have an impact in forming the thermal environment of the urban area because of thermal properties of materials used as building envelopes namely specific heats (kJ/(kg K)), thermal conductivity (W/(m K)), and density (kg/m^3). Building materials that have high
specific heat and density can store a large amount of heat and act as heat storage. The use of these materials in building envelope and pavement causes urban areas to absorb and store heat which then has an impact on increasing thermal environment known as the UHI phenomenon. The use of materials with high conductance properties on building facades causes the heat flow from outdoor to indoor through radiation and conduction mechanism, causing a large cooling load that increasing energy consumption to achieve thermal comfort.

Thus, the perspective of energy consumption and environmental effect in the use of building materials is very important for dense urban environments such as TOD areas.

Building materials, in general, are classified into heavyweight building materials and lightweight building materials. This kind of materials form the urban area and dominantly affect the energy consumption of the building. Besides, the use of both heavyweight materials and lightweight materials contributes to the UHI Phenomenon.

In the TOD area that forms a corridor, both the orientation and building materials play a major role in controlling the thermal environment. The orientation of the corridor affects the intensity of solar radiation absorbed by the building envelopes in the whole corridor of the TOD area. Building materials that used as pavement, facades, walls, and roofs also contribute to forming the thermal environment of the TOD area. The development of the TOD area is potentially raising the issue of the UHI phenomenon due to its physical characteristics. Thus, the role of building material in the TOD area is necessary to be concerned. The illustration of the corridor formed by developing the TOD area is shown in figure 1.

3.1. Heavyweight Building Materials
The buildings in an urban area, in general, used heavyweight materials i.e.; brick and concrete for envelope walls, pavements, and floor [9]. Heavyweight building materials performed as a thermal collector if it is facing the side which has a large intensity of solar radiation [10]. Heavyweight Building materials are material with high heat capacity which makes heavyweight building materials can store an amount of heat inside before released the heat to the environment. Heavyweight materials cover large of an area in urban development. Building materials such as brick and concrete blocks are categorized as heavyweight [9]. Heavyweight materials such as concrete and asphalt have a high heat capacity and can store a large amount of heat from solar radiation. The stored heat is then distributed to the surrounding environment and causes an increase in regional temperature.

3.2. Lightweight Building Materials
Lightweight materials are popularly used in an urban area with high-density living. This material usually applied for non-structural construction in the building. Glasses, metal sheet, and aluminium composite panels are the most popular material for façade, window, and roof cover [9]. Lightweight materials such as glass and aluminium have relatively little specific heat, which makes it easy to be heated when exposed to direct sunlight. This situation causes heat from this material to be irradiated to the
surrounding environment. The lightweight material performs as a thin skin of a building that allows the heat flow to the indoor environment and rises the cooling load and energy consumption of HVAC. Some experts also report that this lightweight material increases the outdoor air temperature [11]. Lightweight materials usually have a lower density compared to heavyweight materials.

4. The Role of Building Materials towards Energy Consumption in Building

Building materials discussed in this paper are materials that mostly used in the urban area. Both heavyweight materials and lightweight materials are dominantly used in the urban area. Building materials such as concrete, asphalt, aluminium, and glass are discussed in this paper.

4.1. Concrete

Concrete is a material that usually used in structural construction and building walls. Concrete is a good thermal collector due to its high heat capacity. Comparison of the heat conductivity shows that concrete has a higher value than asphalt. It causes a higher rate of heat flow on concrete than asphalt [12]. The heat conductivity of the concrete causes the heat storage below the surface is larger than asphalt during the heating period [12]. Building with concrete materials on the surface facing high intensity of solar radiation has a high cooling load and therefore increasing the energy consumption for cooling. The use of concrete as a formwork system increase heating and cooling demands to achieve indoor thermal comfort [13].

4.2. Asphalt

Asphalt is the most popular material for street cover in the TOD area. The use of asphalt increases the air temperature means that asphalt has a higher heat capacity than brick and concrete [9]. Asphalt has similar thermal characteristics with concrete. It has high heat capacity and stores an amount of heat that absorbed from solar radiation. The stored heat from solar radiation then released at night due to the different temperatures between asphalt and its surrounding. The heat released from asphalt cause an increasing air temperature. Increasing air temperature cause discomfort towards the thermal environment and indirectly affect thermal comfort in the building. This phenomenon leads to an increase in cooling demand to achieve thermal comfort in building so that the energy consumption for cooling the indoor environment also increases.

