# Czech technical university in Prague

## Faculty of Civil Engineering

### Department of Building Structures


# Master thesis


February 2019 Bc. Tomáš Pospíchal

**ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE**
**Fakulta stavební**
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# ZADÁNÍ DIPLOMOVÉ PRÁCE

## I. OSOBNÍ A STUDIJNÍ ÚDAJE

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Zadávající katedra: K124 - Konstrukce pozemních staveb

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## II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce: Vliv tepelného ostrovu města na energetický návrh budovy

Název diplomové práce anglicky: The Influence of an Urban Heat Island on the energy Design of a Building

Pokyny pro vypracování:

Analýza tepelného ostrova pro vybranou část Prahy. Součástí analýzy bude předpoklad změny klimatu. Cílem simulace tepelného ostrova Prahy bude sledování změny exteriérových podmínek v zadaném území. Na základě anylýzy popište vliv změny klimatu na návrh energetické koncepce budovy. Na závěr bude proveďte diskuzi o úpravě vnějšího prostředí tak, aby bylo dosaženo příznivějších podmínek jak v exteriéru, tak v interiéru budov.

Analýzu proveďte pod vedením doktora Tzu-Ping Lina z fakulty architektury NCKU Taiwan během studijního pobytu.

Seznam doporučené literatury:

Dle doporučení doktora Tzu-Ping Lina.

Jméno vedoucího diplomové práce: prof. Ing. Petr Hájek, CSc.

Datum zadání diplomové práce: 20. 08. 2018 Termín odevzdání diplomové práce: 06. 01. 2019

*Údaj uveďte v souladu s datem v časovém plánu příslušného ak. roku*

Podpis vedoucího práce Podpis vedoucího katedry

## III. PŘEVZETÍ ZADÁNÍ

*Beru na vědomí, že jsem povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací. Seznam použité literatury, jiných pramenů a jmen konzultantů je nutné uvést v diplomové práci a při citování postupovat v souladu s metodickou příručkou ČVUT „Jak psát vysokoškolské závěrečné práce" a metodickým pokynem ČVUT „O dodržování etických principů při přípravě vysokoškolských závěrečných prací".*

Datum převzetí zadání Podpis studenta(ky)

I declare, that the Master thesis was made on my own, based on consultations with my supervisors prof. Ing. Petr Hájek, CSc., Feng. and professor Tzu-Ping Lin, Ph.D.

……………………………

I give thanks to my advisor prof. Ing. Petr Hájek, CSc., FEng. for expert guidance, advices on master thesis work and helpfulness in consultations. Next, I thank to my advisor from National Cheng Kung University professor Tzu-Ping Lin, Ph.D. and his colleagues from Buildings&Climate Lab. I highly appreciate all the help and advices you provided me during my stay in Tainan.

# The Influence of an Urban Heat Island on the energy Design of a Building

# Vliv tepelného ostrovu města na energetický návrh budovy

# Abstract:

The Master thesis is focused on the evaluation of an urban heat island. The analysis is set up in the specified locality in Prague. Climate change is presumed in the analysis. The objective of the urban heat island simulation is to observe changes of exterior conditions in the given territory. The climate changes influence the outdoor comfort as well as the interior comfort in buildings. Subsequently, the analysis will be used to describe the impact of climate change on the design of the building's energy concept. Finally, discussions will be held to find a solution for minimizing the negative influence of climate change. The goal is to achieve favorable conditions both in the exterior and in the interior of buildings.

**Keywords:** Urban heat island, energy design of a building, climate changes, outdoor simulation

# Anotace:

Diplomová práce je zaměřena na vyhodnocení tepelného ostrovu města. Analýza tepelného ostrova je provedena pro zadanou část hlavního města Prahy. Součástí analýzy bude předpoklad změny klimatu. Cílem simulace tepelného ostrovu Prahy je sledování změny exteriérových podmínek v zadaném území. Tyto změny mají vliv na tepelnou pohodu nejen v exteriéru, ale i v interiéru budov. Součástí analýzy bude popis vlivu změny klimatu na návrh energetické koncepce budovy. Na závěr bude provedena diskuze o úpravě vnějšího prostředí takovým způsobem, aby bylo dosaženo příznivějších podmínek jak v exteriéru, tak v interiéru budov.

**Klíčová slova:** Tepelný ostrov města, energetický návrh budovy, klimatické změny, simulace vnějšího prostředí

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# List of used symbols

| | | |
|---|---|---|
| H | [m] | Height of a building |
| W | [m] | Width of a building |
| q | $[W.m^{-2}]$ | Density of heat flux |
| $q_{cd}$ | $[kg.m^{-2}.s^{-1}]$ | Density of diffusion stream |
| c | $[J.kg^{-1}.K^{-1}]$ | Specific heat capacity |
| $\lambda$ | $[W.m^{-1}.K^{-1}]$ | Thermal conductivity coefficient |
| R | $[m^2.K.W^{-1}]$ | Heat resistance |
| U | $[W.m^{-2}.K^{-1}]$ | Heat transfer coefficient |
| $H_f$ | $[W.K^{-1}]$ | Specific heat flux |
| Q | [W] | Heat flux |
| E | [J] | Energy |
| $\mu$ | [–] | Diffusion resistance factor |
| p | [Pa] | Partial water vapor pressure |
| $p_{sat}$ | [Pa] | Partial pressure of saturated water vapor |
| v | $[kg.m^{-3}]$ | Water vapor concentration |
| $v_{sat}$ | $[kg.m^{-3}]$ | The concentration of saturated water vapor |
| $\varphi$ | [–] | Relative humidity |
| G | $[kg.s^{-1}]$ | Humidity flow |
| $\rho$ | $[kg.m^{-3}]$ | Bulk density |
| t | [s] | Time |
| T | [K] | Temperature |
| $\Theta$ | [°C] | Temperature |
| $\Delta\Theta_{a,n}$ | [°C] | Temperature difference of LCZ at night |
| $\Theta_{a,n,max}$ | [°C] | Max. hour temp. of particular LCZ at night |
| $\Delta\Theta_{a,d}$ | [°C] | Temperature difference of LCZ at day time |
| $\Theta_{a,d,max}$ | [°C] | Min. hour temp. of particular LCZ at day time |
| d | [m] | Thickness |
| A | $[m^2]$ | Area |
| V | $[m^3]$ | Volume |

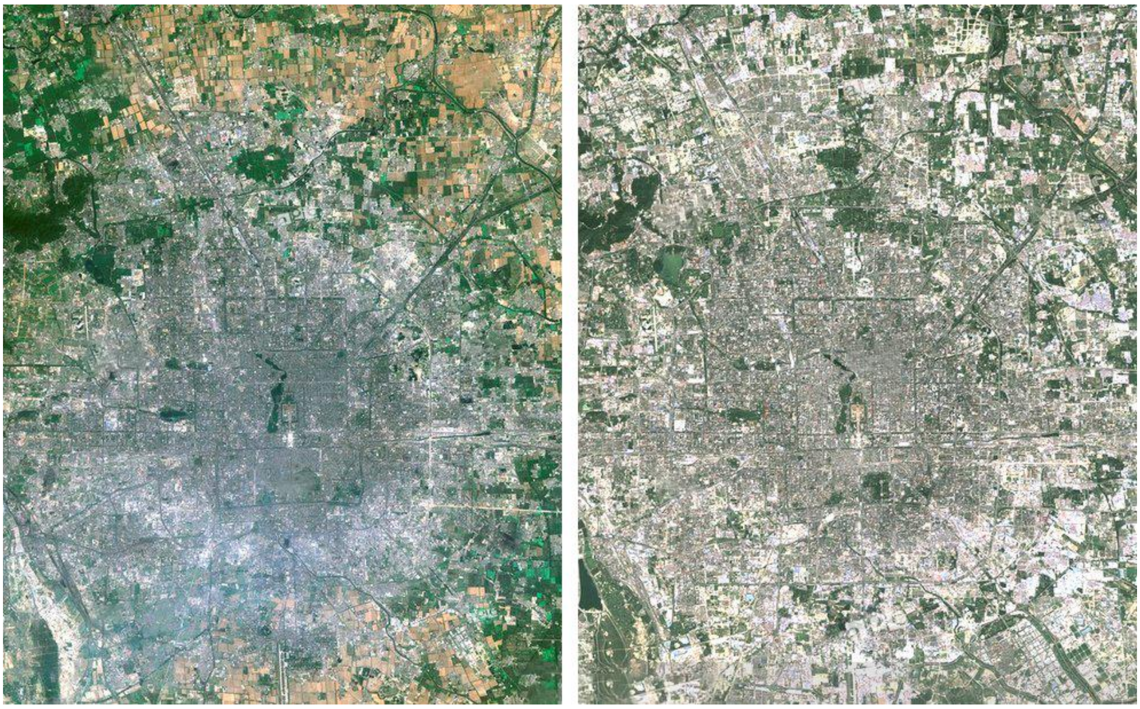
| | | |
|---|---|---|
| $V_a$ | $[m^3.h^{-1}]$ | Supply air volume flow |
| n | $[h^{-1}]$ | Air exchange rate |
| $\psi_{sky}$ | [-] | Sky view factor |
| $\lambda_f$ | [-] | Frontal aspect ratio |
| $\lambda_h$ | [%] | Building plan fraction |
| $\lambda_i$ | [%] | Impervious plan fraction |
| $\lambda_s$ | H/W [-] | Canyon aspect ration |
| $Z_h$ | [m] | Mean height of roughness elements |
| $Z_0$ | [m] | Aerodynamical roughness length |
| $\alpha$ | [-] | Roughness |
| $\mu$ | $[J.m^{-2}.s^{-0,5}.K^{-1}]$ | Thermal admittance of system |
| $Q_f$ | $[W.m^2]$ | Anthropogenic heat flux density |

# 1 Introduction

The project "The Influence of an Urban Heat Island on the energy Design of a Building" was drafted in cooperation with National Cheng Kung University in Tainan, especially with professor Tzu-Ping Lin and the Buildings&Climate Lab at the Department of Architecture in the College of Planning and Design.

The topic of this thesis is based on successive changes in the environment, predominantly on the global climate change. Its influence is visible on every part of the Earth. Significant influence has the role of human activity. Since the population is getting bigger, the industrial production grows. There is not enough living space and the natural environment is being transformed.

In the nineteenth century, the tendency of population growth was linear and now it is quadratic. Because people need a place to live, the natural space around us is being reduced. The cities are getting bigger and the greenery is decreasing. The more people there are in the city, the more heat and moisture from their typical activities is being produces.



*Pic. 1: Beijing, China in 1999 and 2013 (1)*

According to Czech Statistical Office in Prague (2), there is 25 hectares of agricultural land less per day. That is more than 160 thousand hectares since the year 2000. How can these facts influence the thermal comfort in Czech Republic?

The urban heat island effect does not necessarily have to be negative to its population. It depends on the local climate conditions. Some cities with cold climate may use this effect as an advantage. Winters are not as cold and the summer time gets warmer. It can improve the exterior comfort – the weather is more suitable for the population, people can save money for heating during the winter period and the roads may not freeze.

On the other hand, the cities with warm climate may suffer by extensive heat stress in the streets. During this extreme period the mortality of the city citizen in increased. It is especially dangerous for elder people or individuals with health problems. Also, the sportsmen may suffer health issues of eventually death from the effects of overheating.

The next impact is the change of biodiversity and threat of the natural ecosystems. But it is more an issue of climate change in general.

Here are the causes of UHI effect by Timothy R. Oke defined in 1982:

„Greater absorption of solar radiation due to multiple reflection and radiation trapping by building walls and vertical surfaces in the city. Greater absorption is not, as often assumed, due solely to lower albedo of urban materials.

Greater retention of infrared radiation in street canyons due to restricted view of the radiatively „cold" sky hemisphere. Sky view becomes increasingly restricted with taller and more compact buildings.

Greater uptake and delayed release of heat by buildings and paved surfaces in the city. Often incorrectly attributed only to the thermal properties of the materials, this effect is also due to the solar and infrared radiation „trap" and to reduced convective losses in the canopy layer where airflow is retarded.

Greater portion of absorbed solar radiation at the surface is converted to sensible rather than latent heat forms. This effect is due to the replacement of moist soils and plants with paved and water proofed surfaces, and a resultant decline in surface evaporation.

Greater release of sensible and latent heat from the combustion of fuels for urban transport, industrial processing, and domestic space heating/cooling. Heat and moisture are also released from human metabolism, but this is usually a minor component of the surface energy balance.” (3)

At the beginning of this project, the climate conditions in Czech Republic and Taiwan were compared. The description of differences in construction methods in both countries is included.

After the climate description, an urban heat island analysis of Prague was executed. The analysis got us know better the exterior conditions of selected part of Prague. LCZ maps of both cities were compared in order to local climate conditions and the city urbanism. After the urban heat island analysis is completed, the discussion over efficient energy design of a building was held. The placement of the building into the selected territory can have a significant impact to the design itself. The goal is to achieve favorable conditions in the interior and also not to worsen the outdoor conditions.

