

# Typology Study of Urban Canyon in Residential Area and The Quality of Its Thermal Environment

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**Abstract.** The current physical development in urban area turns the cityscape into vertical growth with building that separated by narrow streets. Consequently, canyon formed in urban residential impact on thermal quality. Surfaces in canyon receive shortwave radiation and increase the Urban Heat Island (UHI) intensity. This paper discusses the quality of thermal quality in various urban canyons form which are influenced by several factors such as density, materials, topography, building arrangement and vegetations. The aims to categorize a number of residential canyon causes and its qualities of thermal environment. The initial result shows that building materials, canyon geometry and orientation gives significant role to their thermal environment.

## 1. Introduction

The availability of limited land makes the urban vertically and dense designed. The phenomenon of vertical residential design forms a building cliff called urban canyon phenomenon. Buildings that are made vertically also lead to heating due to solar radiation absorbed by urban surfaces such as roofs, walls of buildings and roads. However, the radiation cannot be released directly into the atmosphere due to urban structure density. Aksoy & Ekici [1] stated that vertical surfaces are increasingly important in terms of solar absorption due to increasing of vertical urbanization in recent years.

According to Nunez and Oke [2] 30% of solar thermal energy is absorbed and stored by canyon material and released at night with the result increasing the ambient temperature. The increasing of the air temperature in the urban at night and the temperature difference between urban and peri urban



is an indication of heat island phenomenon. The difference in atmospheric stability between the urban and its surroundings is due to the greater heat capacity of the urban canyon structure (Kusuka and Kimura [3], Santamouris et.al [4] also found a high intensity of the heat island with an increase in air temperature of 13°C around the canyon at night due to anthropogenic heat and the use of heat-absorbing material.

Air circulation and air temperature distribution within urban canyon have significance for air quality inside buildings as well as outside environment. Buildings that are in canyons of low thermal quality use more energy for air conditioning and even more electricity for lighting [5]. High urban temperatures increase also decrease comfort in open spaces and reduce the potential for cooling by natural convection at night [6]. Akbari et al. [7] found that for every 1 °C rise in air temperature, 2 to 4% of electric energy is required for cooling as an effect of heat island. Based on these findings means that urban canyon has a bearing in the formation of heat islands and as an index to evaluate the quality of thermal environments.

Urban canyon plays an important role in the difference of air temperature between urban and peri urban. This is related to the amount of radiation absorbed by the surface of the canyon. The aspect ratio between the height and width of the canyon is the dominant factor in solar radiation on road and wall surfaces. In the field of shadowed buildings, the heat entering into space only occurs through the conduction process itself due to the difference in outside temperature and inside temperature. However, in the field of buildings exposed to sunlight (not exposed to the shadow), then the heat that enters into space can be through the process of radiation resulting from back radiation of the heat of the walls exposed to sunlight [8] Building orientation and ratio aspect between height of building and road width on canyon impact on urban air distribution have been proven by C. Georgakis and M. Santamouris [9], Takabayasi [10] Niachou et.al,[11]. Canyon geometry and surface orientation that absorb radiation also greatly affect the duration of time and the amount of energy stored and released by the surface of the walls and base of the canyon [2]. Niachou et.al. [11] suggested that the distribution of air temperature inside the canyon is in addition influenced by geometry and canyon orientation also influenced by the optical properties and thermal properties of building materials as well as micro climatic conditions.



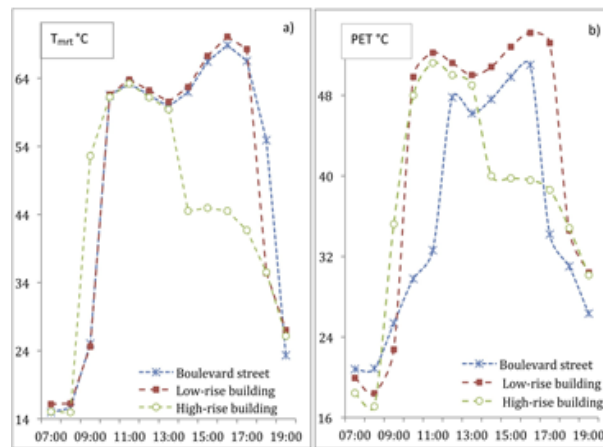
**Figure 1.** Urban canyon phenomenon [12]

## **2. Urban Heat Island In Residential**

Heat island defined as a higher urban air temperatures condition in urban centers compared to rural or suburban areas. Heat islands are formed in urban and suburban areas because many construction materials absorb and retain more solar thermal than natural materials. There are two main reasons for this warming. First, most urban building materials are watertight, so moisture is not available to remove the solar thermal. Second, dark material on concrete buildings with canyon configurations and pavement collecting and trapping more solar energy [13].