4.3. Brick

Brick is mostly used as wall material in building. This material has high heat capacity and low conductivity. Brick performs as a thermal collector during the day and releases the heat it absorbs to the surrounding area at night. A study in a suburban area, reports that brick wall rising the cooling demand in summer by 21% however it reduces the heating demand by around 17%. Another study by Wonorahardjo et al [14] shows that the use of brick as a roof structure causing the air temperature below the ceiling to increase. Bricks wall cause poor thermal performance because it absorbs and stores a lot of heat energy from direct solar penetration during the day and releases heat into the house throughout the night [15]. The envelope wall keeps warm the indoor air temperature during the night hours until early morning because of infrared emission of the wall material [14].

4.4. Aluminium

Aluminium is mostly used in building as a façade material. The use of aluminium on buildings affects the higher indoor temperature and as the result of energy consumption could not be neglected. It is because of its high thermal conductivity. These materials transfer heat gain from solar radiation to the indoor environment and cause the temperature to increase. Increasing temperature in building cause energy consumption to cooling the building increase linearly. The use of aluminium panel should incorporate the additional thermal breaks layer due to its high thermal conductivity to enhanced thermal performance [16]. Aluminium used in the building envelope requires well planned thermal insulation because of its high heat conductivity value (λRAlu = 200 W/mK, λRAloy = 160 W/mK) [16]. The use
of aluminium cladding with an air gap (5cm) and gypsum layer (1.3cm) decreased 16% of the cooling energy [17].

4.5. Glass
Glass is popularly used as façade materials due to its lightweight and easy construction. The U-value of a glass determines the glass performance in heat loss. This can be achieved by adding a glazing layer, applying a special coating to control solar radiation, and adding gases with low thermal conductivity such as argon and krypton in the air gap between the glass layers to reduce the glass conductivity when applied as building facade materials [18]. A study by Tamimi et al [19] shows that the maximum reduction in indoor temperature can be achieved by changing the glass type. Replacing the clear glass with a reflective glass gives a positive result in energy saving. The area of the glazed surface on a building façade determine the annual energy consumption [20]. The use of double clear glazed windows can reduce the heat conduction coefficient and peak cooling load by up to 23% more than single clear glazing [21]. Compared with other glass types, the reflective ones shows the best performance in reducing indoor air temperature in a tropical climate such as Indonesia [19]. Reducing conductivity in glass materials in building façade decrease the cooling load of the building due to the low heat gain that transmitted from solar radiation.

5. Effects of Building Materials to The Thermal Environment
Building materials play an important role in the thermal environment of the urban area. Thermal properties of each material used as building envelope, pavement, and roofs affect the thermal environment around these materials. The solar radiations bring heat energy that it is reflected, absorbed, and also transmitted to the indoor environment. The heat trapped in the material re-emitted to the surrounding environment and increases the temperature and raising the heat island intensity in an urban area.

5.1. Concrete
The concrete material has a wide range of thermal conductivity depends on its aggregates composition [22]. Depending on the aggregate type and concrete mixture used, the thermal conductivity of concrete varies from 0.1 W/m K to 1.7 W/m K [23]. Concrete stores a significant amount of heat inside during the day and released at night because the heat conducted more rapidly from the surface to the layers below [12]. The pavement could store a large amount of heat energy due to its high heat conductivity, and specific heat. It causes the heat that released to the atmosphere at night was also large. The heat conduction of the concrete reduces the surface temperature of the concrete pavement during the heating period [12]. The use of concrete as building materials increase the thermal environment of the urban area because the heat it absorbs that released at night causing the urban temperature to increase.

5.2. Asphalt
Asphalt that used as a pavement increasing urban temperature significantly. Asphalt is heated significantly during sunny hours especially in summer days compared to other pavement materials. Asphalt releases an amount of heat through sensible heat flux. The infrared emission is released by the asphalt surface to the atmosphere during the day and night [12].

5.3. Brick
Bricks are mostly used as material for building walls. Commonly a good brick has a higher density than a low-quality brick. The use of bricks as wall materials causing a significant increase in HII during the afternoon [24]. Brick performs as thermal storage due to its high heat capacity. The delay effect provides a cooler indoor air temperature during the daytime by using bricks. However, the warmer impact on the outdoor environment during night hours occurs due to the delay effect. [24].
5.4. Aluminium
The use of aluminium harms the thermal environment. This material is easy to be heated by solar radiation due to its high conductivity and low specific heat. A study by Perera et al [25] shows that aluminium cladding recorded the highest UHI intensity of 2.87°C in the Commercial area. Similarly, simulations that explored material combinations in street canyons showed that the inclusion of Aluminium cladding adversely affected the UHI intensity than those of other combinations [25].