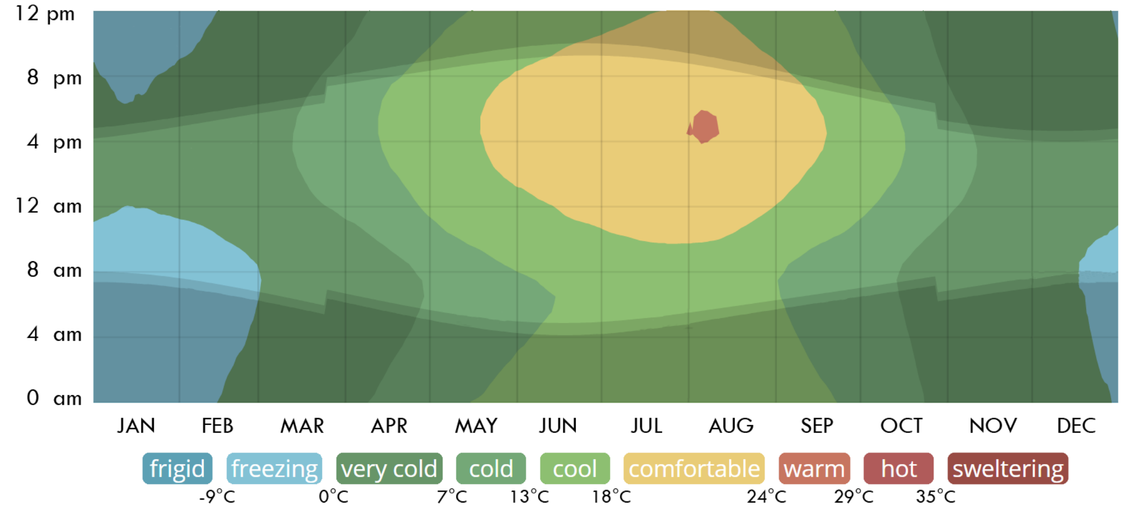
# 2 Comparison of climate and geographic conditions in the Czech Republic and Taiwan (ROC)

## 2.1 General information – Czechia

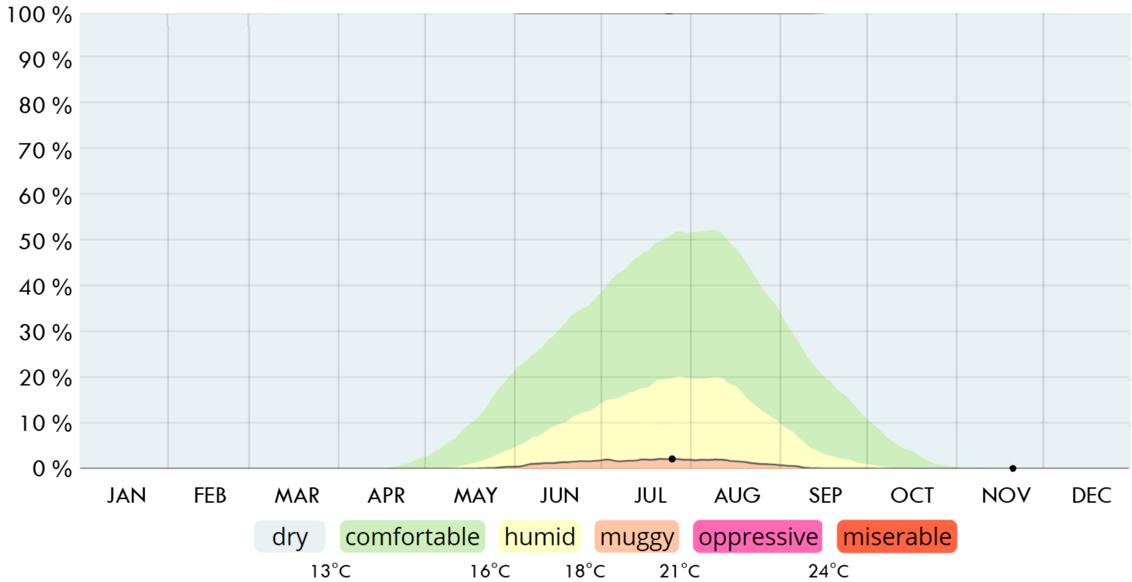
Czech Republic is located in the central Europe at 50° north latitude and 16° east longitude. It borders with Germany in the west, Poland in the north-east, Slovakia in the south-east and Austria in the south. The area in Czech is 78,866 km$^2$ and the population is 10.611 mil. people. The climate in Czech Republic is mostly mild and continental. The precipitation is mostly steady with heavier rains in the summer season. Most of the territory in Czech Republic is classified a Dfb (humid continental climate) in the Köppen-Geiger classifficition system. Only a small areas are classiffied as Cfb (oceanic climate – especially in the Ore Mountains and in The Krkonoše) and Dfc (subarctic climate – especially in the Bohemian Forest).

*Pic. 2: Location of Czech Republic on the Globe (4)*

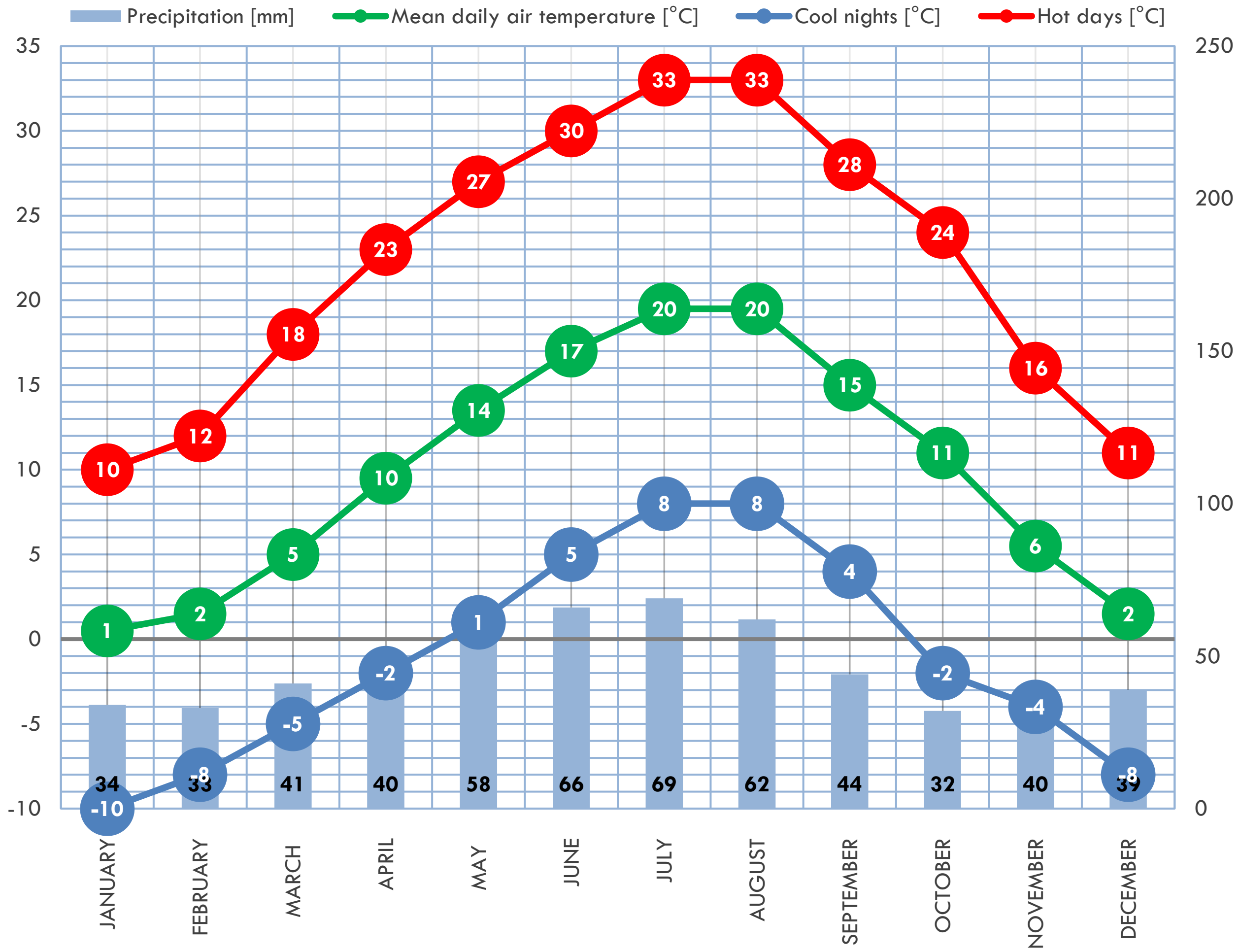
The placement of Czech Republic in the center of Europe has a significant influence to the local climate conditions. It is characteristic with the temperature fluctuation. There are considerable air temperature fluctuations in winter and summer. But there are also great differences between the day and night air temperature. The hottest month is June and July. The coolest month is December together with January and February.




*Pic. 3: Average hourly temperature in Prague (5)*




*Pic. 4: Humidity comfort levels in Prague (5)*




*Pic. 5: Climate data Prague, Czech Republic (6)*

Central Europe has four seasons. Spring, summer, autumn and winter. Spring starts on the 1st march and it is characterized by temperatures around 10 °C. In this period, the flowers and trees bloom. Summer is the hottest season. The average temperature differentiates according to the locality. The autumn is known for lower temperatures, it also brings continuous raining.

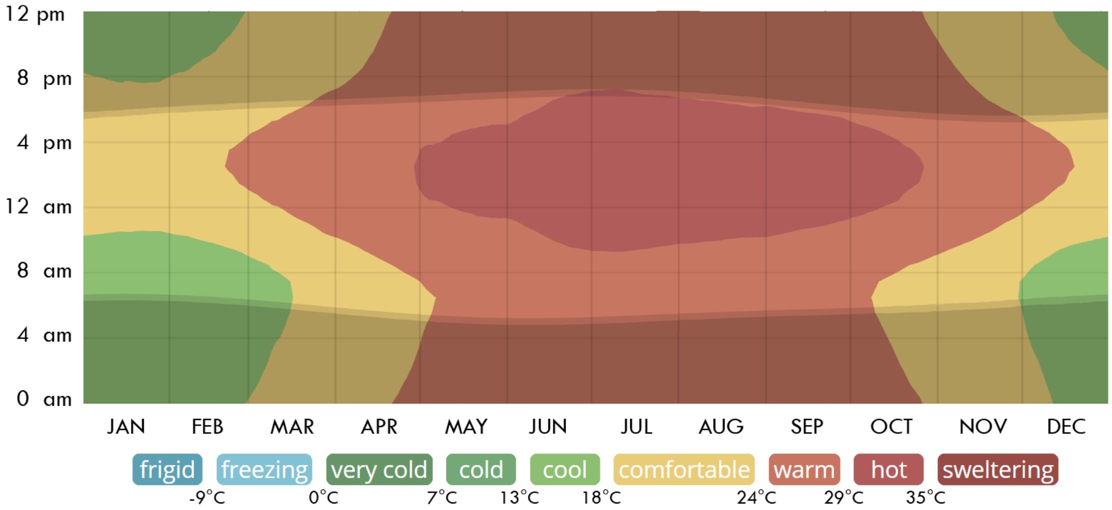
Winter temperature can get under -20 °C, the lowest recorded temperatures on the Czech territory reached values lower than -40 °C.

## 2.2 General information – Taiwan (ROC)

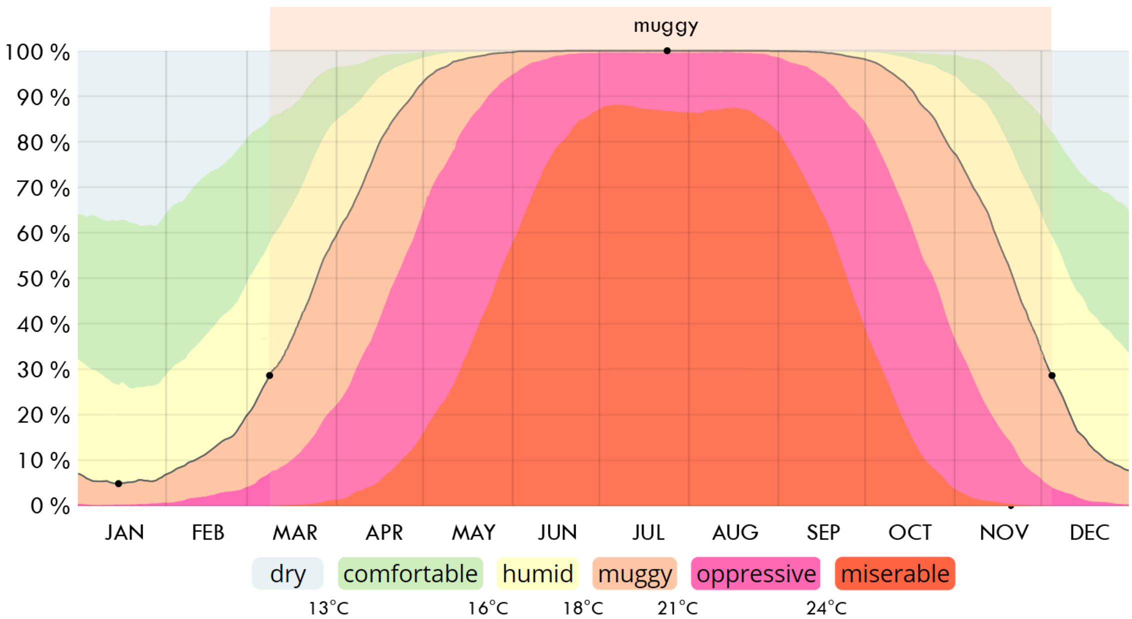
Republic of China (ROC), better known as Taiwan, is located in the east Asia at 24° north latitude and 121° east longitude. It consists of six islands – Taiwan Island, Matsu Island, Penghu, Kinmen, Taiping Island and Dongsha Island. The Taiwan Island is the fourth highest island on the World. The highest point is almost 4 km. It is being surrounded by the South China Sea in the southwest, Philippine Sea in the east and the East China Sea in the northeast. The island was created by the tectonic shifts and volcanic activity. Four dominant cities are Taipei, Taichung City, Tainan City and Kaohsiung City. The area in Taiwan is 36,197 $km^2$ and the population is 23.572 mil. people. The climate is marine and tropical. According to Köppen-Geiger classification, the Taiwanese climate is classified as Cfa – humid subtropical. A small south part of Taiwan is classified as Aw – a tropical monsoon climate. The sky is cloudy during most time in the year. There is a rainy/typhoon season from June to October.