Changes in land use which settlements into trading has changed the physical condition of the spatial region. Building originally in the form of single level buildings transformed into a densely populated area with a vertical- narrow building. Wonorahardjo [14] analyzed the physical character of ten districts in Bandung Air temperature in old and well planned residential district is relatively higher than others (29.06°C). The trade center and settlement district had higher density of buildings than the other districts. Density aspect of the district could be explained as function of buiding material (wall, roof, street), in which case this aspect act an entrapment effect of hot air surrounding buildings. A dense district like residential district tend to trap the air inside the canyon and increase the air temperature compared with the rare district.

In Putrajaya, Malaysia, the UHI occurred in high-rise buildings are lower than low-rise buildings. The high-rise buildings are thermally comfortable, while low-rise buildings suffer from a heat stress. However, the low-rise building experienced the highest mean radiant temperature which exceeded 70 °C and it received the longest period of Tmrt around 10 h. The high-rise residential received a shorter period of Tmrt with the maximum value reaching 63 °C in high-rise building.

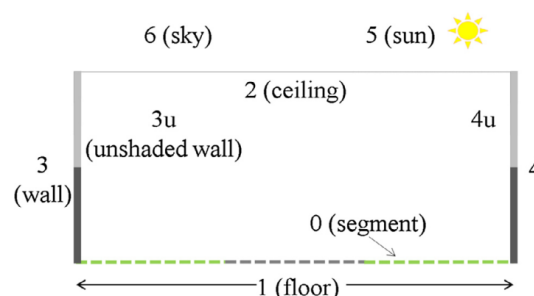


**Figure 2** (a) Mean radiant temperature ( $T_{mrt}$  °C), (b) physiologically equivalent temperature (PET °C) [15].

Yang et al. [16] studied the UHI in three areas of high-rise residential buildings, the study found that the density, layout and greenery have impacts on UHI patterns. Site shading factor is closely related to day-time UHI. Variations in density and plot layout have different impacts on-site shading condition. The lowest in day-time UHI achieved with high building density, while long-near layout with low density is the highest. In practice TSF can be used for thermal environment assessment at design stage.

### 3. Typology Of Urban Canyon

The urban canyon's characteristics are places (usually roads) flanked by two buildings on both sides [2]. Air circulation and air temperature distribution within urban canyon have significance for air quality inside buildings as well as outside environment.



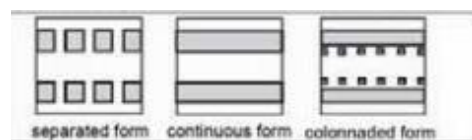
**Figure 3.** Elements of urban Canyon (surface 0-4) and light source (surface 5 and 6). [17]

Buildings located in canyons without high climate quality use more electricity for air conditioning and for lighting [5]. Akbari et al. [7] found that for every 1 °C rise in air temperature, 2 to 4% of electric energy is required for cooling as a result of heat islands. Based on these findings means urban canyon has a bearing in the formation of heat islands and as an index to evaluate the thermal

environments quality. An understanding of the specific thermal characteristics is essential for understanding airflow within the canyon and for the study of natural ventilation and hybrid in urban environments [11]. This is related to the amount of energy absorbed by the urban surface. Santamouris et al [4] revealed that there is a temperature difference on the opposite wall of the building. This occurs because of the impact of the convection phenomenon of adjacent wall surfaces.

A number of studies in urban canyon have been conducted to improve thermal quality. Niachou et.al, [11] stated that the distribution of air temperature within the canyon of is a geometry function and canyon orientation, thermal properties of buildings and road materials and weather conditions.

There are three typical canyon patterns that presented by Shashua-Bar [18]: continuous, separated form and colonnaded form (figure.4).



**Figure 4.** Three archetype streets forms [18]

### 3.1. Geometry of Canyon

Pearlmutter et al. [19] noted the importance of street orientation and aspect ratio in thermal quality control in the canyon. The distribution of air temperature within the canyon is influenced by geometry, canyon orientation, optical and thermal properties of buildings and materials.

