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A Review of Thermal Environmental Quality in Residential Areas in Tropical Cities

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Abstract. The development of residential areas in big cities is characterized by a vertical-horizontal growth in the center of the city and horizontal growth in the edge of the city. The growth of the city has changed Land Use and Land Cover (LULC) and significantly altered the thermal environmental quality and urban heat island (UHI). This paper discusses the effects of the change LULC in several cities to their thermal environmental quality due to the development of residential area. We compare the effects of the change of LULC that occurred in residential areas in tropical cities. This study involves some factors such as the character building of residential, land cover, sun, and wind orientation. The results of this study present a map of various issues on the change of LULC in residential areas in tropical cities.

1. Development of residential areas

The development in urban areas generates a massive urbanization that causes land use intensification and building density in urban areas. It is indicated by changing of land cover types and vegetation index [1]. The development in an urban area can be controlled by using land use planning regulation with consideration of urban structure, site selection, street layout and building density based on climatic adaptation and ecological principles [2].

The development is an attractiveness factor for urbanization and also for expansion residential areas. Residential areas become an important part of a city that influence directly to ambient of a city. Therefore the quality of residential areas gives a direct effect on thermal quality of the city. Housing needs in a city increase density of residential areas due to limited of land areas.

Limitation of area for residential generates a housing area expansion to other lands that previously are not recommended for residential area such as wetland. Many efforts to convert the wetland into residential area such as put some pillars as supports of houses that change the characteristics of the land. The most popular effort is landfill that converts wetland into dry areas. Characteristic of land area alter due to landfill for housing area. The changing of wet and dry land influence ecosystem quality of the city [3].

2. The impact of urban physical development on thermal environment quality

Urban development encourages the development of area became built-up area. The development of built-up area cause the changes in land cover, building structure material and reduction nature of surface [4]. Land cover and building structure material which use reflective properties cause increasing the value of surface albedo [5, 4], emissivity, and infrared emissivity [5]. Reduction nature of surface in the form of decreasing of vegetation affect evapotranspiration in the area [5]. The change of surface albedo, emissivity, infrared emissivity and evapotranspiration will affect the thermal environmental quality and microclimate [5].

Thermal environmental quality and microclimate an area are formed due to urban geometry [6, 7, 8, 9], construction materials [8] and urban texture [10]. Urban geometry is element configuration of the area that affects thermal environmental quality in the form street geometry, orientation [11], street axes and building height [6], sky view factor, local and neighborhood scale [9]. Urban geometry affects the thermal environmental quality and microclimate because this factors related to solar radiation exposure on the surface area which is influenced by street geometry and orientation, trees, wind speed and horizontal surface [11]. Urban geometry has an impact on the environment in the level mesoscale and microscale [12].

The urban texture is element configuration of surface characteristic that impacts air and surface temperature, solar irradiation on horizontal and vertical surfaces, wind speed and direction [13]. Urban texture related to construction material, form (smooth and roughly the surface) and color elements that affect the heat gains and albedo.

The change of microclimate in residential areas affect the intensity of Urban Heat Island (UHI) because most of the urban areas are the residential area. If microclimate of residential areas increase than the intensity of UHI will increase too. The increasing of UHI related with material used [14, 15], building configuration [14, 16], lack of vegetation and water bodies [17]. The increasing of UHI have a correlation with the increasing of urbanization, air pollution and anthropogenic heat sources [4].

3. The changes of land use and land cover (LULC)

Development of residential areas causes the changes in land use land cover. The change of land use in the form of open space, street and building, the change of land cover in the form of pavement, building, vegetation and water body. The changes in Land Use Land Cover (LULC) significantly alter the thermal environmental characteristics [18] with radius 50m–200m in the form hardscape and soft scape material [19].

The change of LULC affects thermal environmental quality due to the ability of the material to absorb and store the heat in the form of albedo [20, 5]. Asphalt roads and concrete with white aggregate, light-colored walls and the roof with low emissivity, vegetation and trees are the material with high albedo [21]. Material asphalt roads, concrete and material covered will absorb and store heat in the material [14, 15]. Asphalt roads and roof are the material with a large surface heat value in the daytime while the exterior wall material and the tree have a large surface heat value in the nighttime. Green areas have a low surface temperature in the daytime and high surface temperature in the nighttime while soil and building have a high surface temperature in the daytime and low surface temperature in the nighttime [22].

3.1. Open Space

Open space has some various material land cover with morphologic features and properties of the material forming which affect the thermal environment [8].