*Pic. 6: Location of Taiwan on the Globe (4)*

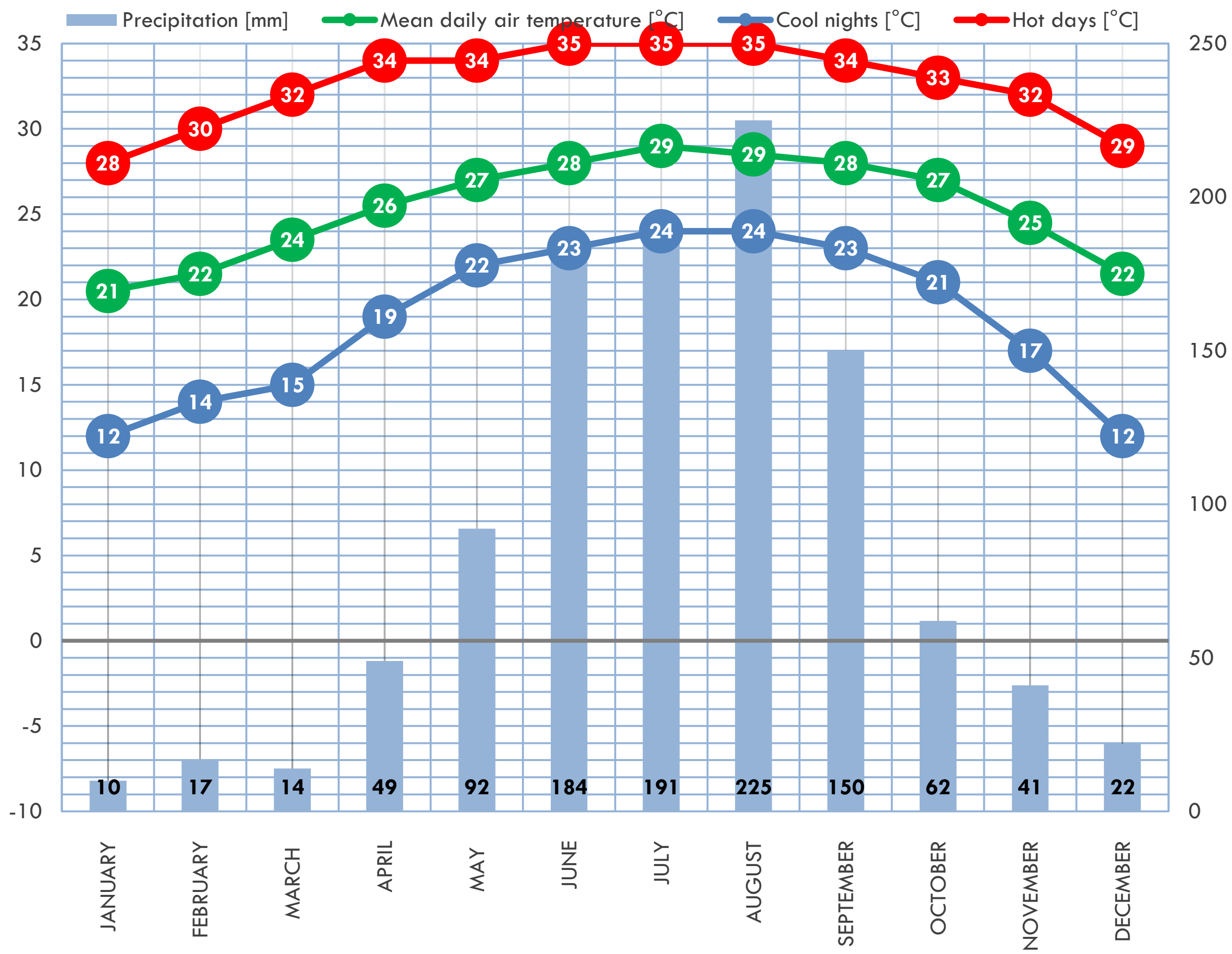
Location of Taiwan and its placement in the ocean determines local climate. The winters days and nights are colder than summer ones. The meat air temperature fluctuation between summer and winter is around 7 °C. In Czech Republic the difference was 25 °C. That is more than 3 times more. It is raining significantly less in the winter. The humid summer time is coming in April. The average month precipitation grows rapidly due to upcoming summer monsoon in June. In this time, intensive raining can cause flooding. Summer storms above the sea can also initiate creation of a typhoon.




*Pic. 7: Average hourly temperature in Tainan (5)*




*Pic. 8: Humidity comfort levels in Tainan (5)*




*Pic. 9: Climate data Tainan, Taiwan (6)*

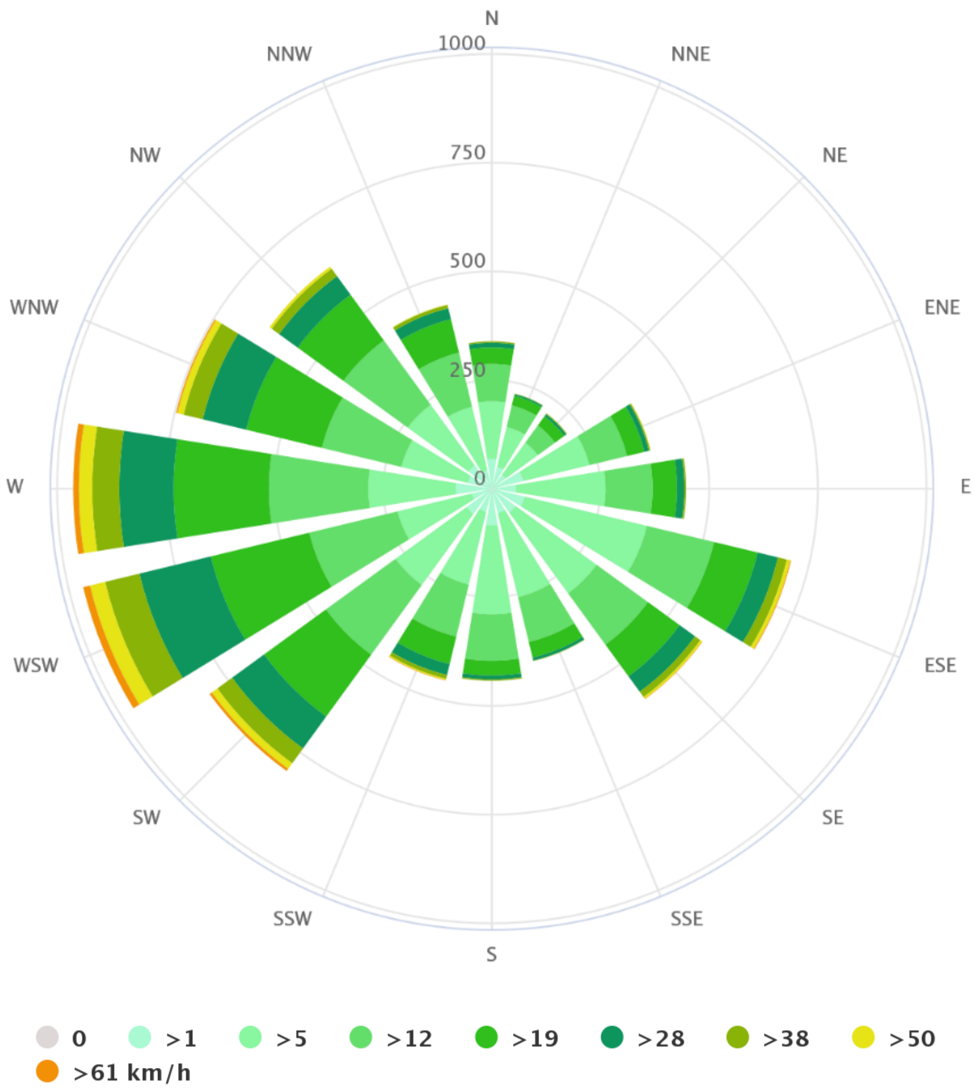
In comparison with Czech Republic, the total amount of precipitation during the year is two times bigger. Also, most of the precipitation rains during the summer season. In Czech Republic it is raining more stable. On the other hand, the air temperature fluctuation is more stable in Taiwan. The most noticeable difference is the absolute humidity of the air. The warmer air can hold larger amount of water vapor.

## 2.3 Wind specification – Prague, Czechia

The overcoming western wind stream and the position of Czech Republic in order to Atlantic ocean brings continental character from the west to the east. Although the size of the country is relativelly small, so the differences between the west and the east are not enormous.

The western facades are often more exposed to the effect of wind forces. The wind speed achieves greater values than the wind speed in Tainan. The wind speed and direction in concrete month has a significant influece to the urban heat island distribution. Wind rose used for evaluation of UHI is more precize.

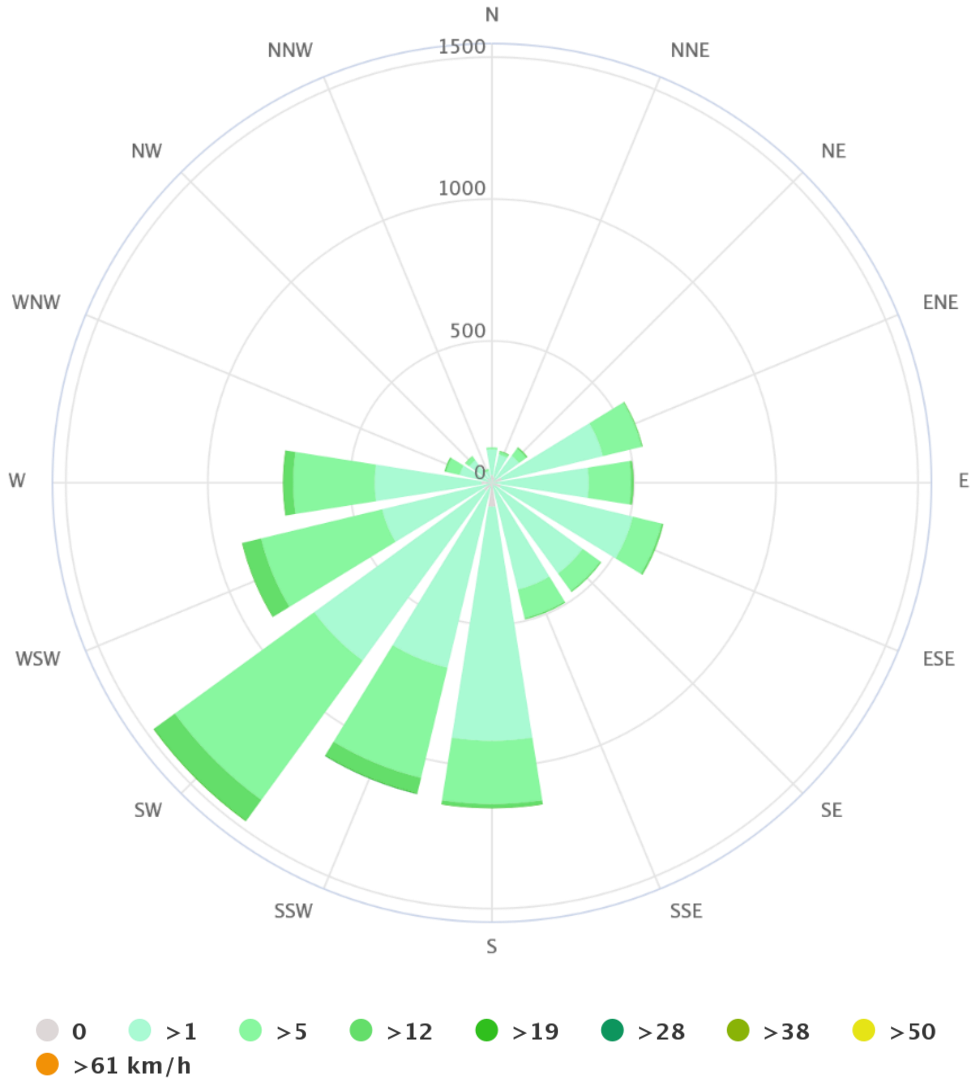
This wind rose consists of annual data statistics.




*Pic. 11: Annual wind diagram Prague, Czech Republic (6)*

## 2.4 Wind specification – Prague, Taiwan

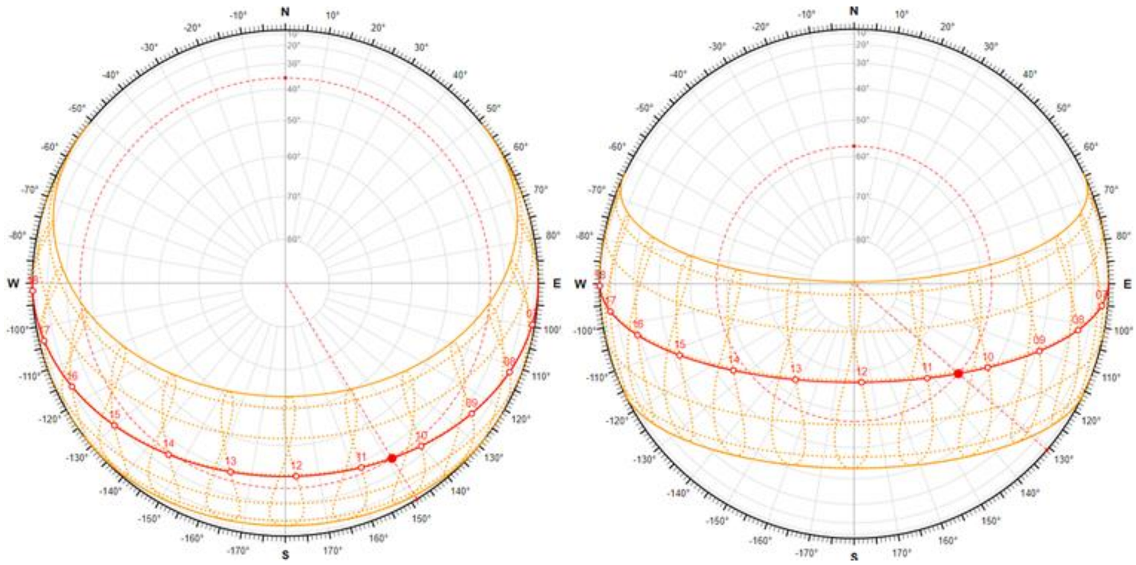
The wind description is shown by the wind rose on the bottom of this page. Although, this wind rose shows annual wind statistics in Tainan. The wind direction and wind speed differentiate according to the position of particular station. The average month statistics are also different from this annual wind rose. Especially for the summer season, the wind is coming significantly more from the North to the South. The wind intensity is slower than the intensity in Czechia. The wind coming from the ocean is being slowed down by the surrounding mountains and forests – the roughness is much bigger. Prague is much flatter, so it allows the air travel faster. Note: The scale of the following wind rose is different apart from the previous one.




*Pic. 12: Annual wind diagram Tainan, Taiwan (6)*

## 2.5 Sun path specification – Prague, Czechia vs. Tainan, Taiwan

Prague is located at the 50° north latitude. Taiwan lies at the 24°north latitude. So, the sunshine in Prague comes more from the horizon, while the sunshine at Tainan comes more from above. This position also influences the summer and winter day time. During the summer solstice, the Sun shines on Tainan for 13.5 hours. In Prague the Sun shines for 16.4 hours. During the winter solstice, the Sun shines on Tainan for 10.8 hours. In Prague, the Sun shines only for 8 hours. The amount of incident light greatly affects the local climate.



