Sulfur-extended asphalt concrete with assessing the surface temperature of roads affecting urban heat island

Minh tuan Le, Huu Tuan Le, Ilkhomzhon Shukurov and Mikhail Slesarev
Moscow State university of Civil Engineering, Yaroslavskoye Shosse, 26, Moscow, 129337, Russia
E-mail: Architect290587@gmail.com

Abstract. The Urban Heat Island (UHI) is a phenomenon that affects many millions of people worldwide. The higher temperatures experienced in urban areas compared to the surrounding countryside has enormous consequences for the health and wellbeing of people living in cities. The paper studies the temperature dependence of the surface of the asphalt concrete on the air temperature of Hanoi city with a view to determine the road surface temperature compared to the comfort threshold of Vietnamese people. Research data on microclimate of Hanoi city was taken from hydro-meteorological station in the period 2010yr – 2015yr. The paper selects two most famous methods of calculating the surface temperature of asphalt concrete: The Method of Kovalev Y.N (Russia) and the method of "Superpave" method (USA). This review article outlines the contribution that pavements make to the urban heat island (UHI) effect and analyses localized and citywide mitigation strategies against the UHI. Asphalt concrete is one of the most common pavements surfacing materials and is a significant contributor to the UHI effect. Dense asphalt concrete has low albedo and high volumetric heat capacity, which results in surface temperatures reaching upwards to 60°C on hot summer days. Application of sulfur-extended asphalt concrete with advanced properties instead of asphalt concrete reduces the urban heat island effect and increase the quality and life of roads in Hanoi (Vietnam).

1. Introduction
Urban heat island (UHI) is affected by surface temperature, albedo and physical factors of asphalt concrete. The UHI effect was determined and analyzed in previous studies [1, 2, 3]. Methods of mitigation of this phenomenon, are being hotly discussed. The mechanism for improving the technical condition of roads is an urgent problem for many cities in Vietnam, a careful study of which will help to achieve economic efficiency by increasing the service life of coating materials. Many factors affect the strength and service time of road structures, including weather and climate. It is known, that asphalt is a material [4], so one of the climatic factors that significantly affect the movement of vehicles, as well as the intensity and characteristics of deformation of the asphalt concrete material in the construction of the road surface is the temperature. The deformed state and service life of asphalt concrete coatings depend on the temperature.

Most research in this area focuses on the study of albedo, density and permeability of the coating, moisture retention in the upper layer, as it has been shown that these properties have a strong impact on surface temperature of the road [5, 6]. However, changes in the structure and physical properties of the road will also impact strategies to mitigate the UHI effect.

Pavement are divided into flexible and rigid. Rigid and flexible coatings consist of several layers. Flexible pavements have a worn surface, usually asphalt, covering the top of the base and the
underlying surface. Together, these three layers and sublayers form the pavement structure that is located on the base. Hard pavement usually has a thick concrete layer. When forming a hard pavement, concrete can be left as a worn surface or covered with a thin layer of asphalt. Flexible coatings are designed to be deformed under load, since horizontal tensile and compressive deformations are formed in the coating layers. Rigid sidewalks have high bending strength and distribute the load over a wider area of the pavements. Therefore, hard coatings do not transmit deformation across the layers.

Many studies show that the pavements have a significant impact on the effect of urban heat island [5]. This is due to the large areas in cities which are covered by pavements, and relatively low albedo of the dark surface of the sidewalk [6]. Pavements constitute about 40% of the area of cities. In various studies, mesoscale images from thermal and infrared satellites have shown that the pavement is a powerful source of thermal radiation [7].

Asphalt concrete absorbs approximately 95% of sunlight (5% albedo). In solar radiation, there is usually 43% of solar energy, 52% of near-infrared light and 5% of ultraviolet light [8], and a large percentage of this is absorbed and consumed by the asphalt surface. Therefore, to improve the heat in cities, consideration should be given to the implementation of appropriate methods and materials.

Asphalt concrete is composed of coarse and fine aggregate, mineral fillers and bituminous binders. Asphalt concrete is usually made of aggregates evenly distributed between coarse, fine and compact in such a way that the asphalt surface is almost impermeable.

