The Impact of Site Elements to Micro-Climate Air Temperature
ผลกระทบขององค์ประกอบรอบที่ตั้งต่ออุณหภูมิอากาศ ในเขตภูมิอากาศเฉพาะพื้นที่

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Abstract

Global warming effect has been a serious issue for decades. The impact of site element is one of influence factors in architectural design and energy conservation. This study focused on material heat capacity properties of wet grass (0.7 Btu/°F), wet-soil (0.6 Btu/°F), concrete (0.23 Btu/°F) and dry-soil (0.19 Btu/°F) surfaces. Outdoor air temperature was influenced by those selected materials. Air temperature data were collected for 24 hours. During daytime, those surfaces received heat from solar radiation in a range of 240 to 260 Btu/ft^2/h It is found that outside air temperature among wet-grass surface had raised 0.9°C similar to wet-soil as 1.8°C while concrete 2.6°C and dry-soil 2.9°C. This illustrates that high heat capacity outdoor surfaces have less effected to raise air temperature than the others. Shades can reduce air temperature covered dry-soil and concrete ground by 3.7°C and 4.9°C, respectively. Therefore, it can be concluded that to reduce outdoor air temperature, those materials should have high heat capacity property and shade from vegetation can shield materials with low heat capacity. It has less effect outdoor air temperature raise which cause energy conservation in building.

Keywords
Heat Capacity
Site Elements
Air Temperature
Micro-climate

บทคัดย่อ

ปัจจุบันการออกแบบอาคารเพื่อการอนุรักษ์พลังงาน เป็นที่สนใจของเจ้าของอาคารและผู้ออกแบบโดยทั่วไป การศึกษาอิทธิพลขององค์ประกอบรอบที่ตั้งที่มีผลต่อการเปลี่ยนแปลงอุณหภูมิอากาศโดยรอบ เป็นปัจจัยหนึ่งที่มีผลต่อการใช้พลังงานในอาคาร การศึกษาวิจัยนี้กำหนดให้ศึกษาตัวแปรของความจุความร้อนที่เกิดจากองค์ประกอบรอบที่ตั้ง โดยศึกษากลุ่มตัวอย่างพื้นผิว 4 ประเภท ได้แก่ พื้นหญ้าชุ่มน้ำ (0.7 Btu/°F) พื้นดินชุ่มน้ำ (0.6 Btu/°F) พื้นคอนกรีต (0.23 Btu/°F) และพื้นดินแห้ง (0.19 Btu/°F) ซึ่งมีค่าความจุความร้อนเรียงตามลำดับจากมากไปหาน้อย ภูมิอากาศของสภาพแวดล้อมภายนอกอาคารได้รับอิทธิพลจากพื้นผิวทั้ง 4 ประเภทดังกล่าว ตลอด 24 ชั่วโมง โดยเฉพาะในช่วงกลางวันซึ่งได้รับความร้อนจากรังสีดวงอาทิตย์ระหว่าง 240-260 Btu/ft^2/h ผลการวิจัยพบว่า อุณหภูมิอากาศของสภาพแวดล้อม ที่ได้รับอิทธิพลจากพื้นหญ้าชุ่มน้ำ จะมีอุณหภูมิอากาศเหนือพื้นผิวสูงขึ้น 0.9 องศาเซลเซียส พื้นดินชุ่มน้ำจะมีอุณหภูมิอากาศเหนือพื้นผิวสูงขึ้น 1.8 องศาเซลเซียส พื้นคอนกรีตแห้งจะมีอุณหภูมิอากาศเหนือพื้นผิวสูงขึ้น 2.6 องศาเซลเซียส และพื้นดินแห้งจะมีอุณหภูมิอากาศเหนือพื้นผิวสูงขึ้น 2.9 องศาเซลเซียส จะเห็นได้ว่า อุณหภูมิอากาศที่ได้รับอิทธิพลจากองค์ประกอบรอบที่ตั้งที่มีความจุความร้อนสูงจะมีการเปลี่ยนแปลงของอุณหภูมิอากาศต่ำกว่าผิวองค์ประกอบรอบที่ตั้งที่มีค่าความจุความร้อนต่ำ อิทธิพลร่มเงาธรรมชาติสามารถทำให้อุณหภูมิอากาศเหนือพื้นผิวดินแห้งและพื้นผิวคอนกรีตลดลง 3.7 และ 4.9 องศาเซลเซียสตามลำดับ ดังนั้น การออกแบบหรือเลือกใช้วัสดุภายนอกอาคารโดยรอบที่ตั้งในภูมิภาคเขตร้อนชื้น จึงควรใช้วัสดุที่มีคุณสมบัติความจุความร้อนจำเพาะสูงและสร้างร่มเงาให้กับวัสดุที่มีคุณสมบัติความจุความร้อนต่ำ เพื่อส่งผลให้อุณหภูมิอากาศภายนอกมีการเปลี่ยนแปลงน้อยที่สุด จะมีผลต่อการลดการใช้พลังงานภายในอาคารต่อไป