*Pic. 13: Sun diagram Prague, Czech Republic vs. Tainan, Taiwan (7)*

## 2.6 Natural phenomena influencing the approach to the building design

### 2.6.1 Floods

In Czechia, flood is usually caused by the spillage of excess water it the basin. The spillage may occur due to sudden heavy raining, due to intensive long-term raining or due to spring snow melting. The ground can soak about 15-25 mm of rainwater. After saturation like this, the water cannot be hold anymore. The water is being transferred into the river, which level rises. There are more weak-intensity floods during the year. The bigger the flood is, the probability of its occurrence degreases.

Floods can be harmful in several ways. A soil erosion may occur in the upper streams. This erosion can damage subsoil in near housing area. The onset of the flood is faster than in the lower streams. The water here can spread more and can hit more dens populated areas.

In history, buildings around rivers were usually made of stone. These constructions could be flooded from time to time without greater damage. Nowadays houses usually cannot withstand the tide of a river. Flood can significantly damage and even destroy close building.

Floods in Taiwan have similar causes like the Czech Republic ones except the snow melting. Heavy rains can be also brought to the territory with typhoon. More information about cyclones are listed below.

### 2.6.2 Fires

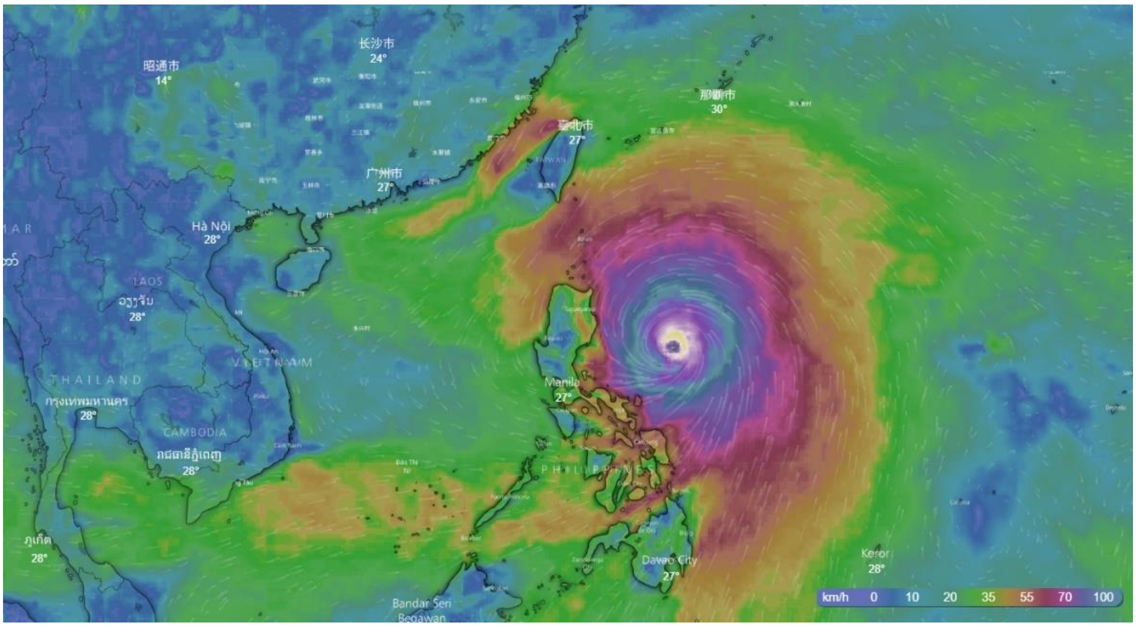
There were plenty of fires in Czech Republic during the summer 2018. The total number was two times higher than the year before. The main cause was the hot and dry weather. More interesting than the count of fires is the fact, that about 50 % of all the fires were set naturally in the countryside.

The worst fires are field fires which can spread rapidly. The spreading speed is increased by the wind forces.

Taiwanese countryside is not affected by fires that much. Higher amount of precipitation keeps the greenery irrigated. Which prevents the spontaneous fire ignition. The solar energy causes the water to evaporate, so the soil does not absorb the energy and the area is not that hot. This cooling effect is not present in Prague, since the soil is desiccated and does not allow to preserve any precipitation. The water cannot be absorbed to the ground and is taken to the sewers. The only way, how to use the water evaporation effect for cooling the streets, is to water the greenery on daily basis.

### 2.6.3 Cyclones

Tropical cyclones, sometimes called hurricanes in America or typhoons in Northwestern Pacific Basin, are atmospheric formations in a shape of a huge storm whirlwind. These low-pressure cyclones are usually formed above the warm ocean waters. They are habitually developed in the summers season between June and November. There are around 100 storms every year. But only a few of them approach coasts with devastating force. Once these cyclones approach the ground, their force weakens.




*Pic. 14: Tropical cyclone on 14th September 2018 near the Filipino and Taiwan coast (8)*

### 2.6.4 Earthquakes

Czechia has a few seismic areas. The main aria is Karlovy Vary Region. Although it is a calm region with only a couple of shakes per decade. (9) The types of earthquakes in Czech Republic are tectonic, mining shocks and earthquake swarm. Unusually strong earthquakes can achieve 4-5 points on the Richter Magnitude scale. These 4-5 points shakes occur on Taiwan weekly. (9) There were 103 earthquakes in past year and the largest one achieved 6.4 points on the Richter Magnitude scale. (10)

Justification for these phenomena is the Taiwanese locality. It is located in the Pacific Ring of Fire – seismically active zone which is 40,000 km long. It goes from the New Zealand area to Indonesia, Philippines, Taiwan, Japan, Kamchatka Peninsula and the west coast of American continent.

Due to these activities, the Taiwanese structures are design differently beside to Czech principles. The column load bearing system is predominant in larger buildings. Fixed joints are used less, even the foundations are flexible – the building does not absorb the shake forces as it would with fixed foundations. These principles have been used for centuries. Even old Taiwanese temples follow meet now-days structural principles.

*Pic. 15: Flexible wooden joint used in old Taiwanese temples, prevents from splitting and cracking built by Hsu Han-Chen (photo taken at the Department of Architecture at the NCKU in Tainan)*

Greater structures use more sophisticated measures. In Taipei 101 there is a 730-ton ball which oscillates to keep the building stable. It absorbs the dynamical forces caused by earthquakes and also wind forces. The device prevents any discomfort of the people. And of course, it precedes the structural failure.

### 2.6.5 Other phenomena

Beside from above phenomena, the Taiwanese approach to building design is significantly amended by the steady outside temperature. The average minimum temperature in Tainan is 14 °C, with the lowest recorded minimum around 8 °C.

This fact changes the approach to the design from a point of view of thermal protection of buildings and building services. The buildings usually do not have any heating system.

According to the Czech decree 194/2007 Coll., the heat supply is started in the heating season when the average outdoor air temperature drops below 13 °C for two consecutive days and the weather cannot be expected to increase above +13 °C for the next day.

If this decree was valid in Taiwan, the heating season would have never come. The buildings also do not need a thermal protection layer – the thermal insulation.

The usual U value of an outer wall is around U=0,8 $W/m^2.K$ which is sufficiently efficient. There are no given specific thermal bonding requirements – the cool outside air penetrating into the interior does not cause the interior surface to cool under the dew point.

Thanks to this fact, there is no need for studying thermal protection of buildings as it is in the Czech Republic. The indoor comfort and building design approach are mostly influenced by summer extreme temperatures.

The attention is paid to the shading design, suitable building placement to the locality, greenery placement around buildings and the design of green facades and roofs. Hand in hand goes the design of building cooling systems. The cooling is predominantly local, central systems are used in larger new buildings like administrative buildings, hospitals, shopping centers etc.

# 3 Field measurement of surface temperatures in Tainan

The goal of the field measurement was to get know the typical outdoor surface temperatures in Tainan in October. This information was important to gain experience about typical conditions in the exterior space in the middle of the day in Tainan. It also helps to define what measures are the most efficient for reducing surface temperatures.

The InfReC thermal-imaging camera was used for this experiment – concretely model InfReC R500EX Series '17/11. The camera is able to detect emitted infrared energy from monitored objects. In converts the energy into temperature. The image shows temperature distribution in the field of a view.


*Pic. 16: Thermal-imaging camera InfReC R500EX Series '17/11*

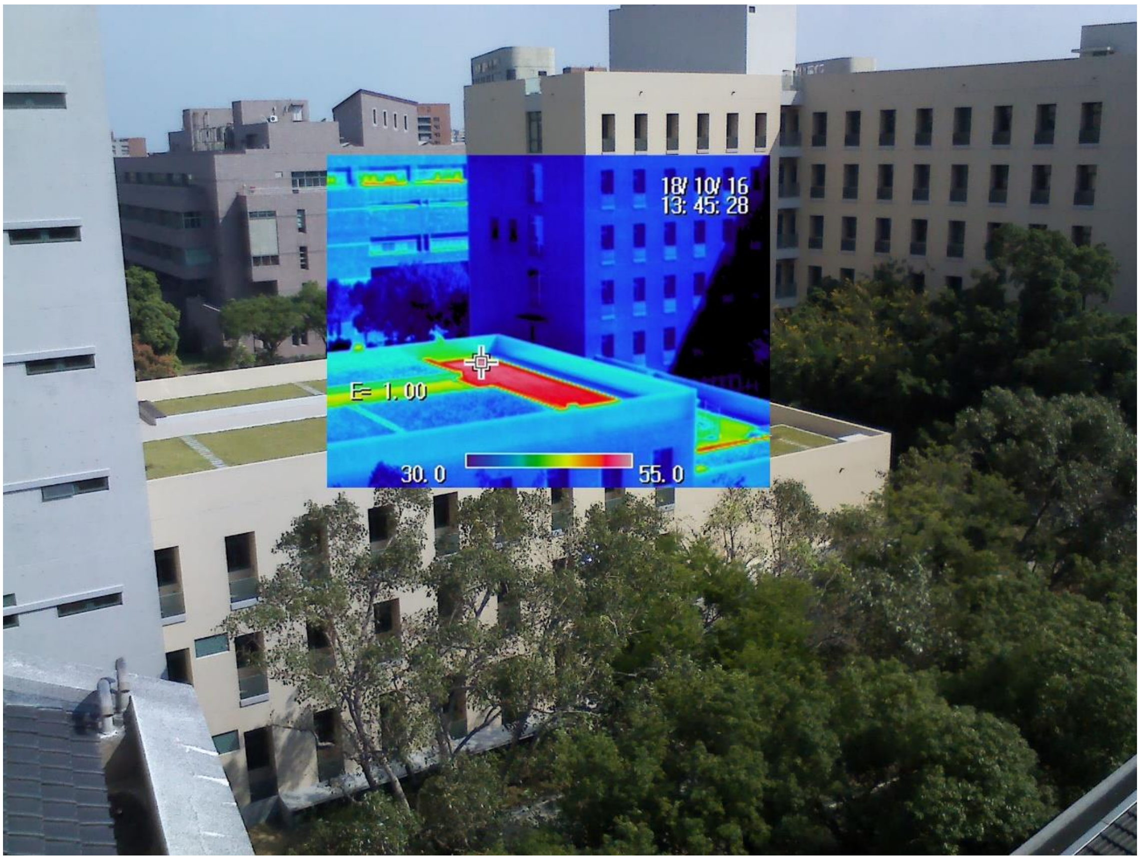
The measurement was takes from 1 pm. to 3 pm. on 16$^{th}$ October 2018 at the campus of NCKU in Tainan. The most searched sceneries were localities with the most diverse materials used in constructions. In the ideal case, the scenery was party shaded. So, there was a visible difference between the surface temperatures.

## 3.1 Green roof vs roof made of solid surface materials

This image shows the surface temperatures of different surfaces on the roof of National Center of Theoretical Sciences. The roof is not shaded during the most of the day. The middle layer, which is composed of a solid white pavement, has the surface temperature around 45 °C. The hot surface (red layer) is also made of solid material but its color is dark. The temperature is higher than 50 °C. The difference between the surfaces is more than 5 °C.

The extensive green roof, which is regularly watered, has 35 °C. So, the difference between the green roof and the dark solid surface is more than 15 °C and the difference between the green roof and the white solid surface in more than 10 °C.

As well it is visible that the difference between white facade temperature and white roof temperature is more than 5 °C.



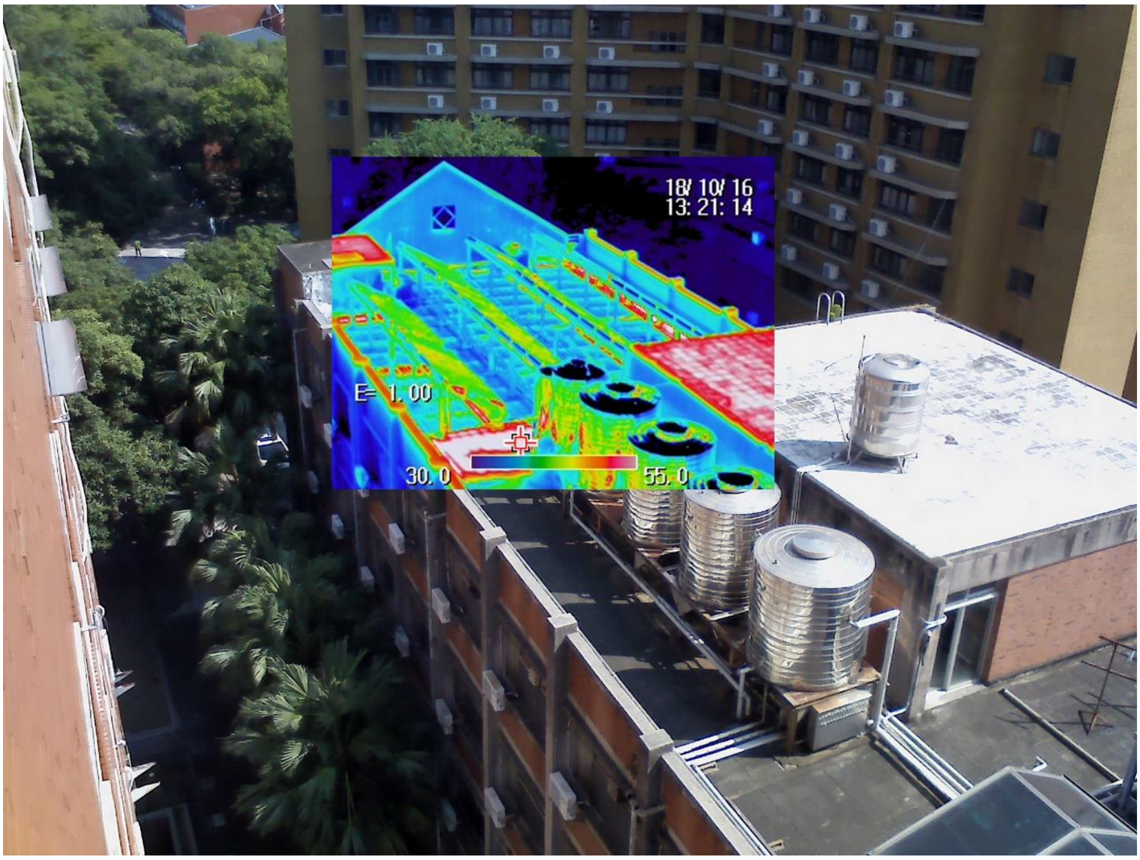

*Pic. 17: Thermal image of green roof and surrounding buildings at NCKU*

## 3.2 Roof with solar panels

This picture shows several building services placed on the roof which is located on the Department of Architecture NCKU. There are solar panels, service water tanks and local air conditioning machines on the NCKU dormitory building.