5.5. Glass
Similar with aluminium, glass is categorized as lightweight material with low specific heat and high conductivity. Glass is void for sunlight so that this material transmits the heat from solar radiation to the inside of the building. Glass with high reflectivity and low emissivity shows bad performance to the environment due to the heat reflected and emitted to the environment and causing the thermal environment to increase. In the context of UHI, the application of glass on a double skin facade (DSF) has resulted in a reduction of about 1.4°C in an outdoor environment. It is a significant enhancement for the urban thermal environment [26]. The use of glass with different glazing shows good performance to the thermal performance of building facades but on the contrary show bad performance for the thermal environment.

6. Discussion
The urban area is formed from a collection of building materials both lightweight building materials and heavyweight building materials. In the Transit-Oriented Development (TOD) area that forms corridors, the use of this material contributes to the increasing temperature of the region. Besides, the use of this material also has an impact on the increase in energy consumption of buildings. Heavyweight materials with high heat capacity store the heat during the day and cause comfortable thermal comfort due to the delay effect but cause an increasing temperature at night-time. Lightweight materials show good performance to the energy consumption of the building but affect the increase in the thermal environment at the same time. Many results of numerical simulations show the building and environment thermal interactions. The building material plays an important role in conditioning the thermal conditions of an urban area [27]. The use of both heavyweight and lightweight construction materials can affect the urban microclimate directly and indirectly [8].

Surface properties of building materials for both heavyweight and lightweight materials play an important role in controlling the energy consumption of the building and thermal environment. The use of materials with a reflective surface reduces the heating effect caused by solar radiation and minimizing heat gain through the building envelope. Another surface property of materials that should be considered is albedo or surface brightness level and surface texture. Other properties of both heavyweight materials and lightweight materials such as thermal conductivity, specific heat, and density should also be considered when choosing a material for building in the urban area.

The application of insulation materials is one of the most effective methods of reducing cooling-related energy consumption in commercial buildings [6]. Thus, the application of thermal insulation leads to better performance from the perspective of energy efficiency and thermal environment. Thermal insulation plays an important role in reducing energy consumption due to its capacity to retard the heat transfer mechanism through conduction. The use of thermal insulation in building facades facing east and west in the TOD area mitigate UHI by reduce the heating load and cooling load of building so that the energy consumption of buildings can be decreased. The use of vegetation can be considered to reduce the air temperature and provide a shading effect that prevents the direct solar radiation to the urban area.

7. Conclusion
Building materials play an important role in forming the thermal environment in the TOD area. The choice of material type has an impact on the energy consumption level as well as the UHI or Heat Island intensity. The Planning of TOD needs to consider the orientation of the corridor formed due to the huge popularity of using heavyweight materials and lightweight materials.
Urban Heat Islands (UHI) phenomenon can occur in the development area with the Transit-Oriented Development (TOD) concept. One of the reasons that have a contribution to the UHI phenomenon is the use of building materials that have high heat storage values and low specific heat values. The high level of building energy consumption due to the use of materials that are less environmentally friendly has an impact in the form of heat emissions to the building environment, especially in the TOD area. Both heavyweight materials and lightweight materials play an important role in both energy consumption and thermal environment in the TOD area. This UHI can be mitigated by applying thermal insulation to the side of buildings which are often exposed to solar radiation so that heat from solar radiation is not distributed to urban areas. Research on UHI mitigation with the application of thermal insulation needs to be developed especially in the TOD area in Indonesia which has a tropical climate and high sunlight intensity each year.

In the TOD area that has been built, there is some program such as the retrofit program to decrease the energy consumption of building and heat emission to the environment. One of the most effective ways to decrease the energy consumption of the retrofit building is the use of thermal insulation.

The use of thermal insulation to mitigate Urban Heat Island in the TOD area needs to be further investigated due to its effect on the thermal environment. Further research in mitigating UHI using thermal insulation materials should be considered not only in building materials but also involves other elements such as vegetation and geometric shapes of the urban areas.

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