คำสำคัญ
ความจุความร้อน
องค์ประกอบรอบที่ตั้ง
อุณหภูมิอากาศ
ภูมิอากาศเฉพาะพื้นที่

Introduction

The earth's temperature has steadily risen since 1980 A.D. due to the Greenhouse Effect that is caused by the anthropogenic greenhouse gas emission. Study of the average air temperature in Thailand between the years 2383-2500 B.D. (Bowring, 1969, pp. 398-400) compared to the present average air temperature between the years 2543-2550 B.D. found that average air temperature is higher throughout the year in the latter years. The air temperatures today during summer (April), winter (November), and rainy season (August) are higher than by 2.4°C, 3°C and 2°C, respectively (Chitranukroh, 2007). Thus, making the air temperature above the comfort zone all year, because the human's desire for development of environments within the country causes the amount of heat to increase. Heat Island is a phenomenon that occurs when there is a thermal effect from site elements within a large, heavily populated city because of its inhabitant's immense energy consumption and heat discharge. For example, heat from material, heat from transportation, and electricity consumed in factories and human buildings. Site elements are variables most influenced by solar radiation. Among surfaces studied by Kongboontiam & Puraprom (2015), surface temperature of asphalt was the highest, at 9°C higher than the average air temperature (35°C). The cover that yielded the lowest surface temperature was water surface of fountain, which was 7°C lower than the average air temperature. This can approximately show the effect of site elements on the air temperature of the micro-climate.

In Thailand, energy consumption from building is approximately 15% of total consumption in country. The Energy Ministry of Thailand stated that the air-conditioning system consumes the most electricity in building reaching 70% of total consumption (Energy Development and Efficiency, 2013) in a building. Furthermore, the outside environment cannot support by heat from solar radiation. From data of the temperature within large cities in the tropic region, it was found that the cities have higher air temperature than the average normal air temperature around the cities and the temperature is increasing every year (Geografika, 2011). If "development" of human continues to cause excessive energy consumption, then it is not possible for a sustainable growth that is in harmony with nature.

Figure 1 shows the change in average air temperature in Bangkok over a period of 160 years. The air temperature rose above the comfort zone throughout the year. In winter, the present average air temperature is 3°C higher than the past. This was possibly caused by context changing of the eras, from agricultural to industrial (Chitranukroh, 2007).

This paper studies the change in outside air temperature over a 24-hour period to compare with the average air temperature. The study concentrates on the heat capacity of the ground coverings that has effect on air temperature. Heat capacity is the amount of heat that a particular material can contain per unit; this varies as each material has different thermal properties. Heat transfer from the ground coverings to the surroundings causes the temperature immediately (Iamtrakul, 2014) above the surface to differ from the average air temperature. The ΔT, or temperature difference between outside and inside building (Stein & Reynolds, 2000), came from the change in temperature obtained from the research results. The aim is to design an environment correctly and with real understanding of its properties, which will enable temperature to be reduce instead of maintained near the human comfort zone (ASHRAE, 2007). With further aim to lower the cooling load of the air-conditioning system within buildings to reduce the national energy consumption and CO_2 emission.

Methodology

1. Study heat capacity factor of site elements
2. Survey data surface temperature and heat transfer at 0.10 m and 0.30 m level on the materials.

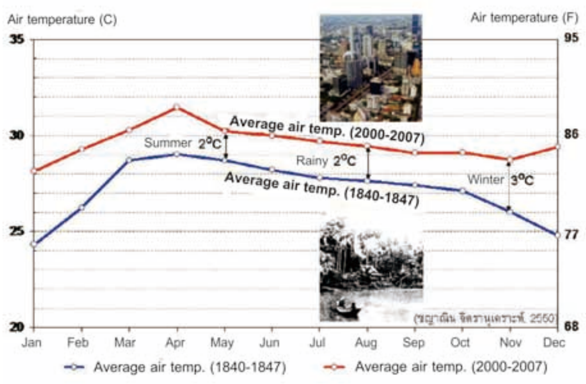

Figure 1. comparing the average air temperatures in Bangkok 160 years apart, 2383-2390 B.E. (1840-1847 A.D.) with 2543-2550 B.E. (2000-2007 A.D.), (Chitranukroh, 2007)

3. Site selection (4 sites) for study according to heat capacity factor of materials.

4. Collect data change of air temperature and surface temperature in selected sites compare to normal air temperature overall 24-hour.