The thermal image captures the surface temperature of solar panels. The panels were directly shined from the Sun. The temperature at 1:21 pm. reached 45 °C.

There are visible air conditioning machines on the right upper side of the picture. The machine that is turned on has the temperature close to 40 °C, which is 10 °C more than the turned off machine.



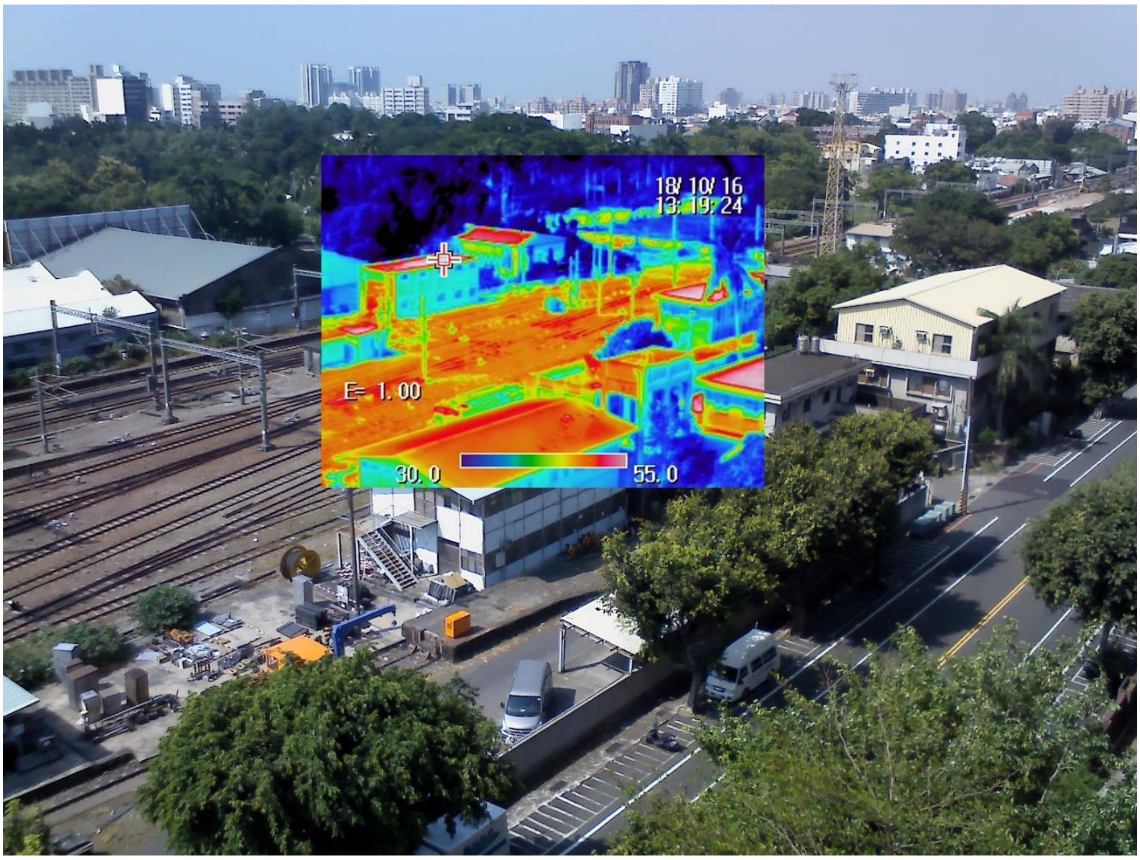

*Pic. 18: Thermal image of solar panels placed on the Dept. of Architecture*

### 3.3 Tainan railway station

Tainan railway station stands on the west side of NCKU campus. It is surrounded by compact building development. On its north-west side there is a Tainan park which can be seen in the photo.

The thermal image shows a variety of surfaces at the station. Railway station are places where the temperatures reaches the peak. The railway is composed by gravel, pavements and iron rails. The outdoor space here is not heated only by the Sun but also from the rail transportation, road transportation and high population density. The trains are well air conditioned. The temperature is even uncomfortably low. To keep this low temperature inside, the AC machines have to give the warm air out. All these facts keep the station one of the warmest places in the city.

The vast majority of surfaces reach a temperature of 50 °C. The coolest place is the nearby park which cover 0.2 km$^2$ big area.



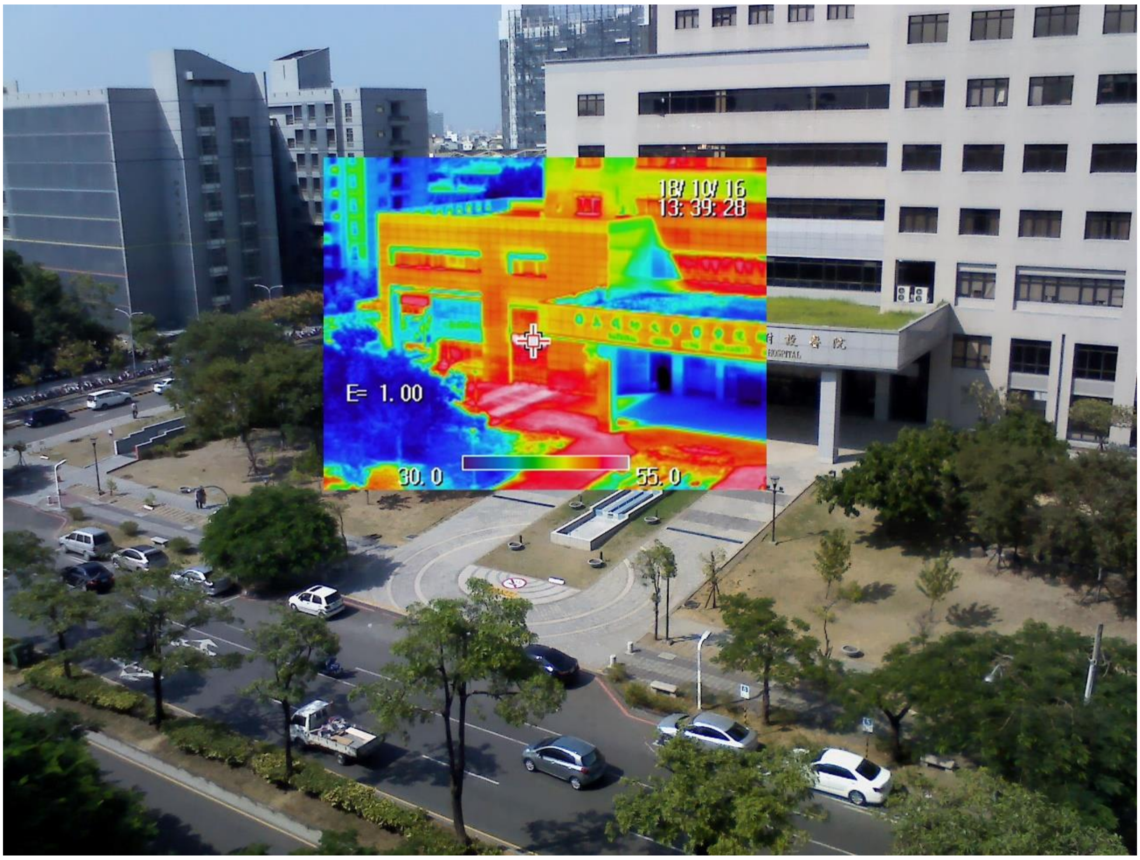

*Pic. 19: Thermal image of the railway station in Tainan*

### 3.4 Hospital facade

The hospital entrance is shown on this image. This scene captures effects of used shadings, various surface materials and colors. The shading can lower the temperature of stone pavement up to 15 °C.

As well it shows the difference between surface temperatures of surrounding trees, watered grass and dry grass. The dry grass/bare soil can reach up to 50 °C. On the other hand, the watered grass reaches around 40 °C.

The symbols on the front of the building are glossy and reflect part of the sunshine. So, its temperature is around 5 °C lower than is the surface of the grey facade.



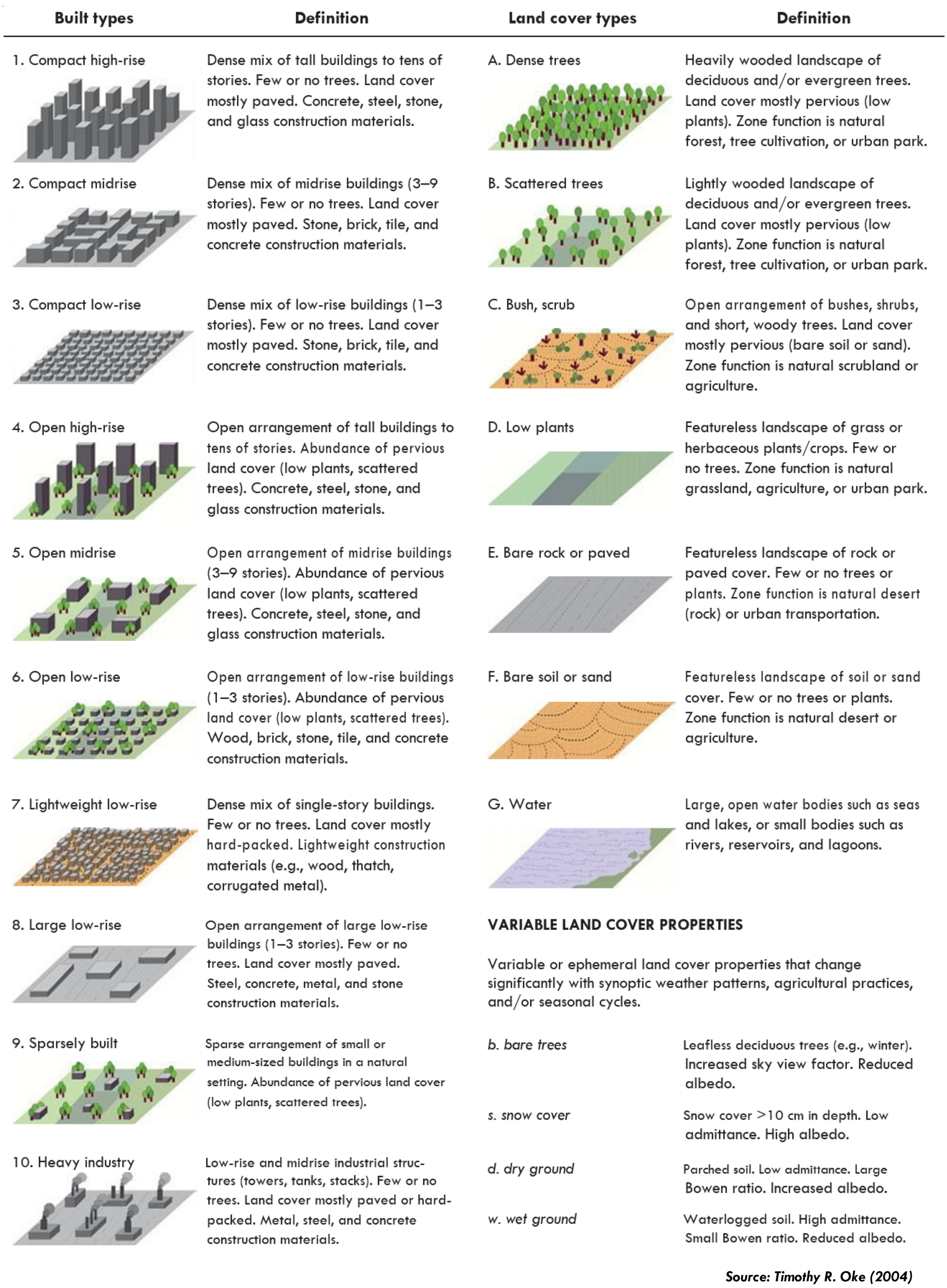

*Pic. 20: Thermal image of hospital building in the center of Tainan*

# 4 Comparison of Local Climate Zone classification in Prague and in Tainan

## 4.1 Local Climate Zone

The variability of urban climate in cities is being influenced by many factors. These factors are: surface materials and their properties (emissivity, specific heat capacity, thermal conductivity, bulk density). Important criterium is the building layout, building shape and its height. These criteria go hand in hand with the population density – heat produced by people.