The used of reflective and constructive material affect the intensity of UHI because this material has a high heat capacity and conductivity so that can deliver the heat in the daytime and then absorb the heat in the material. Reflective material affect surface temperature and air temperature [23]. The land cover material of open space consists of pavement, vegetation, and water.

Open space uses pavement in the form of granite, concrete, and asphalt. The pavement of granite, concrete, and asphalt have a surface temperature which the value of the surface temperature asphalt higher than other pavement. Asphalt has surface temperature higher than the air temperature in the daytime [24].

Open space uses vegetation as material element in the form of trees, low vegetation, and grasses. The ability of trees as elements of microclimate controller depends on the shading performance of solar, longwave radiation and capability to produce latent heat [25, 26]. The ability of grass and low

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vegetation as elements of microclimate controller depends on the condition of groundwater because of the influence of the water surface more dominant than grass and low vegetation surface [8].

The land cover material in the form of water body has the ability to cool thermal environment. The location and the width of water body have a direct correlation with the intensity of Urban Cooling Island (UCI) and UCI efficiency [17], small water body has the intensity of UCI smaller than large water body in the same area. The water body can influence thermal environment quality in the form of river [27], pond [28], and paddy fields [29]. The ability of water body to cooling depends on the distance of water body [27] and the wind movement [28]. The influence of the water body can be reduced if the area near the water body used as a buffer zone, not wetland zone [30].

3.2. Street
The street is hardscape material which forms the street configuration and street canyon to wind movement in the area. Streets can be covered by asphalt, concrete and light-color material [14]. Street affects directly to the thermal environment with parameter ratio, orientation and the presence of trees as shading element [31]. Street with shading of vegetation and building have surface temperature lower than street without shading because the shading of vegetation and building can reduce the heat gain indirectly and decrease the surface temperature [32].

3.3. Building
The building is the element that has a volume (height and width) and the distance so that affect building density and building layout. Building density is influenced horizontal and vertical surface so building density has a linear correlation with albedo so effect directly to thermal environment quality [7] and UHI [33].

Building configuration in the form of building layout affect the movement of the wind flow [10] so building layout should consider wind and sun orientation. Wind orientation affects wind movement so the best configuration layout is the layout toward to the prevailing wind [26]. Sun orientation affect heat gain, the building with east-west orientation receive heat gain directly from the sunlight and the wall with north-south orientation receive heat gain indirectly from the surrounding [32].

The elements of a building that has an effect directly to the thermal environment quality are wall and roof. The capability of the wall and the roof to store and absorb the heat gain of sunlight depends on material and orientation of the building. The wall and roof can use reflective and constructive material as well as can use a cool element such the green wall, the green roof and cool roof.

The green wall (green envelope) using elements of vegetation on the building wall that function to reduce heat gain and cooling loads through shading, cooling transpiration and thermal insulation [34] with potential usage on the west side of the building [35]. The green roof is roof element which using the vegetation on the roof layer that function to reduce the heat gain to surrounding and heating effect to the building [36]. The cool roof is roof element which using high solar reflectance and high thermal remittance material that functions to absorb radiation of the sun so it can reduce the surface roof temperature [37].

4. Analysis
The residential area is a fast-growing area in the city so that the development of this area has a correlation significant with thermal environmental quality of the city. Thermal environmental quality in its relationship with the UHI depend on the surface material and its condition [28] so thermal environmental quality in residential areas in tropical cities depend on the surface and the characteristic tropical cities. The tropical cities have two seasons and receive directly the heat gain from sunlight all the day. This condition affects the solar radiation exposure on the surface area so this needs a planning of some element to control temperature The planning of topography and building geometry can be used to set sun angle so the surface area which is exposed to the heat from sunlight give small impact to day temperature [38].

Some researchers research surface and air temperature in tropical cities to find the elements that affect the thermal environmental quality of residential. The effect of the element in tropical cities is different with other cities because the sun and wind orientation influence thermal environmental quality significantly. Sun and wind orientation of tropical cities affect the capability of soil, building, vegetation and water body to absorb and store heat gain so that affects the air temperature and humidity of the tropical cities.