5. Equipment used:

- Infrared Thermometer (Extech 42511: Temperature range -50 to 600°C. Adjustable emissivity for different surface.)
- Temperature and Humidity data logger (Extech SD500: Temperature range -35 to 80°C and humidity range 20 to 80%)
- Solar meter (TES-1333R: Radiation range 1-2000 w/m^2 or 1-634 Btu/ft^2/h)
- Anemometer (Extech AN100: Air velocity range 0.4 to 30.0 m/s)

6. Analyze data for design guideline.

7. Conclusion

Results

Site elements

In the hot-humid climate, the ground cover that is on the horizontal plane will receive the most heat from solar radiation. Fifteen types of ground coverings were studied Maejo University, Chiang Mai that are heat sources within the test area. The data collection took place in November during the day time (12:00-13:00 hours), and during night time (03:00-04:00 hours). It has been found that the day time's peak solar radiation rate was 250 Btu/m^2/h, and air temperature was 32.2°C. The three types of ground covers that had the highest surface temperature were (1) steel = 64°C, (2) dry-soil = 62.1°C, and (3) wood = 61°C. Their heat capacity were 0.11, 0.19, and 0.2 Btu/oF, respectively, while the three types of ground covers with the lowest surface temperature were (1) water = 28.8°C, (2) wet-grass = 34.2°C, and (3) wet-soil = 38°C. Their heat capacity were 1.0, 0.7, and 0.6 Btu/°F, respectively. Evidently, the day time solar radiation causes the materials with low heat capacity to have higher surface temperatures than those with high heat capacity.

During night time, solar radiation is 0 Btu/m^2/h. The temperature of the sky was -13°C, and average air temperature was 22.4°C. The three types of ground covers that had the highest surface temperature were (1) water = 26.9°C, (2) concrete = 25.7°C, and (3) concrete block = 25.5°C. Their heat capacity were 1.0, 0.23, and 0.18 Btu/°F, respectively. While the three types of ground covers with the lowest surface temperature were (1) steel = 19.8°C, (2) wood = 20 °C, and (3) sand = 20.1°C. Their heat capacity were 0.11, 0.19, and 0.2 Btu/°F, respectively. During night time, it is likely that materials with high heat capacity to have higher surface temperature than those with low heat capacity.

Figure 2 shows that surface temperatures of

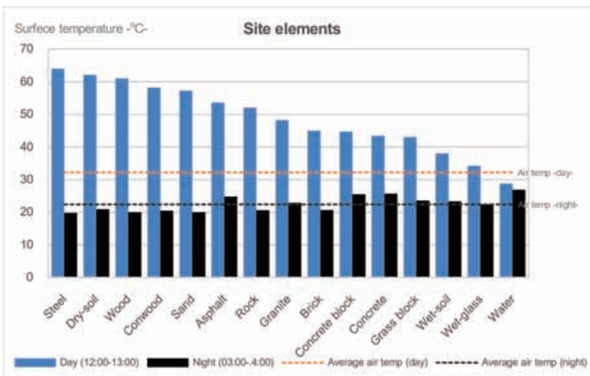

Figure 2. The chart shows surface temperature above surface of 15 elements during noon and midnight, collected in the Maejo University Chiang-mai area.

the ground covers were higher than the air temperature, except for water's surface temperature that was slightly lower. During daytime, surface temperature of steel (heat capacity = 0.11 Btu/°F) was 31.8°C higher than air temperature and the surface temperature of water (heat capacity = 1.0 Btu/°F) was 3.4°C lower than air temperature. Inversely, during night time, which has lower air temperature, water surface temperature was 4.5°C higher than air temperature, and steel surface temperature was 2.6°C lower than air temperature.

The results described the varying heat capacity of different materials that affects their surface temperatures. Furthermore, the heat capacity of each material is directly related to the change in its surface temperature. Environment surface temperature is effected by heat capacity of each material and also depending on thickness. During day time, solar radiation, the main heat source, affects materials. Materials with low specific heat, such as metal, can store small amount of heat causing the surface temperature to increase quickly during daytime, and decrease quickly at night. Materials that have high specific heat can store a lot of heat causing surface temperature to increase slowly during daytime, and decrease slowly at night.

Heat capacity

Heat capacity factor is the ability to store heat of a particular material. Solar radiation changes to heat energy once it comes into contact with surface of opaque materials. Heat will be stored in materials according to its thickness, then causing a change of its temperature to varying degrees. Every 1°C change in temperature per the unit of heat it gains is its heat capacity. Materials with high heat capacity will have lower changes in the temperature, while those with low heat capacity will have higher changes in temperature. Figure 3 shows the surface temperature and heat capacity of 15 sample materials. The surface temperature of the materials with high heat capacity are lower than the materials with low heat capacity. The said process causes heat from the surface of materials to transfer to the surrounding environment (Geiger, 1950). This results in an increase in the temperature of the environment. Therefore, heat capacity of materials has an effect on the change in air temperature.

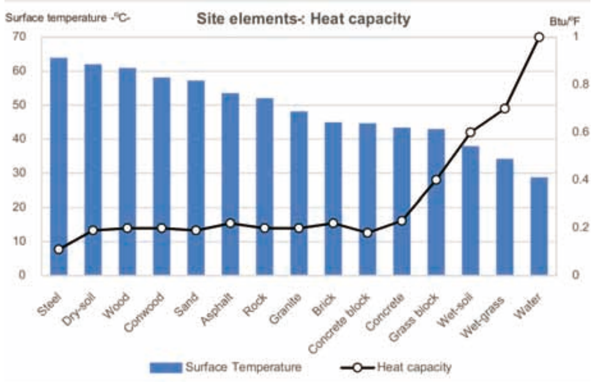

Figure 3. Surface temperature and heat capacity (ASHRAE, 2007) of 15 materials.