Cities usually have more varied areas. To produce a temperature study, it is needed to split the city into areas with similar properties – to the local climate zones. These zones describe the local conditions in the particular zone. The following zones correspond to Timothy R. Oke's urban climate zones from the year 2004. The basic LCZ types divide into built types and land cover types. The varied characteristics of local climate zones are: Building plan fraction $\lambda_h$ [%], impervious plan fraction $\lambda_I$ [%], canyon aspect ratio $\lambda_s$ = Height/Width [-], sky view factor $f_{sky}$ [-], mean height of roughness elements $Z_h$ [m], thermal admittance of system $\mu$ [$J.m^{-2}.s^{-0,5}.k^{-1}$], anthropogenic heat flux density $Q_f$ [$W.m^{-2}$].



| Built types | Definition | Land cover types | Definition |
|---|---|---|---|
| 1. Compact high-rise | Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials. | A. Dense trees | Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park. |
| 2. Compact midrise | Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials. | B. Scattered trees | Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park. |
| 3. Compact low-rise | Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials. | C. Bush, scrub | Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture. |
| 4. Open high-rise | Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials. | D. Low plants | Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park. |
| 5. Open midrise | Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials. | E. Bare rock or paved | Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation. |
| 6. Open low-rise | Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials. | F. Bare soil or sand | Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture. |
| 7. Lightweight low-rise | Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal). | G. Water | Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons. |
| 8. Large low-rise | Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials. | **VARIABLE LAND COVER PROPERTIES** Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles. | |
| 9. Sparsely built | Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees). | *b. bare trees* | Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo. |
| | | *s. snow cover* | Snow cover >10 cm in depth. Low admittance. High albedo. |
| 10. Heavy industry | Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials. | *d. dry ground* | Parched soil. Low admittance. Large Bowen ratio. Increased albedo. |
| | | *w. wet ground* | Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo. |

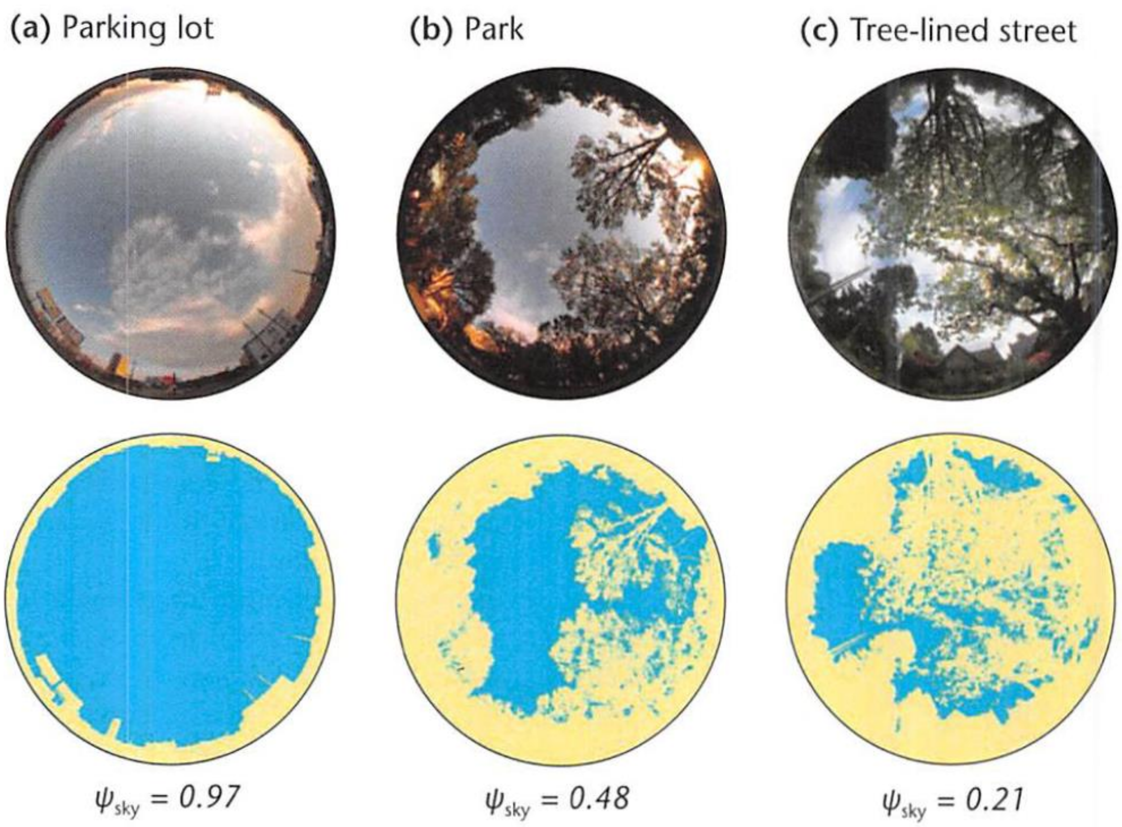
***Source: Timothy R. Oke (2004)***

*Pic. 21: Local climate zones defined by Timothy R. Oke from the University of British Columbia (2004)*

The typical horizontal scale length a zone is around 2x2 m. Roughness of each zone also determines the wind conditions in concrete area. The air flow can fundamentally reduce high city temperatures. If the wind speed is reduced, the heat may accumulate and become a risk. The airflow relevant parameter is the frontal aspect ratio $\lambda_f$.

As reference, it is worth to mention the consequence of a wrong tree placement in the city. The greenery's cooling effect through evaporation and water retention can significantly lower the outdoor temperature. On the other hand, if a group of trees block the air stream going through the city, the air temperature may increase – especially in high-rise areas.

Another interesting diversity of LCZs is the shading. There are typical values of sky view factors determined for each zone. These values were obtained from field measuring on urban sites and are shown below.




*Pic. 22: Example of fish-eye lens photos which are used to calculate the sky view factor (11)*

The LCZ methodology does not have to capture the reality in all cases. The land cover properties may vary according to many factors – like the locality of the zone.

## 4.2 LCZ classification

GIS approach WUDAPT (12) is taken to delimitate LCZ areas. It is needed to set around 5-10 training areas for each type manually. The number of set up zones reaches up to 110 areas. The zones are defined into a map as regions that cover the surface. Each zone has a typical height which is already set. Also, the temperature conditions are specified.

After such procedure, GIS software like SAGA may be utilized to classify an entire city into these areas. The accuracy of SAGA classification depends on the precision of the manual LCZ setting.

From the LCZ study we can observe what will the temperature differentiation in the city be like. According to numerical modelling and field observations, we can estimate the variance of mean air temperature at each zone.

But this access may not be accurate. A careful approach is required. The classifying into zones does not include the location of a zone. The thermal conditions in two identical zones are dependent on the placement of the zone in the city. The heat comfort will differ whether the zone is placed into the center of a city, in the suburbs or in the landscape with no buildings around.

In the center, there is minimum of trees and other greenery, surrounding areas consist of buildings. The population density per square kilometer is much higher – more heat produced by population. The airflow is reduced in the build-up center, so the heat cannot be drifted away. The pollution level is high.

On the other hand, the same zone, placed in the undeveloped natural area, may behave differently. The surrounding green area is characterized by low temperatures. The wind can access the zone to drift the heat away. In general, the zone placed in the suburbs will offer “better” thermal conditions.

The LCZ also does not carry any information about the energy consumption or the building type in the area. It may be a set of highly inefficient buildings, that consume a big load of energy for cooling or the area may be built by green buildings.

The local climate zone study of Prague is attached at the end of this thesis. As well, there is a study of Tainan city. These studies can show us the difference between cities building composition.

## 4.3 Comparison of Prague LCZ map and Tainan LCZ map

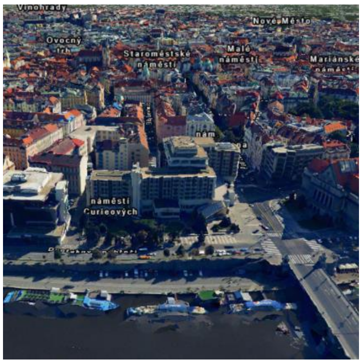
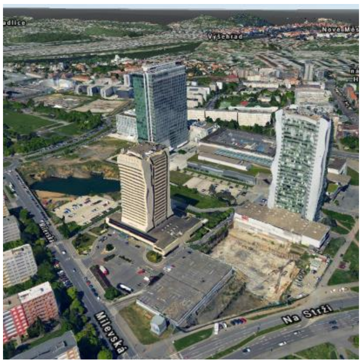
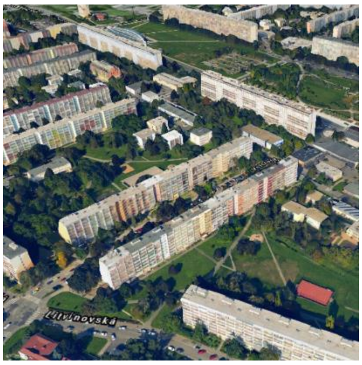
The Prague area is 496 km$^2$, the total population is 1.26 mil. people. Around half of the area is built. The city center is consistent. Usually filled with 4-6 floor buildings with sloping roof – the compact midrise area. The center streets consist of stone brick pavement and tree lines.

The zone type starts to differentiate with a greater distance from the center. It transforms into open midrise, compact low-rise and open low-rise buildings. Typical open midrise zones are the housing estates where around 40 % of Prague people live. These houses have been built since the end of the world war the second, during the communism era till today. Especially whole housing estates were built in the former regime.

There are not so many areas which could be classified to the zone type 1 and 2 – compact/open high-rise. One of those open areas is Pankrác neighborhood. Several commercial high-rise buildings are built in this location.

The compact/open low-rise building may be found usually in the suburb area. But they are still close to the city center, which can be reached by the metro system. An example may be the Podolí district. A calm area with villa houses that has a rural appearance.

*Tab. 1: Examples of picked localities used for LCZ manual settings (13)*

| | | |
|---|---|---|
| |  |  |
| 1 – no area located | 2 – Old Town | 3 – Chodov |
|  |  |  |
| 4 – Pankrác | 5 – Střížkov | 6 – Podolí |

The city center of Tainan is mainly composed of compact low-rise buildings. This zone is complemented by compact midrise and compact high-rise buildings – especially in the location near Tainan train station. The train station is put right next to the NCKU campus on the west.

There are several parks in the city which help the city to lower the maximum temperature. Through the city goes Zengwen River. The river flows into the South China see.

The city transforms into sparsely built zone when getting far from the city center. Apart from Prague, there are no open mid-rise buildings. There are only a few open low-rise areas. In the suburb areas the city is similar to Prague. There are fields which are complemented by smaller towns. The terrain is mostly flat. There are not as much trees as it is in Prague. The terrain mainly consists of smaller plants and bushes.

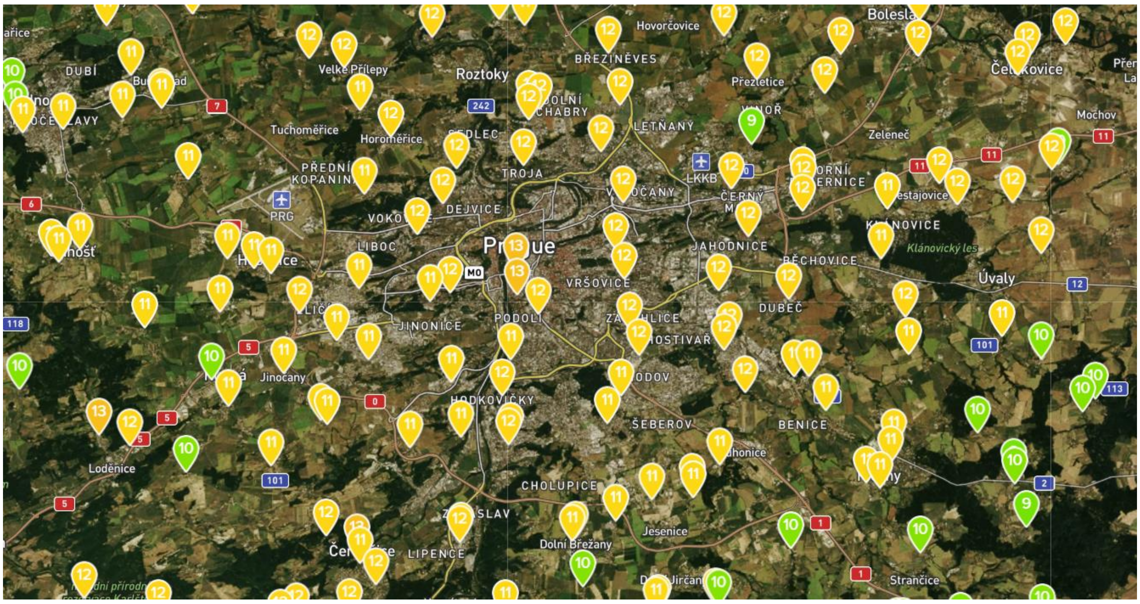
# 5 Thermal distribution map based on LCZ analysis

## 5.1 Methodology of estimating the LCZ temperatures

LCZ analysis is used for creating a thermal distribution map of Prague. This map shows the deviations from the mean air temperature in Prague. The map itself can show interesting data of the city based on the building development.

Every built type and land cover type has a specified hourly maximum air temperature for the hottest summer day. This estimation is based on observations of temperatures in given zones and expert assessment. It would be more precise to use data from meteorological stations from Prague. But since there are not enough stations, this study process has to be replaced. The measuring of outdoor air temperatures in Tainan (part of thermal-imaging study) was helpful to realize how temperatures differ in various zones.

The NETATMO (14) company map is used to find out the differences between temperatures in contrasting city locations. These data come from local meteorological station all around the city. They were used for more precise estimation of mean daily maximums. The NETATMO is a company which develops intuitive smart electronics including local weather stations. These stations are able to measure current values of these characteristics: temperature, humidity, air quality, ventilation warning ($CO_2$ emissions), sound intensity.