Studies have shown that conventional asphalt concrete coatings in summer climates have temperatures above 60 °C [5, 9]. It takes place because of the relatively low albedo of asphalt concrete comparing with other road surface materials, as well as because of its high thermal absorption and conductivity. Thermal properties of road surfaces are divided into two categories: transfer of energy qualities and thermodynamic characteristics [10]. Impervious to the Transmission of the properties energy related to conductivity and radiation - characteristics determines the movement of energy between the road surface and its environment. On the other hand, the characteristics thermodynamics related to energy balance in the asphalt and the volume heat capacity and heat conductivity [10].

The change of the thermal conductivity of the road surface impact temperature minimum and maximum. Reduced thermal conductivity of the road surface will reduce the rate of heat transfer into the earth and receive heat from the soil.

2. Materials and methods

2.1. Materials

2.1.1. Microclimate data from meteorological station “Ha Dong” for the research

Hanoi city (21,0278 °N, 105,8342 °E) is one of the largest cities in Vietnam, located on a complex territory that descends from North to South and from West to East, of which the delta accounts for 75% of the city. In the natural area, the average height of Hanoi is 5 – 20 meters above sea level, so the climatic conditions are characterized by hot, humid summers and cold winters. The hot season lasts from April to October, the prevailing direction of the wind is South-East. The average temperature is around 24 – 29°C. The hot season is also accompanied by tropical rainfalls from July to September. The average annual precipitation is 1605.2 mm. The cold season starts in November and continues till March, the prevailing wind direction is North-East, cold and dry weather is observed. The average temperature in this season is about 15 – 22 °C. The average annual humidity is 83%. Storms usually occur in July and September of each year, with strong winds from level 8 to 10, and sometimes up to level 12.

The assessment was conducted in June 2010, which was the hottest month on record of the air temperature at “Ha Dong” station for the period 2010 – 2015. The peak condition was chosen in order to assess the most significant possible effects of using energy to cool residential buildings in a high-intensity urban heat island (table 1).
Table 1. Average maximum monthly air temperature (°C) for the period 2010 – 2015

| Year | January | February | March | April | May | June | July | August | September | October | November | December |
|------|---------|----------|-------|-------|-----|------|------|--------|-----------|---------|-----------|----------|
| 2010 | 18.43   | 20.49    | 21.82 | 23.91 | 29.58 | 31.47 | 31.50 | 28.94  | 29.14     | 25.93   | 22.50     | 19.86    |
| 2011 | 12.99   | 18.28    | 17.46 | 24.44 | 27.76 | 30.00 | 30.78 | 29.69  | 27.00     | 24.86   | 24.21     | 17.86    |
| 2012 | 14.83   | 16.44    | 20.59 | 26.85 | 29.66 | 30.87 | 30.20 | 29.68  | 29.79     | 27.22   | 23.73     | 18.76    |
| 2013 | 15.57   | 20.35    | 24.54 | 25.50 | 29.48 | 30.58 | 29.30 | 29.34  | 27.06     | 25.90   | 23.03     | 19.15    |
| 2014 | 17.99   | 17.42    | 20.05 | 27.77 | 30.00 | 30.51 | 30.17 | 29.22  | 29.41     | 27.20   | 23.07     | 17.64    |
| 2015 | 18.18   | 19.02    | 21.68 | 25.72 | 31.19 | 31.31 | 30.78 | 30.18  | 28.50     | 28.15   | 24.49     | 19.49    |
| Average | 16.33 | 18.67 | 21.02 | 25.70 | 29.61 | 30.79 | 30.45 | 29.51  | 28.63     | 26.54   | 23.30     | 18.79    |

Highest temperature: 31.50°C in July 2010.

Lowest temperature: 12.99°C in January 2011.

An important technical and economic task of asphalt concrete coatings in Vietnam is to ensure their high transport and operational performance, extending its service life, since the quality of asphalt concrete coatings has a significant impact on the traffic capacity and on the reliability of the road network.

As a result of the usage of asphalt concrete, various deformations occur on the surface of the coatings. Wear and tear of roads is formed by external and internal influences on the asphalt pavement. Internal factors associated with the destruction of asphalt pavement arise due to incorrect design for roads, their improper construction and repair. Defects on the coating caused by the influence of external factors include:

- power load from the road wheels;
- precipitation (rain, temperature changes, thawing, snow, freezing).