Table 1. The factor that affects residential thermal environmental quality in tropical cities

No	Researchers	Building	Wind	Factor								
				Pavement	Street	Building		Vegetation				
						Wall	Roof	Wall	Roof	Open Space	Park	Forest
1	Sharmin, Steemers, & Matzarakis, [39]	Vertical	v	v	v	v	v					
2	Ardalan et al [40]	Vertical						v	v	v		
3	Xue, Gou, Siu, & Lau [41]	Vertical				v			v		v	
4	Roth & Lim [42]	Vertical				v					v	
5	Didem, Stocker, Carruthers, & Hunt [43]	Vertical	v			v	v					
6	Ayanlade [44]	Horizontal										v
7	Li & Norford [45]	Vertical	v				v		v			
8	R, Pereira, & Karam [46]	Horizontal-Vertical										v
9	Sharmin et al [47]	Vertical	v		v	v	v			v		
10	Rajagopalan, Lim, & Jamei [48]	Vertical	v			v				v		
11	Wong & Yu [49]	Vertical								v	v	v

v=affect

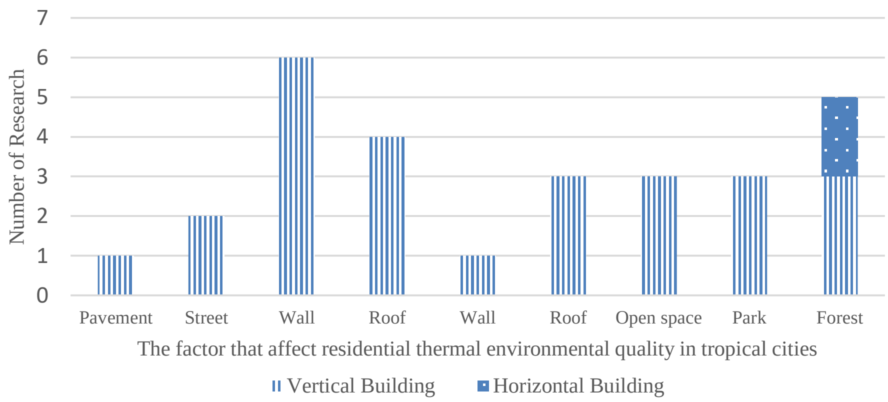

Figure 1. The number of residential thermal environmental quality research in tropical cities

4.1. Pavement and Street

Pavement and street are hardscape material that can absorb and store heat gain in the material. Pavement can use concrete, brick, granite, asphalt and etc while street can use asphalt, soil, and etc.

Pavement and street are influenced by texture and color of material. The dark color material has lower surface temperatures than light color material [8]. The texture and color of coating pavement material can cause the pavement be cool material that called by the cool pavement [50].

The use of concrete as material pavement and asphalt as street material can affect residential thermal environmental quality in tropical cities [39].

4.2. Building

Thermal environmental quality is influenced by building form and building distance with parameter H/W Ratio (building height/street width) and SVF (Sky View Factor) [39]. Building form and building distance set the building so that formed the character of building.

The character of building consists of horizontal and vertical building that influence residential thermal environmental quality in tropical cities. The most influential on the horizontal building is the roof while the most influential on the vertical building is wall and roof.

The influence of the building is determined by building surface material. The material of building will store and absorb heat gain in the vertical and horizontal surface in the form wall and roof. The use of material on the wall [48, 47, 41, 39, 43, 42] and roof building [47, 45, 39] can affect residential thermal environmental quality in tropical cities. The use of construction material (concrete and brick) can absorb and store heat gain in the daytime so that this material affects air temperature in the daytime and nighttime. The use of cool material and green material can absorb and reduce the heat gain so that the air temperature in the daytime can be controlled.

4.3. Vegetation

Vegetation can be used as wall material, roof material and land cover material. The use of vegetation as material on wall of building [40], roof of building [45, 40, 41], material in open space [49, 48, 47, 46, 40], park [49, 41, 42] and forest [49, 44, 45] can affect residential thermal environmental quality in tropical cities.

Vegetation is an active element that can absorb and reflect the solar radiation in large number. Vegetation has radiative temperature lower than other objects with same color. Reduction of vegetation can increase thermal environmental quality and affect the intensity of UHI [44].

4.4. Water Body

Water body as cooling element can affect thermal environmental quality. Temperature and humidity of the area will be declining if the area away from the water body [51] so water body affects microscale environment as evaporative cooling [28]. The scattered water affects thermal environmental quality better than the centralized water body [52] with water body orientation to prevailing wind [53].

Water body has a major impact on the thermal environmental quality in tropical cities because water body can reduce air temperature in the daytime and raise air temperature in the nighttime. The researcher rarely do research in this field whereas the influence of the water body in residential area in the tropical cities different from other areas and have specific characteristics.

5. Discussion

The development of residential area depends on housing need and the availability of the land. In the developing country, the development of residential area in the center of the city are dominated vertical-horizontal growth and the development of residential area in the edge of the city is dominated horizontal growth [32]. The growth of residential causes the changing land cover especially the change of open space become building area in the form of horizontal and vertical building. The change of land cover affects wind movement and surface area that exposed solar radiation. The horizontal building has the horizontal surface more dominant than the vertical surface so the absorption of solar irradiation is dominated by the horizontal surface. This condition cause thermal environmental quality in the residential area is influenced by the form and size of the building.