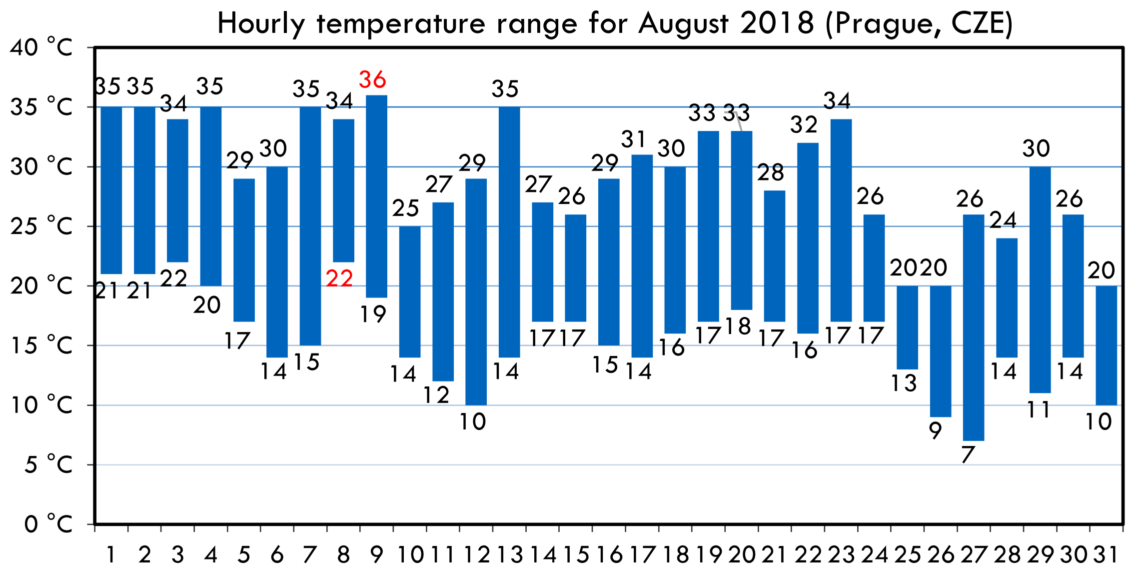

*Pic. 23: NETATMO data map from local weather stations (14)*

On the other hand, the temperature data are not precise. The data are rounded to integers. There is also no information about the meteorological station placement. It can stand in a shadow or in the sunshine. The station may be exposed to direct wind forces or not. In other words, this tool has to be used wisely. Not all the provided information is relevant.

To gain relatively accurate information, it was needed to gather data from all parts of the city (for each zone). Every zone temperature is set as an average out of 12 values. The highest and the lowest value was excluded out of the calculation. The rest was used to calculate the mean value. This average was calculated two times – first time for the night time (2 am.) and then for the day time (2 pm.). The night time temperature is marked by n bottom coefficient, the night time temperature is marked by d bottom coefficient.

Subsequently it is needed to find out summer maximum temperature that occur in Prague. The day/night maximum temperature data are recorded by a few meteorological stations in Prague. For our purpose, the Libuš station data were applied. Libuš is operated by the Czech Hydrometeorological Institute.

The maximum day temperature in August reached $\Theta_{a,d,max} = 36$ °C, at night the maximum temperature was $\Theta_{a,n,max} = 22$ °C. These high temperatures occurred in many other Czech cities like Brno, Ostrava, Plzeň etc. The following graph shows the range of temperatures in Prague recorded in the Libuš station. The highest value was used for UHI analysis as a default temperature.




*Pic. 24: Lowest/highest temperature graph from Prague Libuš meteorological station (15)*

## 5.2 Formula for calculating the average LCZ temperature

$$\o\Theta_{\mathrm{a,d,max}} = \Theta_{\mathrm{a,d,max}} + \Delta\Theta_{\mathrm{a,d}}\ [°\mathrm{C}] \tag{1}$$

„$\o\Theta_{a,d,max}$“ [°C] is a theoretical hourly maximum in the local climate zone, „$\Delta\Theta_{a,n}$“ [°C] is a deviation from $\Theta_{a,d,max}$ in the local climate zone.

$$\Delta\Theta_{\mathrm{a,d}} = \o\Theta_{\mathrm{a,d}} - \o\Theta_{\mathrm{a,d,prg}}\ [°\mathrm{C}] \tag{2}$$

„$\o\Theta_{a,d,prg}$“ [°C] is an average temperature in Prague, „$\o\Theta_{a,d}$“ [°C] is an average temperature in the local climate zone.

$$\o\Theta_{\mathrm{a,d}} = \frac{\sum_{i=1}^{n}\Theta_{\mathrm{a,d,i}}}{n}\ [°\mathrm{C}] \tag{3}$$

„$\Theta_{a,d,i}$“ [°C] are temperatures of local stations in Prague, “n” [-] stands for the number of stations which are used in calculating the average value.

## 5.3 Calculations of maximum LCZ temperature

Following tabs show values used for calculation the difference between the local climate zones in Prague. There are also final data used for map interpolation – hourly day maximum for 9th August 2018 and the hourly night maximum for 8th August 2018.

*Tab. 2: Calculation of LCZ night maximum temperatures*

$\varnothing\Theta_{a,n,prg}$ [°C] = 7.5 $\Theta_{a,n,\,max}$ [°C] = 22.0

| LCZ | LCZ clas. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | $\varnothing\Theta_{a,n}$ | $\Delta\Theta_{a,n}$ | $\varnothing\Theta_{a,n,max}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Compact midrise | 11 | 9 | 8 | 9 | 12 | 9 | 9 | 7 | 11 | 8 | 11 | 9 | 9.4 | 1.9 | 23.9 |
| 4 | Open high-rise | 7 | 9 | 8 | 11 | 8 | 9 | 8 | 8 | 9 | 9 | 10 | 8 | 8.6 | 1.1 | 23.1 |
| 5 | Open midrise | 9 | 9 | 6 | 8 | 10 | 8 | 7 | 8 | 9 | 7 | 10 | 7 | 8.2 | 0.7 | 22.7 |
| 6 | Open low-rise | 10 | 8 | 7 | 8 | 11 | 7 | 8 | 7 | 6 | 10 | 8 | 6 | 7,9 | 0.4 | 22.4 |
| 8 | Large low-rise | 8 | 9 | 8 | 7 | 6 | 7 | 8 | 9 | 8 | 8 | 10 | 10 | 8.2 | 0.7 | 22.7 |
| 9 | Sparsely built | 8 | 7 | 8 | 6 | 9 | 7 | 8 | 6 | 8 | 7 | 7 | 9 | 7.5 | 0.0 | 22.0 |
| 10 | Heavy industry | 9 | 9 | 9 | 9 | 10 | 8 | 10 | 9 | 8 | 7 | 9 | 8 | 8.8 | 1.3 | 23.3 |
| 101 | Dense trees | 7 | 8 | 9 | 7 | 7 | 7 | 6 | 7 | 6 | 7 | 7 | 6 | 6.9 | -0.6 | 21.4 |
| 102 | Scattered trees | 6 | 6 | 8 | 7 | 6 | 7 | 6 | 7 | 8 | 5 | 6 | 6 | 6.5 | -1.0 | 21.0 |
| 104 | Low plants | 7 | 3 | 5 | 6 | 6 | 5 | 6 | 4 | 7 | 7 | 6 | 6 | 5.8 | -1.7 | 20.3 |
| 107 | Water | 3 | 6 | 3 | 7 | 6 | 5 | 5 | 6 | 6 | 5 | 6 | 4 | 5.2 | -2.3 | 19.7 |

The data were read from the NETATMO weather map on 2nd November 2018 at 2 am CET.

*Tab. 3: Calculation of LCZ day maximum temperatures*

$\varnothing\Theta_{a,d,prg}$ [°C] = 15.0 $\Theta_{a,d,\,max}$ [°C] = 36.0

| LCZ | LCZ clas. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | $\varnothing\Theta_{a,d}$ | $\Delta\Theta_{a,d}$ | $\varnothing\Theta_{a,d,max}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Compact midrise | 15 | 15 | 14 | 18 | 19 | 14 | 22 | 17 | 18 | 15 | 15 | 16 | 16.2 | 1.2 | 37.2 |
| 4 | Open high-rise | 14 | 15 | 15 | 16 | 19 | 18 | 15 | 17 | 15 | 17 | 18 | 17 | 16.3 | 1.3 | 37.3 |
| 5 | Open midrise | 16 | 13 | 14 | 16 | 16 | 14 | 15 | 15 | 14 | 15 | 19 | 17 | 15.2 | 0.2 | 36.2 |
| 6 | Open low-rise | 17 | 16 | 15 | 17 | 15 | 14 | 11 | 15 | 16 | 15 | 15 | 18 | 15.5 | 0.5 | 36.5 |
| 8 | Large low-rise | 16 | 15 | 15 | 14 | 14 | 16 | 15 | 15 | 16 | 17 | 15 | 16 | 15.3 | 0.3 | 36.3 |
| 9 | Sparsely built | 15 | 16 | 15 | 13 | 16 | 17 | 12 | 15 | 15 | 13 | 14 | 14 | 14.6 | -0.4 | 35.6 |
| 10 | Heavy industry | 16 | 16 | 15 | 15 | 15 | 16 | 14 | 15 | 17 | 18 | 22 | 18 | 16.1 | 1.1 | 37.1 |
| 101 | Dense trees | 13 | 13 | 15 | 14 | 16 | 16 | 15 | 15 | 14 | 13 | 14 | 14 | 14.3 | -0.7 | 35.3 |
| 102 | Scattered trees | 13 | 15 | 15 | 12 | 15 | 11 | 14 | 14 | 15 | 16 | 12 | 15 | 14.0 | -1.0 | 35.0 |
| 104 | Low plants | 12 | 12 | 13 | 15 | 14 | 15 | 14 | 14 | 15 | 14 | 12 | 15 | 13.8 | -1.2 | 34.8 |
| 107 | Water | 13 | 12 | 14 | 15 | 13 | 14 | 15 | 14 | 14 | 12 | 14 | 13 | 13.6 | -1.4 | 34.6 |

The data were read from the NETATMO weather map on 2nd November 2018 at 2 pm CET.

*Tab. 4: Overview of maximum hourly temp. used for calc. of UHI distr. map*

| LCZ no. | LCZ classification | $\Delta\Theta_{a,n}$ [°C] | **$\varnothing\Theta_{a,n,max}$ [°C]** | $\Delta\Theta_{a,d}$ [°C] | **$\varnothing\Theta_{a,d,max}$ [°C]** |
|---|---|---|---|---|---|
| 2 | Compact midrise | 1.9 | **23.9** | 1.2 | **37.2** |
| 4 | Open high-rise | 1.1 | **23.1** | 1.3 | **37.3** |
| 5 | Open midrise | 0.7 | **22.7** | 0.2 | **36.2** |
| 6 | Open low-rise | 0.4 | **22.4** | 0.5 | **36.5** |
| 8 | Large low-rise | 0.7 | **22.7** | 0.3 | **36.3** |
| 9 | Sparsely built | 0.0 | **22.0** | -0.4 | **35.6** |
| 10 | Heavy industry | 1.3 | **23.3** | 1.1 | **37.1** |
| 101 | Dense trees | -0.6 | **21.4** | -0.7 | **35.3** |
| 102 | Scattered trees | -1.0 | **21.0** | -1.0 | **35.0** |
| 104 | Low plants | -1.7 | **20.3** | -1.2 | **34.8** |
| 107 | Water | -2.3 | **19.7** | -1.4 | **34.6** |

## 5.4 Integration of wind speed data

The wind speed and profile of a wind is different in every zone. This is influenced by the “roughness length” of the zone.

„Roughness length is a critical parameter for estimation of wind conditions, and it is therefore also relevant for the estimation of human thermal conditions in urban areas. The high density of buildings in urban areas causes large changes in land coverage, thereby increasing surface roughness. This influence atmospheric flow and also leads to a reduction in urban air ventilation, thus increasing the risk of human thermal stress.” (16)

This data may be useful to observe wind speed conditions in Prague. The air flow may have a great influence to temperatures reduction. The roughness estimation is based on Local Climate Zone study. Every zone has its typical roughness length already set. Here are the roughness length values for every zone. Data source: Davenport et al. (2000).

*Tab. 5: Davenport classification of effective terrain roughness. (11)*

| Davenport class | $Z_0$ [m] | Landscape description | LCZ correspondence |
|---|---|---|---|
| 1. Sea | 0.0002 | Open water, snow-covered flat plain, featureless desert, tarmac, and concrete, with a free fetch of several kilometers. | E, F, G |
| 2. Smooth | 0.0005 | Featureless landscape with no obstacles and little if any vegetation (e.g., marsh, snow-covered or fallow open country). | E, F |
| 3. Open | 0.03 | Level country with low vegetation and isolated obstacles separated by 50 obstacle heights (e.g., grass, tundra, airport runway). | D |
| 4. Roughly open | 0.10 | Low crops or plant covers; moderately open country with occasional obstacles (e.g., isolated trees, low buildings) separated by 20 obstacle heights. | 7, C, D |
| 5. Rough | 0.25 | High crops, or crops of varying height; scattered obstacles separated by 8 to 15 obstacle heights, depending on porosity (e.g., buildings, tree belts). | 5-10, B, C |
| 6. Very rough | 0.50 | Intensely cultivated landscape with large farms and forest clumps separated by 8 obstacle heights; bushland, orchards. Urban areas with low buildings interspaced by 3 to 7 building heights; no high trees. | 2, 3, 5, 6, 9, 10, B |
| 7. Skimming | 1.0 | Landscape covered with large, similar-height obstacles, separated by 1 obstacle height (e.g., mature forests). Dense urban areas without significant building-height variation. | 2, 4 |
| 8. Chaotic | >2.0 | Landscape with irregularly distributed large obstacles (e.g., dense urban areas with mix of low and high-rise buildings, large forest with many clearings). | 1, 4, A |

At first, it is needed to calculate the roughness parameter from the roughness length par. Calculation is done by the following formula (Source: Oke, 2017):

$$\alpha = 0.096\ \log_{10} Z_0 + 0.016\,(\log_{10} Z_0)^2 + 0.24\ [-] \tag{4}$$

„α" [-] is a roughness parameter, $Z_0$ [m] is a roughness length parameter.

$$u_{Z1} = u_{Z2}\left[\frac{Z_1 - Z_d}{Z_2 - Z_d}\right]^{\alpha}\ [\mathrm{m/s}] \tag{5}$$

„$u_{Z1}$" [m/s] is a wind speed in the local climate zone, „$u_{Z2}$" [m/s] is a measured wind speed, „$z_d$" [m] is a zero plane displacement, „$z_1$" [m] is a pedestrian level height, „$z_2$" [m] is a height of placed measuring station. „$u_{Z1}$" [m/s] parameter is variable in two cases – the lowest hourly wind speed in July/August and the highest hourly wind speed in July/August.