Defects on the road surface are most often formed as a result of weather conditions, when during the rains moisture penetrates into the asphalt roadbed, and the hot sun rays destroy the top layer of the road. The deterioration of the asphalt concrete strength is carried out, which leads to the formation of potholes. During sub-zero temperatures, the collected moisture in the layers of asphalt concrete can increase in volume and thus destroy the structure and compaction of asphalt.

The capital of Hanoi, Vietnam, is located on the Indochina Peninsula, which is located in the area of the tropical climate belt. The climate of Hanoi is characterized by [11]:

- average minimum air temperature - from 12 to 15 °C;
- absolute minimum air temperature -5°C;
- the average maximum air temperature from 32 °to 35 ° C;
- absolute maximum air temperature -41.6 °C;
- average relative humidity-from 81 to 87 %;
- annual precipitation - from 18 to 1700 mm.

In accordance with TCVN (Vietnamese: TCVN) – State Standard, Vietnamese National Standard – 4088:1985 characteristic features of the climate of Vietnam also are as follows:

- rain intensity - 5 mm / min;
- temperature of water (natural water bodies) from 1 to 40 °C;
- the content of sulfur dioxide in the atmosphere (corrosive agent) in the open air - up to 0.025 mg/m³;
- the content of chlorides (corrosive agent) in the atmosphere in the open air - from 30 to 300 mg/m²*day;
- ozone concentration-40 mg/m3;
- integrated surface energy flux density of solar radiation-1125 W / m² (0.027cal/m²*s), including the flux density of the ultraviolet part of the spectrum (wavelength 280-400 nm) - 68 W/m² (0.0016 cal/cm²*s).
2.2. Methods

2.2.1. The method of calculating outdoor thermal comfort

The thermal of the road surface is one of the factors negative impact to outdoor thermal comfort in particular and the urban heat island effect in general. For a long time working in the field of thermal physical construction, Vietnamese specialists have tried to find the optimal method to assess the effect of microclimate on the thermal sensation for Vietnamese people. The method of assessing outdoor thermal comfort fully reflects the point of view that the conditions for establishing thermal equilibrium between a person and the environment are determined by the thermal sensation of a person.

\[ P = \frac{Q_{ch}^u}{Q_{ch}^{\text{max}}} \]  

The ratio of the required amount of heat spent by the body on the evaporation of moisture per hour to establish thermal equilibrium to the ability of the environment to take the maximum amount of human heat through perspiration. The more \( Q_{ch}^u \) compared with \( Q_{ch}^{\text{max}} \), the less will be the intensity of sweating when a person feels the greatest thermal comfort. Therefore, the task was to create optimal conditions in hot conditions so that \( Q_{ch}^u \) is minimal, and vice versa, \( Q_{ch}^{\text{max}} \) is maximum.

\( Q_{ch}^u \): The total energy production mainly depends on the nature of the work performed by a person.

\[ Q_{ch}^u = 29.1 V_n^{0.8} (42 - e_v) \]  

\( e_v \): air speed (m/s).

\( e_v \): evaporation pressure of the maximum amount of moisture in the air (mmHg).

2.2.2. The methods of calculating the road surface temperature

Asphalt concrete dramatically changes its properties depending on the temperature. At positive temperatures, asphalt concrete has the properties of a viscous plastic material, while at negative temperatures it has the properties of an elastic one. With increasing temperature, the strength of asphalt concrete decreases. Thermoplastic features of the material also explain the nature of deformations on coatings in Hanoi: in the summer in Hanoi city, the temperature of the asphalt concrete coating rises to 50 – 60 °C, the bitumen softens and reduces the strength of the asphalt concrete to 0.8 – 1.0 MPa. It is important to note that the ability of asphalt concrete to resist low-temperature cracking or variable freezing-thawing in a tropical climate is not a criterion for the quality of the material, as in Hanoi city the air temperature rarely falls below 5 °C [11].

When the temperature changes, the structural and rheological characteristics of the bituminous binder in asphalt concrete also change. It should be taken into account that the surface temperature of the asphalt concrete coating may differ from the ambient temperature in the winter up to 30 %, and in the summer up to 50 %. For example, in a tropical climate, the surface temperature of asphalt pavement in Hanoi can reach 65 °C.

There are many methods for calculating the surface temperature of asphalt concrete. Compare the 2 most famous: the method of Y. N. Kovalev (Russia) [24], the method of "Superpave" (USA) [25].