The growth of residential in the center of the city causes all areas used as a built-up area with the development of the area is dominated by pavement and building [39] so that reduce the space to vegetation and water body.

The development of horizontal residential in the center of the city is dominated by pavement and horizontal building so that this area becomes horizontal dense area [32]. The building was built near each other with small space for vegetation and water body. This condition causes this area be a dense area so that affects the wind movement in the area. Thermal environmental quality is influenced by small wind movement, pavement and building material (especially material roof).

The development of vertical residential in the center of the city is dominated by pavement, street, vertical building, vegetation and water body. The building was built vertically so that the area still has an empty land as the area of vegetation and water body. The distance between the vertical building causes wind movement can occur in the area although influenced by the height of the building. The vertical building causes the wall of building be the important elements that affect the thermal environmental quality because the wall of building affects the wind movement and have large surface if compared with other materials.

The development of horizontal residential on the edge of the city is dominated by pavement, street, horizontal building, vegetation and water body. The building can be built with a certain distance and the area can have space for vegetation and water body so that this area becomes horizontal rare area [32]. The distance between the building causes significant wind movement has occurred in the area. Thermal environmental quality is influenced by wind movement and material of pavement, street, building, vegetation and water body.

Thermal environmental quality is influenced by the ability of element material as the heating and cooling element. In the tropical cities, sunlight shine surface area every day throughout the year so that the element of this material will always affect the thermal environmental quality. Thermal environmental quality can be controlled by balancing the use of heating and cooling element so that the change of LULC does not affect the thermal environmental quality significantly. Horizontal residential in the center of the city can use light-colored pavement, roof material with low emissivity and green roof. Vertical residential in the center of the city can use light-colored pavement, wall and roof material with low emissivity, green wall (green envelope) and green roof. Horizontal residential in the edge of the city can use light-colored pavement with low emissivity, open space with vegetation, park with vegetation and water body as cooling element.

Table 2. The factor that affects thermal environmental quality in the city

Location	Form of Building	Wind Movement	Factor								
			Pavement	Street	Building		Vegetation				Water Body
					Wall	Roof	Wall	Roof	Open Space	Park, etc	Pond, etc
In the center of the city	Horizontal	-	-	v	-	v	-	v	-	-	-
	Vertical	v	v	v	v	v	v	v	v	v	v
In the edge of the city	Horizontal	v	v	v	-	v	v	v	v	v	v

v = affect

In the tropical cities that have wetland area, the change of LULC should not change the characteristics of the area especially in the center of the city. Development of residential areas is not done with landfill because it will interfere ecology and increase surface and air temperature. Wetland area has the potential cooling element that can help to control the thermal environmental quality. The residential areas in the wetland have water body as cooling element to decrease the mean minimum temperature. The residential areas with the cooling element are the best condition because the cooling element can control the minimum cooling degree and maximum heating degrees [54].

The residential areas in wetland have UHI and UCI element that can affect the air temperature. This element can be used to balance the daytime and nighttime temperature. The temperature balance is done by using the heating from the elements that produce heat gains and the cooling from the elements that affect the humidity. The heating from the elements that produce heat gains is stored and then used to raise the nighttime air temperature while cooling element is used to provide the humidity of the daytime temperature. The existence of UCI element in the wetland in the tropical cities has direct effect significantly, the sun shines longer than another characteristic city so that affect evapotranspiration process. The evapotranspiration process from UCI element and the characteristic wind in the tropical cities (speed and direction wind) can provide maximum humidity for the surrounding.

6. Conclusions

The growth of the residential area in tropical cities consists of horizontal and vertical building in the center of city and in the edge of the city. The growth of the residential gives significant influence to urban heat island intensity that consists of several factors such as urban geometry, construction materials and urban texture. Development of residential areas in tropical cities affects thermal environmental and microclimate directly because of the changes LULC affect heating and cooling process during daytime and nighttime. The material element that affects thermal environmental quality is pavement, street, building, vegetation and water body.

The research of wetland residential in tropical cities still rarely so that this research can be done with the aim of the research to find out the influence of the water body against thermal environmental quality. Research can be emphasized on the horizontal research building in the center of the city. The existence of the wetland element in residential area in tropical cities can be used as UCI element. UCI element provides a possibility of balancing the day and night air temperature in a different way with air temperature in the dry land. The water body can influence humidity and store heat gain so that gives the cooling effect during the daytime and heating effect air temperature in the night time.

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