Urban geometry and thermal properties of urban surface are found as two main parameters affecting the urban climate [20]. The height of the building ( $H$ ) and the width between both of them ( $W$ ) affects the number of both. Radiation in and out and also affects wind speed. Nocturnal heat island has been proved increasing with the ratio  $H = W$  because the outgoing wave radiation is reduced due to decreased sky view factor (SVF) [21].

Another proof is stated by Emmanuel [20] that deep canyons with higher aspect ratios (building height: road width,  $H / W$ ), can provide more shade at street level during the day.

It can be concluded that the comparison between the height of the building ( $H$ ) and the width of the street ( $W$ ) will form a space in canyon and give shadow protection in the street canyon. Shadow protection decrease temperature, thereby providing thermal comfort to its users.

### 3.2. Canyon Orientation

Chatzidimitriou [23] used a simulation model to analyze the aspect ratio and canyon orientation. The results show that the most comfortable conditions in summer occur in north-south oriented to medium or high aspect ratio nuances while the East-West oriented requires repairs such as additional shade on the open north side. Street oriented in a north-south direction, shade can be provided by the

buildings with high H/W in both the morning and the afternoon. However, around noon, shade cannot be provided by the buildings alone.

### 3.3. Material

*3.3.1. Potential of urban surface in the improvement of thermal quality.* The balance of urban thermal is defined by the materials optical characteristics that make up the urban envelope. The building envelope is responsible for the most significant load of external environmental quality. Materials in urban areas absorb solar and infrared radiation, and heat accumulation is transferred to buildings or released into the atmosphere.

The materials used in building envelopes and urban structures play a very important role in urban thermal balance. They absorb solar and infrared radiation and throw some of the heat accumulated through convective and radiation processes into the atmosphere that increases the ambient temperature. Thus, the technical characteristics of the materials used determine the level of energy consumption and the comfort conditions of individual buildings or even open spaces.

The thermal capacity of the canyon surface material also contributes to nocturnal heat islands because most of the incoming heat during the day is stored in such materials and is not released until the evening [21]. Many research have been done to have better understanding of the optical characteristics and thermal material as well as its impact on the urban climate and systematic environment temperatures over different types of materials have been reported [24].

Therefore, improving optical properties (albedo and emissivity) of urban surfaces can reduce the consumption of cooling energy, due to the decrease of air and surface temperatures [25]. Highly reflective or cold materials are a cost-effective technique, environmental friendly and passive that contributes to achieve energy efficiency in buildings by lowering energy requirements for cooling and increasing the microclimate in the air by lowering surface and air temperatures. Cold material is characterized by:

#### a. Solar reflance (SR)

Solar reflance is capability of a surface material to reflect solar radiation and indicate total surface fluctuations, remember the reflection of hemispherical radiation, which is integrated through the solar spectrum, including specular reflections and difeksi. It is measured on a scale of 0 to 1 (or 0-100%) [24]. The balance of the thermal material is determined primarily by their reflections to solar radiation and their emissivity against long-wave radiation during the day. Therefore the dark surface is warmer than the light-colored ones. The use of 'cold' material contributes to the reduction of air temperature due to heat transfer phenomenon. However the use of warm than cold materials is used for urban environmental structures. This use is due to economic and aesthetic reasons, or by poor

environmental planning. As a result, temperatures in urban environments are increasing and demand for cooling loads in buildings is growing [26].

b. Infrared Emissivity (IRE)

Infrared emissivity is a measure of surface ability to release, absorb heat. This determines how well the surface radiates energy from itself compared to the black body operating at the same temperature. Infrared input is measured on a scale from 0 to 1 [22]. The value for emissivity ( $\epsilon$ ) can be between 0 (perfect reflector mirror) and 1 (perfectly emitter black body). Consequently, emissivity plays an important role in constructing thermo graphic surveys and relies on temperature, wavelength and surface conditions. Surfaces with low emissivity values (eg aluminum, steel, etc.) serve as a mirror (high reflection).

*3.3.2. Material Properties on the building surface.* Solar radiation exposed by urban surfaces such as building facades, sidewalks, roofs and roads is not flattened back into the atmosphere due to urban structures density. It is also known that vertical surfaces are increasingly important in terms of solar absorption due to increased vertical urbanization in recent years [1]. The parameters of each building material are solar reflectance, Emissivity, thermal conductivity, heat capacity [10]

According to Rosenlund in Noerwasito and Santosa [27], the material resistance against heat that affects buildings, called thermal properties are: Density: has a unit of  $\text{kg} / \text{m}^3$ , is the ratio between weight and volume, density holds a large role for thermal properties, the material has a mild density that has greater insulation power than large density materials. Conductivity: has a unit of  $\text{W} / \text{mK}$ , is the ability of the material to conduct heat conduction. Materials which have low conductivity have good insulator power; otherwise the material having high conductivity is a good conducting material. Specific heat: has a unit  $\text{Wh} / \text{kgK}$ , is indicating the material that has the ability to store some energy. High specificity heat means the material has the ability to store lots of heat (heat storage).