According to Kovalev Y. N. the minimum temperature of the asphalt concrete coating is determined by the formula:

\[ T_p^{\text{min}} = 0.7 T_{\text{min}} \]  

Where: \( T_p^{\text{min}} \) - calculated minimum surface temperature of asphalt concrete coating, °C;

\( T_{\text{min}} \) - the minimum outdoor temperature, °C.

Maximum temperature:

\[ T_C = T_{\text{air}} + T_{eq} \]  

Where: \( T_C \) - calculated maximum surface temperature of asphalt concrete coating, °C;

\( T_{\text{air}} \) - air temperature, °C;

\( T_{eq} \) - equivalent temperature, °C;

\[ T_{eq} = \left(1 - A\right) \frac{l}{a_n} \]
A - surface albedo, characterized by its reflectivity, for asphalt concrete: 10%
I - solar radiation intensity, for Hanoi climate: 16.75 W/m²
αᵣ - conductivity coefficient, for asphalt concrete: 1.05 W/(m²·°C)

«Superpave» method:

\[ T_{E}^{\text{min}} = 0.859 T_{\text{min}} + 1.7 \]  \hspace{1cm} (5)

Where:
\( T_{E}^{\text{min}} \) - calculated minimum surface temperature of asphalt concrete coating, °C;
\( T_{\text{min}} \) - the minimum air temperature on average in the year set according to meteorological data, °C.

\[ T_{2}^{\text{max}} = 0.9545 (T_{C7} - 0.00618W^2 + 0.2289W + 42.2) - 17.18 \]  \hspace{1cm} (6)

Where:
\( T_{2}^{\text{max}} \) - maximum calculated coating temperature at a depth of 2 cm, °C;
\( T_{C7} \) - average weekly maximum air temperature, °C;
\( W \) - object latitude in degrees, for Hanoi: 21.0278°N.

3. Research results

3.1. Outdoor comfort thermal on Hanoi streets

The comfort zone in the construction of the psychrometric diagram is well known as an important indicator used in climate analysis and the development of climate design strategies. The earliest attempts to establish a comfort zone and climatic chart of a building might have established some publications. However, this is still an argument that under certain conditions the comfort zone for different climatic regions remains unchanged. Based on steady-state heat balance theory of Fanger [12], ASHRAE [13] reported that under steady-state condition, “people cannot physiologically adapt to preferring warmer or colder environments, and therefore the same comfort conditions can likely be applied throughout the world”. However, the usual comfort zone proposed by ASHRAE standard 55 [14] seems inappropriate for the Vietnamese due to the fact that it does not have the effect of moisture adaptation of people living in hot humid climates. In this standard, the upper comfort limit of 0.012 kg of water / kg of dry air is rather stringent because this requirement is unlikely to be satisfied in hot humid climates where relative humidity usually exceeds 80%.

According to Pham Ngọc Đặng [15, 16], the value of the intensity of perspiration \( P \) in two seasons of the year when a person stays outdoor with different purposes is proposed:

Winter \( P = -0.4 \) for outdoor of buildings of all purposes.
Summer \( P = 0.4 \) for outdoor of residential, public buildings.

Figure 1. Scheme for determining the effective temperature from air temperatures (nomogram for determining the effective temperature). The characterization of the state of the body and the acclimatization of a person affects the comfort zone of the microclimate.
Table 2. The thermal sensation of the Vietnamese.

| Microclimate | Thermal sensation | According to the chart of effective temperature | Air temperature (°C) (φ=80%; \( v=0,3+0,5 \ m/s \)) |
|--------------|-------------------|-----------------------------------------------|-----------------------------------------------|
|              |                   | Cold season | Hot season | Cold season | Hot season |
| Comfort      | Lower             | 20,0        |            | 21,5        |            |
|              | comfortable      | 23,3        | 24,0       | 24,5        | 25,5       |
| High Limit   |                   | 26,5        | 28,0       | 29          | 29,5       |

In winter, comfortable time takes only 10% of the season, and only passive solar heating will be effective. In other seasons, natural ventilation would provide comfort of at least 54% of the total time of day [17]. Under humid conditions, natural ventilation offers many benefits, such as improving indoor air quality and preventing mound growth. Other strategies, as well as a combination of different strategies, are not recommended because the improvement in comfort is not noticeably higher.