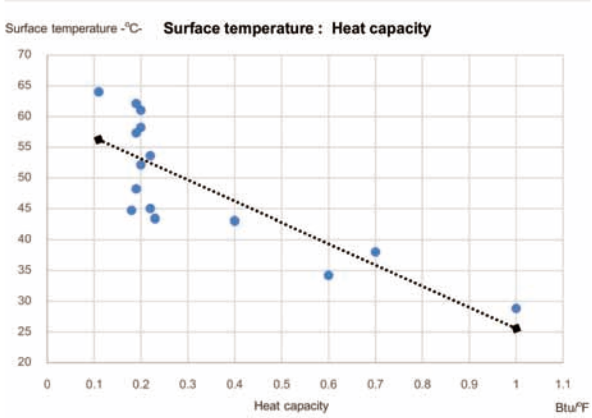

Figure 4. Correlation of surface temperatures and heat capacity of 15 materials.

At the test and data collection area, 73% of the area is covered by materials that have a heat capacity value of lower than 0.3 Btu/°F. This led to a hypothesis: the research area has a higher temperature of material surface than the air temperature.

The study can be separated by materials types in two groups by their heat capacity as shown below:

Group A: Low heat capacity of materials 0-0.5 Btu/°F

Such as: metal-sheet, dry-soil, wood, cement-wood, sand, asphalt, rock (gravel), granite, brick, concrete, concrete-block.

Group B: High heat capacity of materials 0.51-1 Btu/°F

Such as: grass-block, grass, wet soil, water

Air temperature

The increase in surface temperature of ground cover materials has an effect on air temperature. The study has collected data of the changes in air temperature above each material during noon at the height levels: 0.10 m and 0.30 m comparing with air temperature. The study found that the heat from different ground cover materials causes varying changes in air temperature. At the 0.10 m level, the three materials that caused highest change in air temperature from the group of materials with low heat capacity were: (1) steel (+15.5°C), (2) rock (+14.4°C), and (3) cement wood (+13.1°C). And the three materials that caused lowest change in air temperature from the group of materials with high heat capacity were: (1) water (-4.1°C), (2) wet-grass (+1.9°C), and (3) wet-soil (+7.3°C). At the 0.30 m level, the three materials that caused highest change in air temperature from the group of materials with low heat capacity were: (1) steel (+9°C), (2) rock (+7.1°C), and (3) cement wood (+7°C). And the three materials that caused lowest change in air temperature from the group of materials with high heat capacity were: (1) water (-3.1°C), (2) wet-grass (+0.9°C), and (3) wet-soil (+5.9°C). When the weather is peak solar radiation, having materials with low heat capacity will effect the air temperature than high heat capacity, whereas materials with high heat capacity will cause a slightly temperature increase. Water is the only site element that has less affected to outside air temperature raise because of the evaporation effect and low surface temperature compare to the other materials. However, as distance from the materials increase, the effect of the materials on the change in air temperature decreases. The difference in the temperature above the test materials and the air temperature shows that there is heat that coming from the site elements. An environment where there is steel, rock, and cement wood will have higher air temperature than one that is made up of water, wet-soil, and wet-grass.

Data of air temperature directly above 15 materials that were gathered showed the impact of heat capacity on the change in air temperature. Heat is stored within materials to their capacity, and cause them to have higher temperatures than the air temperature. The excess heat is transferred from the surface of the materials to the surrounding air that has a lower temperature. This makes air temperature in the area higher than the normal air temperature, and much higher than the human thermal comfort zone.

Due to the change in air temperature throughout 24 hours, it is necessary to study the effect of ground covers on the change in air temperature during both daytime and nighttime. Data was collected on an hourly basis to observe the changes in air temperature over a 24 hour period. Selecting samples by heat capacity for data collection had the following criteria.

Group A: Low heat capacity of materials

(1) Dry-soil with a heat capacity of 0.19 Btu/°F

(2) Concrete with a heat capacity of 0.23 Btu/°F

Group B: High heat capacity of materials

(3) Wet-soil with a heat capacity of 0.6 Btu/°F

(4) Wet-grass with a heat capacity of 0.7 Btu/°F

Data of all four materials were collected at the surface temperature and the effect air temperature at 0.30 m height, then compared to normal air temperature over a 24-hour period - from 06:00 am to 05:00 am the next day. The record data addition on environment factor that has an effect on change in air temperature, such as solar radiation, wind speed, and relative humidity were collected.

Impact of site elements

The study found that the 4 test samples causes an increase in the air temperature throughout the 24-hour period.