The combination of these three thermal properties materials results in what is called Time lag, the maximum time the wall uses to remove heat from the outside surface of the wall to the inside of the wall. The material also has thermal capacity; the amount of heat stored by the material, then releasing it.

The dynamic thermal performance of the building envelope depends on three basic properties; Heat capacity, density, and thermal conductivity. High heat capacity and density maximizes the amount of heat absorbed in every m of the material and the thermal conductivity required for the material to make useful heat capacity. A sufficient thermal conductivity allows the material to exchange heat with an air environment at an appropriate level. The thermal diffusivity of the material is a measure of how quickly the temperature of the material adjusts to the ambient temperature. The lower the diffusivity is, the greater time-lag material will be [28].



Thermal conductivity and specific heat capacity are important properties of building materials. These values are required, for example in thermal performance calculations. However, the resulting values for material properties are usually not accurate enough. The fact that certain products such as plaster, may have very diverse material properties. Since many of the material properties are listed commonly to the whole ingredient group, the value is determined from the actual product required to achieve a high degree of accuracy in the calculation for a particular case.

#### 4. Discussion

In line with Niachou et.al [11] research, which stated that the distribution of air temperature within the urban canyon is a function of geometry and orientation, as well as the optical properties of buildings and road materials and weather conditions. This is in line with other studies conducted such as research in the desert town of El Oued Algeria, Bourbia and Awbi [30] reported that the maximum temperature tends to decrease as the H / W ratio increase. While in the hot, humid Dhaka environment of Bangladesh, Ahmed [31] found that the average daily maximum temperature decreased, by 4.5 K when the H / W ratio increased from 0.3 to 2.8. The results show a clear relationship between urban geometry and microclimate on the road level.

The surface temperature of the material also affects the air temperature. Correspondingly, Radhi et.al [32] the material temperature on the surface and air temperature depends on the color, thermophysical properties and radiation properties of the material. Doulos et al. [26] observed that materials which surface is darker are warmer than bright ones. The use of 'cold' material decrease air temperature due to heat transfer phenomenon. However the use of warm materials rather than cold materials is more widely used for urban environmental structures. This use is due to economic, aesthetic, or poor environmental planning reasons. As a result, the temperature in urban environments increases and is an indication of the low thermal quality.

The balance of material thermal determines the material's reflection ability and its emissivity against long-wave radiation during the day. The albedo effect of the building surface has the highest effect that is on the maximum at the day temperature while the emissivity has the highest effect at the minimum night time temperature. High use of albedo on the surface material of the canyon can lower air temperature, reduce energy use, achieve thermal comfort and decrease the intensity of heat islands

In surface temperature at the soil surface. The parameters of each building material are Solar Reflectance, Emissivity, Thermal Conductivity, Heat Capacity [10] The temperature of the canyon surface material is governed by the thermal balance [11].

#### 5. Conclusion

Various studies have dealt with thermal environment in urban canyon. In urban areas where land is limited, the cityscape grows vertically. Consequently, it is formed the urban canyon that impact on



thermal quality. The results of research on thermal quality in canyon are influenced by canyon geometry and materials. All of these conclusions are closely related to the geometry of the canyon and the angle of the sun. The aspect ratio between the height and width of the canyon is the dominant factor in solar radiation on road and wall surfaces. The key property of the urban canyon road is expressed by its  $W / H$  aspect ratio. In addition, it is also influenced by the orientation of the building, which is related to the direction of solar radiation.

The material thermal balance is determined the material's reflection ability and its emissivity against long-wave radiation during the day. The albedo effect of the building surface has the highest effect that is on the maximum temperature during the day while the emissivity has the highest effect at the minimum night time temperature. Surfaces in canyon that receive radiation can increase the Urban Heat Island (UHI) intensity. The parameters that describe the canyon are geometric dimensions (wall height, road width, and roof width), solar reflectance surface (albedo), infrared emissivity, and thermal surface properties (heat capacity).

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