3.2. Results of thermal surface of Hanoi streets

The "Superpave" method is regulated by the calculated maximum coating temperature for the top layer at a depth of 2 cm from the surface and the lowest calculated temperature on the surface of the coating. To calculate the surface temperature of asphalt concrete in Hanoi, we use data from weather conditions in 2015 (Fig. 2, 3). The data were used to determine the temperature dependence of roads on the ambient temperature taken from hydrometeorological stations of the cities of the corresponding zones in Vietnam. The values of the maximum and minimum temperatures of the asphalt concrete pavement are usually used when choosing a grade and justifying the temperatures of testing a bitumen binder. It is conventionally assumed that the binder heat resistance index should correspond to the maximum temperature of the asphalt concrete pavement.

![Figure 2](image1.png)  
**Figure 2.** The result of comparing the minimum temperature of the road surface.

![Figure 3](image2.png)  
**Figure 3.** The result of comparing the maximum temperature of the road surface.
Comparison of air temperature in summer taken from meteorological stations and temperature of the road surface graph by "Superpave" (USA) method shows the value similarity (Fig. 3). Therefore, to calculate the road surface temperature in summer it is possible to use the USA calculation method.

From the results of calculating the surface temperature of asphalt concrete, you can make the following conclusions:

1. It is especially important to predict changes in the temperature regime of the road surface in the winter and on cloudy days.
2. The temperature of the asphalt concrete pavement changes during the day within significant limits, which negatively affects the physical and mechanical properties of asphalt concrete, transport and performance characteristics of the road surface.
3. The range of fluctuations in the temperature of asphalt pavement is approximately proportional to the range of air temperatures, which is confirmed by their correlation (Fig. 2, 3).
4. Daily fluctuations in road surface temperature in summer are sharper than in winter.
5. The calculation thermal of the road surface in winter it is possible to use the Russian calculation method (Y. N. Kovalev) and the calculation thermal of the road surface in summer it is possible to use the USA calculation method.

The study of road surface temperature assessment shows that in the summer of Hanoi the city has high heat radiation. The road surface temperature can be higher than 60 °C. Based on Table 2 on thermal comfort for Vietnamese people, the surface temperature of the road is more than 2 times higher than the highest level in the summer. Therefore, in the summer in Hanoi city, human activities on the road always feel stress and not good for health.

3.3. Thermal properties of asphalt concrete

In the case of study, ordinary black asphalt concrete pavements in a summer climate have a temperature range upwards of 60°C. This is due to the relatively low albedo of asphalt concrete compared to other road materials, as well as its affinity for heat absorption and electrical conductivity. Thermal properties of road surfaces are divided into two categories: energy transfer properties and thermodynamic characteristics [10]. Thermal properties of the road surface are divided into two categories: transfer characteristics power and thermal characteristics dynamic. Characteristic energy transfer refers to conductivity and radiation of the road surface. Characteristics, thermodynamics refers to the energy balance on the road surface and related to the heat capacity the volumetric and the thermal diffusion. [10]. In most cases, asphalt concrete with a higher volumetric heat capacity can accumulate more heat, which means it usually has a lower temperature [18]. Achieving the heat balance in the structure of the road surface is a rather complicated procedure, since it is influenced by various processes of energy transfer and thermodynamic factors. First of all, heat transfer is achieved due to the absorption of solar and infrared radiation, due to convection between the surface of the road and the surrounding air, and also due to the conductivity between the surface of the road and the underlying soil and inside it [5]. The degree to which the road surface responds to thermal influences can be called thermal tolerance or thermal inertia. This thermal inertia and the thermal properties of the road surface are highly dependent on its constituent components, which is why many UHI solutions involve changing the properties of asphalt concrete. The constantly changing properties of each mortar make it difficult to obtain the thermal conductivity of road surfaces, which is determined by such factors as the type of asphalt mix and aggregates used, the size of aggregates, the moisture and mineral content [10].