This research shows that the outside air

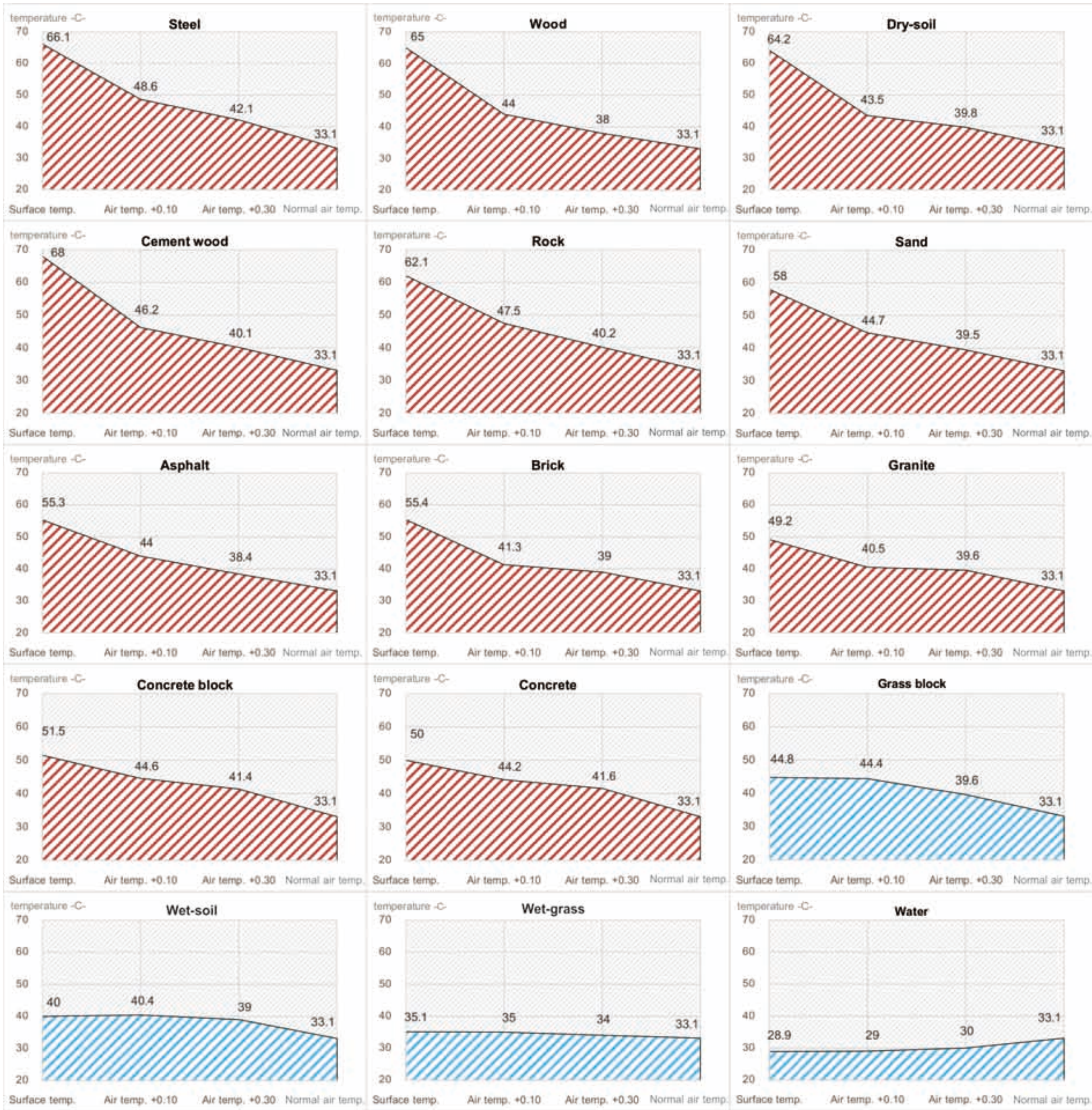

Figure 5. The surface temperature and the effect of all 15 sample materials on air temperature at the heights 0.10 m and 0.30 m, compared with normal air temperature. (red: low-heat capacity, blue: high-heat capacity)

Figure 6. Demonstrate air temperature data collection on the samples such as dry-soil, concrete, wet-soil, and wet-grass within Maejo University.

temperature of both high and low peak during the day.

During the day time period (2:00 pm) air temperature was highest (34.6°C).

(1) Dry-soil can increase air temperature by 3°C

(2) Concrete can increase air temperature by 2.7°C

(3) Wet-soil can increase air temperature by 1.8°C

(4) Wet-grass can increase temperature by 0.9°C

During the night time period (05:00 am) air temperature was lowest (20°C).

(1) Dry-soil can increase air temperature by 3.2°C
(2) Concrete can increase air temperature by 3.6°C
(3) Wet-soil can increase air temperature by 1.9°C
(4) Wet-grass can increase air temperature by 1.7°C

The increase in effect air temperature that was caused by the 4 site elements was higher during night time than day time. This is because the environment during night time was lower than the day time temperature, hence allowed easier heat transfer from the materials to the surroundings. This makes the temperature above the surface of the materials significantly higher than the normal air temperature.

1. Dry -soil

Dry-soil has a specific heat at 0.19 Btu/°F. The impact of dry-soil increased the air temperature above its surface. During day time the effect average air temperature was 3.34°C higher than the normal air temperature. During night time the effect air temperature was approximately 3.95°C higher than the normal air temperature. Dry soil caused the air temperature to increase sharply in the morning and decreased quickly after 14:00 h, which was the time that it had peak air temperature (time lag = 2 hours). The average rate of increase was 2.0°C per hour, which was higher that the increase of the normal air temperature by 0.2°C per hour.

2. Concrete

Concrete has a specific heat of 0.23 Btu/°F. The impact of concrete increased the air temperature above its surface. During day time the effect average air temperature was 3.43°C higher than the normal air temperature. During night time the effect air temperature was approximately 4.54°C higher than the normal air temperature. Concrete caused the air temperature to increase slowly in the day time and decreased slowly after 15:00 h, which was the time that it had peak air temperature (time lag = 3 hours). The average rate of increase was 1.8°C per hour, which was the same as the rate of increase of the normal air temperature.

3. Wet-soil

Wet-soil has a specific heat of 0.6 Btu/°F. The impact of wet-soil increased the air temperature above its surface. During day time the effect average air temperature was 1.9°C higher than the normal air temperature. During night time the effect air temperature was approximately 2.33°C higher than the normal air temperature. Wet soil caused the air temperature above its surface to rise almost as high as the normal air temperature in the daytime, and decreased after 15:00 h, which was the time it had peak air temperature (time lag = 3 hours). The average rate of increase was 1.7°C per hour, which was slower than the rate of increase of the normal air temperature by 0.1°C.

4. Wet-grass

Wet-grass has a specific heat of 0.7 Btu/°F. The impact of wet-grass increased the air temperature above its surface. During day time the effect average air temperature was 1.99°C higher than the normal air temperature. During night time the effect air temperature was also approximately 1.99°C higher than the normal air temperature. Wet grass caused the air temperature to increase at the same rate as the normal air temperature in the morning (06:00-09:00), but slowed down afterwards (10:00-16:00), when it reached peak air temperature at 16:00 (time lag = 4 hours), then the air temperature dropped sharply after 17:00. The average rate of increase was 1.5°C per hour, which was slower than normal air temperature change by 0.3°C per hour

Figure 7-8 show that air temperature difference, ordered from highest to lowest, were: dry-soil = 16.1°C (the most difference air temperature 6.7°C at 9:00-10:00), concrete = 16°C (the most difference air temperature 5.8°C at 17:00-18:00), wet-soil =15.5°C (the most difference air temperature 3.9°C at 9:00-

10:00), and wet-grass =15.3°C (the most difference air temperature 5.5°C at 9:00-10:00) higher than the normal temperature by 1.5, 1.4, 0.9, and 0.7°C respectively. The sample group with low heat capacity (Figure 8) caused surface temperature to be higher than the normal air temperature all day, and heat transfer from the surface to the surrounding of environment over a 24-hour period. Except for wet-grass that had almost the same surface temperature as the air temperature at night time. This is because grass blades have low mass and were quickly affected by the coldness radiated from the night sky, which caused the surface temperature on its be similar to normal air temperature.

Discussion

Hot-humid climate regions desire an environment where site elements do not cause an increase in air temperature. This should be the guideline in the design of a microclimate for human comfort in micro-climate.

- Creating an environment that do not cause air temperature increase can be achieved through using site elements with high heat capacity such as soil or grass that are habitually watered. This is because water can absorb a high amount of heat from solar radiation (heat capacity = 1), causing the air temperature within the area stable. Humidity of materials may be another factor that cause lower air temperature.

- In winter, creating an environment that causes air temperature to increase can be achieved through using site elements with low heat capacity such as concrete, dry-soil, and asphalt. This will cause air temperature to increase both during day time and night time.

- In summer, creating an environment that causes air temperature to decrease is difficult to achieve. From research data, lowering air temperature in hot-humid climate needs other external factors such as evaporation of a large body water, and the effect of shading from trees.

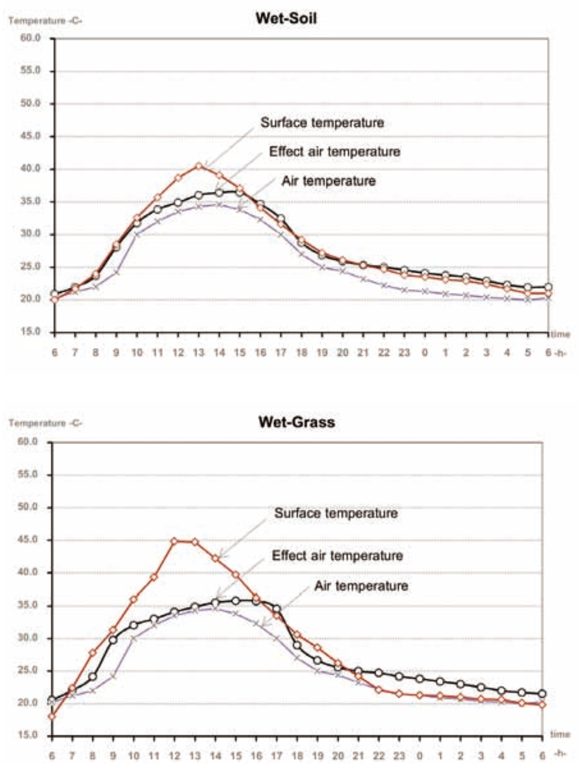

Figure 7. Surface temperatures and effected air temperatures of wet-soil and wet-grass compared to air temperature.