The increase in thermal conductivity (heat flux) serves to reduce the surface temperature of the asphalt, because the more the heat dissipation from the surface, as well as conductivity greater than for the earth. The change in thermal conductivity of the surface affects both the temperature minimum and maximum. Reducing the electrical conductivity of the road surface reduces the speed with which it can transfer heat to the soil and, in turn, receive heat from the soil [19].
When using more heat-conducting fillers in comparison with sulfur, an increase in the degree of filling leads to a regular proportional increase in the thermal conductivity of sulfur-extended asphalt concrete [20].

Currently, in Vietnam, the use of sulfur as a component of asphalt concrete mix is a promising direction for improving the durability and transport and operational performance of road surfaces.

Sulfur-extended asphalt concrete is used for paving in a dry, hot climate. Sulfur-extended asphalt concrete improves the quality of road surfaces, has good operational and physical-mechanical properties (high compressive strength, high values of coefficients of heat resistance and water resistance, resistant with prolonged water saturation, frost, resistance to rutting), maintainability (increase of overhaul periods, and consequently reduces the total cost of construction and repair of pavements), safety, prolonged durability of asphalt concrete pavements service.

At high temperatures, the difference in the strength of sulfur-extended asphalt concrete and traditional asphalt concrete increases: the compressive strength at 50°C of sulfur-asphalt concrete containing 30 and 40% of the sulfur modifier is higher than the control composition by 43 and 64%, respectively (figure 4) [21]. Thus, the data obtained indicate that sulfur-extended asphalt concrete mixtures have increased heat resistance, and an increase in the content of sulfur modifier contributes to the increase of this parameter.

![Figure 4](https://example.com/image)

**Figure 4.** A comparison of the strength of the grey asphalt and conventional asphalt concrete. The dependence of the thermal conductivity coefficient of sulfur-asphalt concrete $\lambda = f (\nu_f)$ is quite accurately described by a linear dependence:

$$\lambda = k \nu_f + b$$  \hspace{1cm} (7)

Where: $\nu_f$ - volumetric degree of filling; $k$, $b$, are empirical coefficients.

Classical concepts also obey the dependences of the thermal conductivity of sulfur composites on their average density and total porosity.

Thus, when creating sulfur-extended asphalt concrete, it is important at the stage of designing compositions to determine the influence of the type and amount of filler on the value of the thermal conductivity of the material.

However, the usage of sulfur-asphalt concrete has not received wide practical application, it has a significant limitation associated with sanitary problems – emission of toxic gases (H$_2$S and SO$_2$) in the production and installation of sulfur-asphalt mixes. To solve this problem, neutralizers are used. For example manganese oxide, zinc oxide, copper oxide, zinc, dolomite, diatomite, iron chloride hexahydrate... are capable of chemical interaction with hydrogen sulfide and sulfur dioxide to form low or insoluble compounds, which can solve the environmental problem of using sulfur-extended asphalt concrete, significantly expand the use of sulfur-extended asphalt concrete and increase the quality and service life of roads.
4. Conclusion and discussion

The introduction of reflective materials to mitigate the UHI effect has been well documented and researched, and has also been recognized as an innovative solution. However, to date, the influence of these materials and the increase in reflected heat and light on the local environment are not sufficiently studied in science [22]. Future research should take into account the impact of reflective materials on the building environment and air temperature. Reflective coatings may also undesirably reduce the coating temperature in winter, further enhancing the importance of research given a longer time frame. Urban heat island countermeasures will have little impact on indoor heat risk in cities with high prevalence of air conditioning. In cities and areas where there are few air-conditioned buildings, the impact of measures to counteract heat islands in cities and passive cooling on the health risks associated with heat will be higher. Reducing the net heat flow in an urban environment will have a positive impact on the indoor environment; however, the potential for passive cooling is limited by the existing building design. Therefore, taking into account the health consequences of an urban heat island, it is necessary to find a balance between permanent air conditioning and urban planning. The study suggests that air conditioning should be provided from renewable sources, and that only a strict passive-cooled building design and urban countermeasures in heat islands on an urban scale can be associated with the health risks decline.

In conclusion, it was found that the thermal properties of asphalt concrete are strong factors influencing the effect of urban heat islands in cities. There is an ongoing need to reduce the impact of urban heat island due to its adverse impact on the viability, well-being and health of the urban citizens. The ever-expanding nature of cities and the increased use of solid, heat-absorbing substances make a significant contribution to the urban heat island. Various mitigation measures have been proposed, which include reflective coatings, evaporative coatings, improved environmental friendliness, and the use of wind and water-cooling effects. It often turns out that using multiple methods in combination with each other is the most effective strategy to reduce the effect of urban heat island. There are many methods that are being investigated, and further research is needed for these measures at any time of the year to find the best possible solution for urban heat island mitigation. The biggest problem with urban heat island is that conditions are not the same in every urban environment. Cities around the world vary greatly, and solutions that meet and exceed the needs of each individual city around the world must be found.

The widespread introduction of advanced environmentally friendly sulfur-containing materials - sulfur-extended asphalt concrete with modifiers containing neutralizers of toxic gas emissions, which has higher physical and mechanical properties (wear resistance, etc.) at a lower or equal cost, can open up opportunities for increasing the quality and service life of roads in Hanoi (Vietnam).

References

[1] Minh Tuan Le, Thi Anh Tuyet Cao, Nguyen Anh Quan Tran 2019. *E3S Web conferences* 97 (FORM-2019), 01013.
[2] Minh Tuan Le, Nguyen Anh Quan Tran 2019. *E3S Web of conferences* 91 (TPACEE-2018), 05005.
[3] Minh Tuan Le et al 2019 IOP Conf. Ser.: Master.sci. Eng. **661** 012090.
[4] Podolskiy Vladislav Petrovich, Nguyen Van Long, and Le Van Chung 2013 *Vestnik MGSU*. 1, p139-147.
[5] Santamouris M., 2013b *Energy Rev.* 26, 224-240.
[6] Synnefa A., Karlessi T., Gaitani N., Santamouris M., Assimakopoulos D.N.,Papakatsikas C., 2011 *Build. Environment*. 46 1, 38-44.
[7] Gorsevski V., Taha H., Quattrochi D., Luvall J., 1998 *Proceedings of the ACEEE Summer Study, Asilomar, CA*. 9, pp. 23-32.
[8] Golden J.S., Kaloush K.E., 2006 *Int. J. Pavement Eng*. 7 1, 37-52.
[9] Higashiyama H., Sano M., Nakanishi F., Takahashi O., Tsukuma S., 2016 *Case Stud. Constr. Mater* 4, 73-80.
[10] Stempihar J.J., Pourshams-Manzouri T., Kaloush K.E., Rodezno M.C., 2012 Po Transp. Res. Rec. J. Trans. Res. Board 2293 1, p123-130.
[11] TCVN-4088-1985. Climate data used in Vietnam's construction design.
[12] Fange P.O., 1970. Thermal Comfort, Danish Technical Press, Copenhagen.
[13] ASHRAE 2009 ASHRAE Handbook of Fundamentals, ASHRAE, Atlanta.
[14] ASHRAE 2004 ASHRAE Standard 55-2004: Thermal Environmental Conditions for Human Occupancy, ASHRAE, Atlanta.
[15] Pham Ngoc Dang, Pham Duc Nguyen, Luong Minh 1981 Vat ly xay dung (phan 1, nhiet va khi hau). NXB. Xay dung. Hanoi.
[16] Pham Ngoc Dang 1980 Huong dan thiet ke do an nhiet va khi hau kien truc. Hanoi.
[17] Anh Tuan Nguyen, Sigrid Raiter 2014 Energy and Buildings, 68, pp 756-763.
[18] Yavuzturk C., Ksaibati K., Chiasson A., 2005 Mater. Civ. Eng. 17 4, pp 465-475.
[19] Abbas Mohajerani, Jason Bakaric, Tristan Jeffrey-Bailey 2017 Journal of Environmental Management 197, pp 522-538.
[20] Korolev E.V., Kiselev D.G., Proshina N.A., Albakaspov A.I., 2011 Vestnik MGSU 8.
[21] Gladkikh V.A., Korolev E.V., Husid D.L., 2015 Building materials, equipment, technologies of the 21st century, 3, p32-35.
[22] Yang J., Wang Z.-H., Kaloush K.E., 2015 Renew.Sust. Energy Rev. 47 0, 830-843.
[23] B. Givoni 1969 Man Climate and Architecture, Elsevier, Oxford.
[24] Kovalen Y.N 1966 Road-climatic zoning of the territory of the BSSR for the construction of asphalt concrete pavements, pp 64-71.
[25] Asphalt Institute Superpave 1997. 1. p 67.