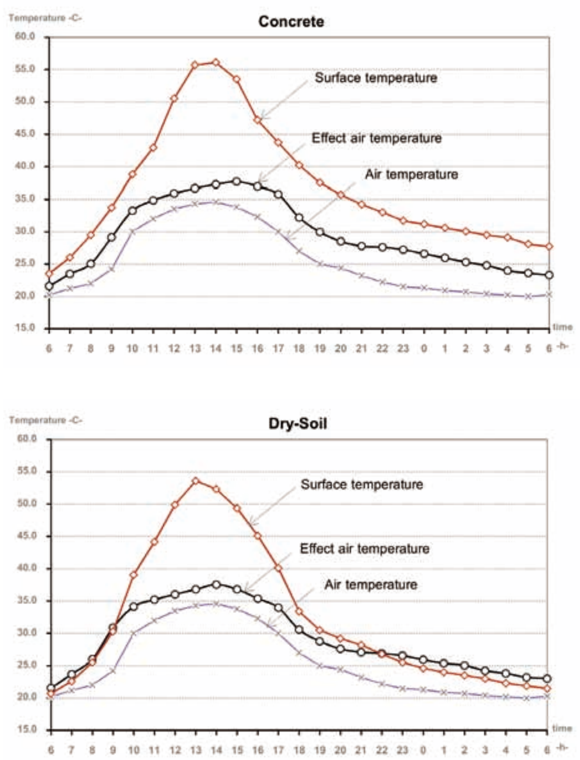

Figure 8. Surface temperature and effected air temperature of concrete and dry-soil compared to air temperature.

The paper has also studied the method to resist solar radiation with the shading effect of large trees (Figure 9) for the low heat capacity material groups: dry-soil and concrete in summer. The study found that a large tree can protect solar radiation by 92 percent. This caused the site elements to have lower surface temperature than air temperature in the day time, and higher in the night time. Air temperature change above the site elements were lower that overall air temperature change throughout the day due to low exposure to solar radiation, which was only 18 percent. This enabled the materials with low heat capacities to absorb the amount of heat that reached their surfaces. Therefore, the effect of shade from large trees is another factor that can lower air temperature in an environment that contains low heat capacity materials.

The site elements that have significant effect on air-temperature are: wet-soil, wet-grass, concrete and dry-soil. Managing these elements is another way to reduce air temperature difference between outside and inside a building, and has led to the concept of environment design using landscaping and urban design.

Conclusions

Changing the site elements has a substantial effect on the change in air temperature (ΔT) which is one of the variables used in the cooling load calculation in an air-conditioned building. At the present, development of the building elements such as the quality of the building envelope, the area of the building and the building area over useable area, has continuous research and development with the aim of reducing energy consumption in the air-conditioning system.

Designing the site elements surrounding a building to reduce air temperature difference between inside and outside (ΔT) can use the following methods:

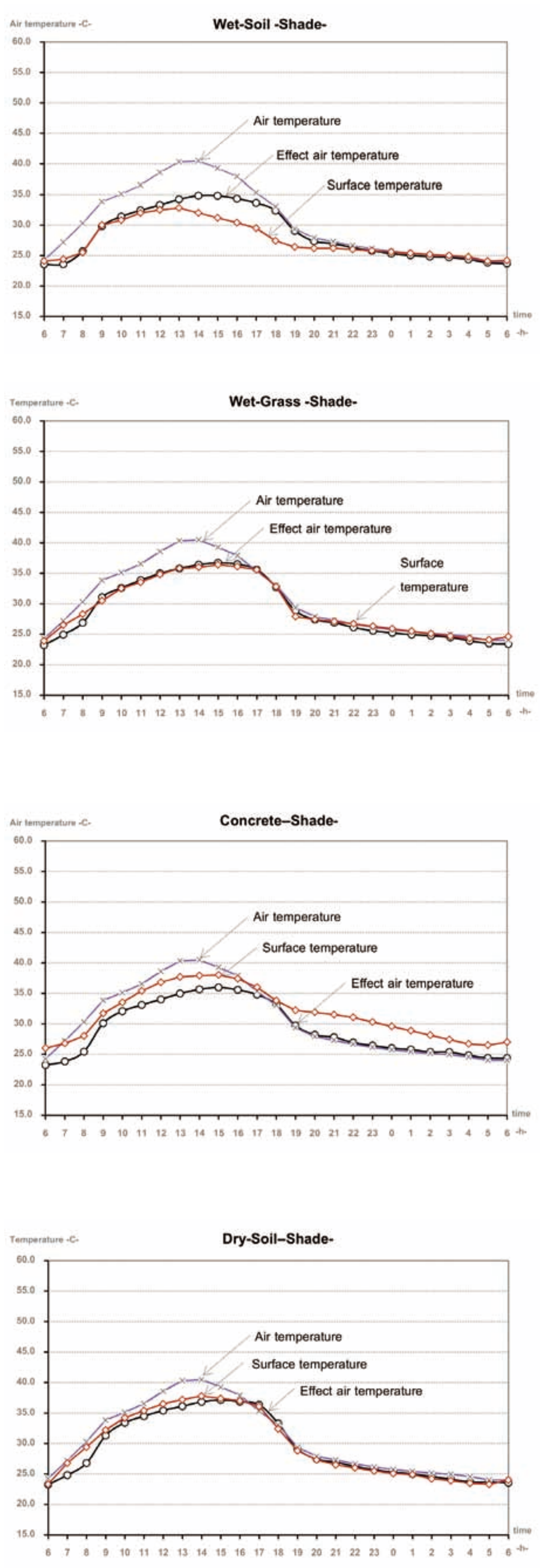

Figure 9. Surface temperature and effect air temperature from site elements (shade) compared to air temperature.

1. Design the ground that are exposed to sunlight to have water as a component, either grass or soil that is watered regularly. Because, water is a natural element that is good to absorb heat from sunlight and has high heat capacity property. It can absorb more heat from the sun during the day. This will cause the area to have lower increasing in air temperature.

2. Design large tree shades cover ground cover materials such as concrete or asphalt to decrease heat storage in these materials.

The above methods can lower air temperature difference between inside and outside air temperature. This is a contributing factor to lowering the load of the cooling system and leads to less energy consumption. Air temperature control using site elements can reduce outside temperature fluctuation, and has effect on the thermal comfort and human sensation. The site elements factors and climate factors can be developed to form an equation to predict temperature of a given environment and landscaping and urban design. Given that, it is still advisable to collect data on the site elements to cover the changes in climate througout the year. This maximize the credibility and accuracy of the prediction. The study's results are the product of correlation ananlysis of the site elements and temperature changes that directly affects energy use within a building. The study of these changes on the human sensation will increase sustainability and fulfillment in the relationship between building, environment and humans.

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References

ASHRAE Standard 90.1 (2007). *Energy standard for buildings except low-rise residential buildings (I-P edition)*. Atlanta: ASHRAE.

Bowring, J. (1969). *The Kingdom and people of Siam*. London: Oxford University Press, UK.

Chitranukroh, J. (2007). *The analysis of essential factors in traditional Thai house technology: central Thailand*. Doctor of Philosophy, Architecture, Chulalongkorn University, Bangkok, Thailand.

Energy Development and Efficiency. (2013). *Facts & figures: energy in Thailand Q1/2013*. Department of Alternative. Bangkok, Thailand.

Geiger, R. (1950). *The climate near the ground*. Cambridge: Harvard University, USA.

Iamtrakul, P., Nusook, T. & Ubolchay, P. (2014). Impact of urban heat island on daily life of people in Bangkok metropolitan region (BMR). *Journal of Architectural/Planning Research and Studies, 11*(2), 53-72.

Kongboontiam, P. & Puraprom, W. (2015). Guidelines for reducing air temperature using effects of ground cover. *Journal of the Faculty of Architecture, Silpakorn University*, 29, 321-334.

Stein, B. & Reynolds, J. S. (2000). *Mechanical and electrical equipment for buildings*. 9thed. New York: John Wiley & Sons.

Bibliography

Boonyatikarn, S. (1982). *A method for developing energy budgets and energy design guidelines for institutional buildings*. Doctoral Dissertation of Architecture, University of Michigan, USA.

Fanger, O. P. (1970). *Thermal comfort.* New York: McGraw-Hill.

Hansen, J. et al. (2006). *The reason global warming is manmade*. The NASA's Goddard Institute for Space Studies.

Meteorological, D. (2015). *Yearly weather summary: Thailand annual weather summary*, Bangkok.

Nusantara, G. (2011). *Why is it hotter in Jakarta? The urban heat island effect in Indonesia*. Kapi'olani Community College in Honolulu. Indonesia.

Olgyay, V. (1992). *Design with climate: bioclimatic approach to architectural regionalism*. New York: Van Nostrand Reinhold.

Saiyavath, P. & Haocharoen, K. (2009). Development of downtown open space to mitigate urban heat island effect: A case study of Silom road, Bangkok. *Journal of Architectural/Planning Research and Studies, 6*(2), 35-44.

Skelhorn, C. (2012). *The impact of vegetation types on air and surface temperatures in a temperature city: A fine scale assessment in Manchester*, UK. Manchester: University of Manchester.

Srivanit, M. & Auttarat, S. (2015). The summer thermal environment and human comfort of shaded outdoor and semi-outdoor spaces to living in the urban area of Chiang mai city. *Journal of Architectural/Planning Research and Studies, 12*(2), 53-72.