# 6 Projection of UHI for future scenarios

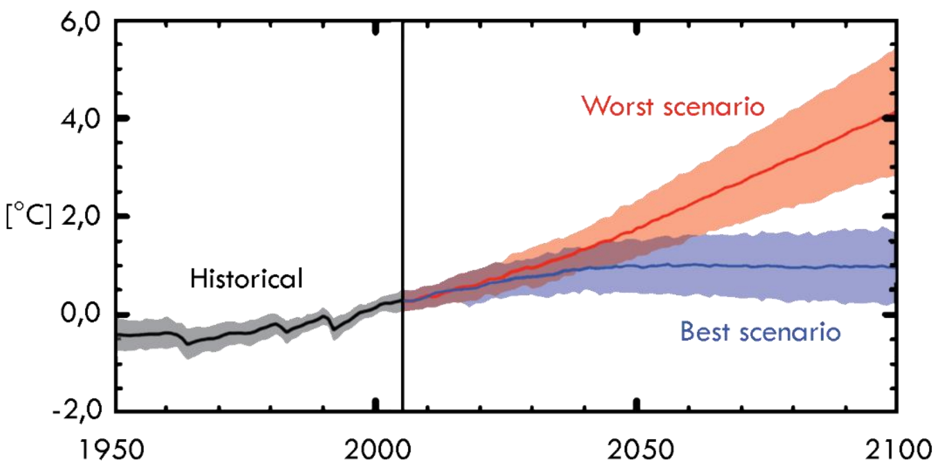
The aim is to investigate future scenarios of urban heat distribution in Prague. The default data will be taken over from the previous chapter. The future scenario is important to find out long term thermal conditions in the city. In the Czech Republic, structures are designed for various lifetime. Buildings and other common constructions should withstand for 50 years period.

In that case, the future study will be performed for the year 2043 and the year 2068. The resulting 6 maps (maximum hourly day/night temperature in August 2018, 2043, 2068) will show us the temperature development in Prague. Maps will be suitable for taking a discussion over the energy design of a building.

The key to determine changes of maximum mean temperatures in Prague is an atmospheric study from Charles University. Concretely, the study no. (17) from the Department of Atmospheric Physics from the year 2015. The researchers of this study calculated the future atmospheric data for Czech territory. The increase of average maximum temperatures will be 1.2 - 2.2 °C in the 50-year period.

Because of this great dispersion, three scenarios will be executed. The first one will describe the best case – the least warming, the second will describe the probable warming and the third will describe the worst possible scenario.

These cases are shown below in the picture of global average surface temperature change.



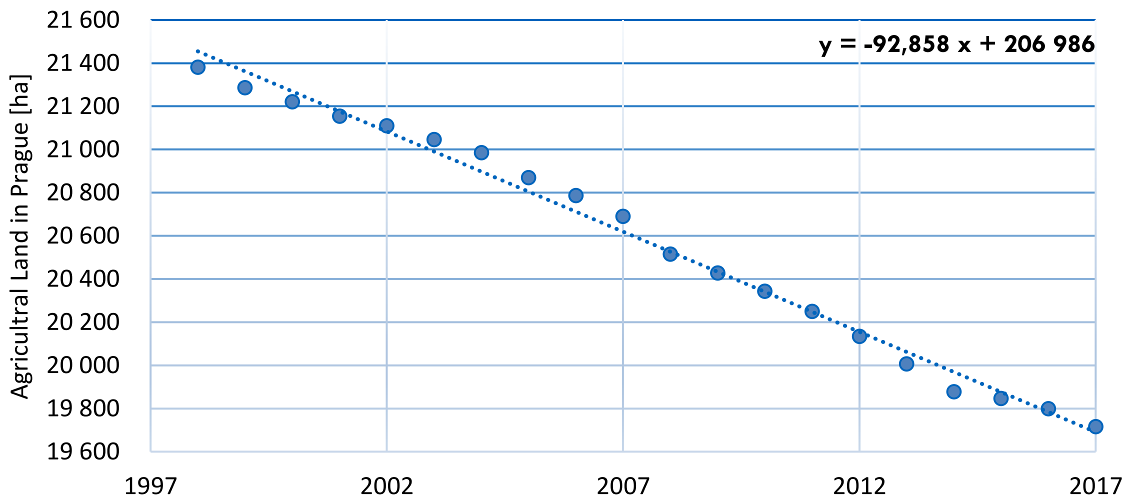

*Pic. 25: Global average surface temperature change (18)*

*Tab. 6: Temperature differences between the scenarios*

| Case | Best scenario | | Probable scenario | | Worst scenario | |
|---|---|---|---|---|---|---|
| Parameter | $\Delta\Theta_{a,n,max,25b}$ | $\Delta\Theta_{a,n,max,50b}$ | $\Delta\Theta_{a,n,max,25p}$ | $\Delta\Theta_{a,n,max,50p}$ | $\Delta\Theta_{a,n,max,25w}$ | $\Delta\Theta_{a,n,max,50w}$ |
| Units | [°C] | [°C] | [°C] | [°C] | [°C] | [°C] |
| Increase | 0.60 | 1.20 | 0.85 | 1.70 | 1.10 | 2.20 |

Next factor that could influence the temperature growth is population. Nevertheless, population is considered to be constant during the 50-year period.

Consequently, low plains in Prague are degreasing. Every year there is less arable land. These lands are being sold to developers. Subsequently, they endeavor for changing purpose of these lands. After territorial proceedings, they often become places determined for building houses. The following tab shows the data from Czech Statistical Office (2). The data show tendency for the decline of agricultural land in Prague.




*Pic. 26: Decline of agricultural land in Prague*

If the decline continues this way, there will be 12.4 % less agricultural land in the year 2043 and 24.1 % less in the year 2068.

This factor is included in the calculation of future heat distribution maps. Concrete decline percentage of arable land (LCZ 104) is replaced by LCZ 5 and LCZ 4 (50/50). The following tab will show considered redistribution of arable land. In the best scenario, it is considered lower decline tendency – about half of the default one. The probable scenario respects the default tendency as well as the worst. For purpose of our calculation, it is needed to change characteristics of LCZ 104. Its new temperature characteristics will consist of zones characteristics 104, 4, 5 (weighted average by land percentage).

*Tab. 7: New redistribution of plain land 104*

| | | Best scenario | | Probable scenario | | Worst scenario | |
|---|---|---|---|---|---|---|---|
| | | **25 year** | **50 years** | **25 year** | **50 years** | **25 year** | **50 years** |
| **Decline** | | 6.2 % | 12.0 % | 12.4 % | 24.0% | 12.4 % | 24.0 % |
| **New redistribution** | **104** | 93.8 % | 88.0 % | 87.6 % | 76.0 % | 87.6 % | 76.0 % |
| | **4** | 3.1 % | 6.0 % | 6.2 % | 12.0 % | 6.2 % | 12.0 % |
| | **5** | 3.1 % | 6.0 % | 6.2 % | 12.0 % | 6.2 % | 12.0 % |

According to the new redistribution table, new temperature values are calculated for the zone 104. The zone now "consists of" zones 104, 4, 5.

*Tab. 8: New temperature data for LCZ 104*

| | Default values for all three scenarios | | | New values with plain land decrease | | | |
|---|---|---|---|---|---|---|---|
| | **4** | **5** | **104** | $104_{6.2\%}$ | $104_{12.0\%}$ | $104_{12.4\%}$ | $104_{24.0\%}$ |
| $\varnothing\Theta_{a,n,max,25b}$ | 23.7 | 23.3 | 20.9 | 21.1 | - | - | - |
| $\varnothing\Theta_{a,n,max,50b}$ | 24.3 | 23.9 | 21.5 | - | - | 21.8 | - |
| $\varnothing\Theta_{a,n,max,25p}$ | 24.0 | 23.6 | 21.2 | - | 21.5 | - | - |
| $\varnothing\Theta_{a,n,max,50p}$ | 24.8 | 24.4 | 22.0 | - | - | - | 22.6 |
| $\varnothing\Theta_{a,n,max,25w}$ | 24.2 | 23.8 | 21.4 | - | 21.7 | - | - |
| $\varnothing\Theta_{a,n,max,50w}$ | 25.3 | 24.9 | 22.5 | - | - | - | 23.1 |
| $\varnothing\Theta_{a,d,max,25b}$ | 37.9 | 36.8 | 35.4 | 35.5 | - | - | - |
| $\varnothing\Theta_{a,d,max,50b}$ | 38.5 | 37.4 | 36.0 | - | - | 36.2 | - |
| $\varnothing\Theta_{a,d,max,25p}$ | 38.2 | 37.1 | 35.7 | - | 35.9 | - | - |
| $\varnothing\Theta_{a,d,max,50p}$ | 39.0 | 37.9 | 36.5 | - | - | - | 37.0 |
| $\varnothing\Theta_{a,d,max,25w}$ | 38.4 | 37.3 | 35.9 | - | 36.1 | - | - |
| $\varnothing\Theta_{a,d,max,50w}$ | 39.5 | 38.4 | 37.0 | - | - | - | 37.5 |

The following data are used to create interpolation maps – they describe all the scenarios including the default state. These maps describe the hourly extreme for a whole year – as it was described previously in chapter 5. People who are prone to high temperatures would most likely suffer health damage during this period. This state taking one hour could be critical.

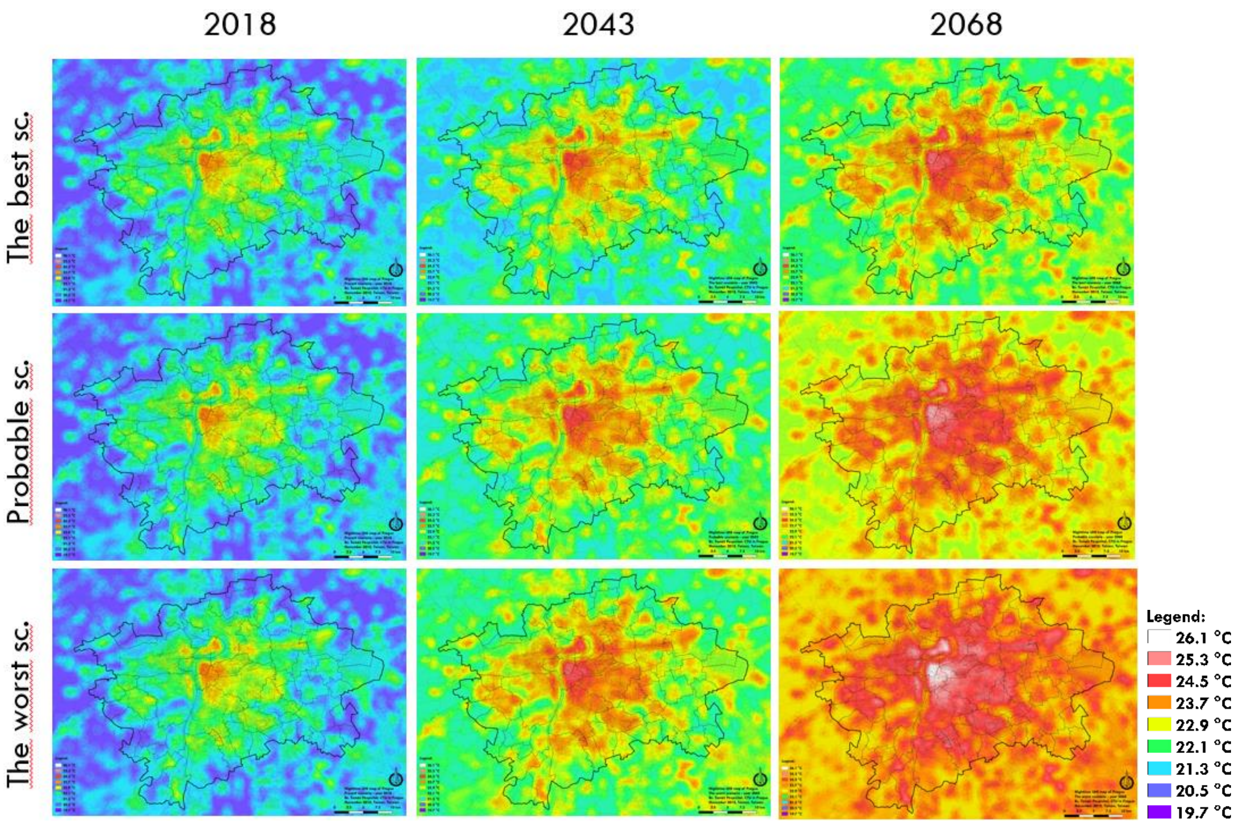
*Tab. 9: Future temperature estimation for the night time*

| **LCZ** | **Default** | **Best scenario** | | **Probable scenario** | | **Worst scenario** | |
|---|---|---|---|---|---|---|---|
| | $\varnothing\Theta_{a,n,max}$ | $\varnothing\Theta_{a,n,max,25b}$ | $\varnothing\Theta_{a,n,max,50b}$ | $\varnothing\Theta_{a,n,max,25p}$ | $\varnothing\Theta_{a,n,max,50p}$ | $\varnothing\Theta_{a,n,max,25w}$ | $\varnothing\Theta_{a,n,max,50w}$ |
| | [°C] | [°C] | [°C] | [°C] | [°C] | [°C] | [°C] |
| **2** | 23.9 | 24.5 | 25.1 | 24.8 | 25.6 | 25.0 | 26.1 |
| **4** | 23.1 | 23.7 | 24.3 | 24.0 | 24.8 | 24.2 | 25.3 |
| **5** | 22.7 | 23.3 | 23.9 | 23.6 | 24.4 | 23.8 | 24.9 |
| **6** | 22.4 | 23.0 | 23.6 | 23.3 | 24.1 | 23.5 | 24.6 |
| **8** | 22.7 | 23.3 | 23.9 | 23.6 | 24.4 | 23.8 | 24.9 |
| **9** | 22.0 | 22.6 | 23.2 | 22.9 | 23.7 | 23.1 | 24.2 |
| **10** | 23.3 | 23.9 | 24.5 | 24.2 | 25.0 | 24.4 | 25.5 |
| **101** | 21.4 | 22.0 | 22.6 | 22.3 | 23.1 | 22.5 | 23.6 |
| **102** | 21.0 | 21.6 | 22.2 | 21.9 | 22.7 | 22.1 | 23.2 |
| **104** | 20.3 | ~~20.9~~→ 21.1 | ~~21.5~~→ 21.8 | ~~21.2~~→ 21.5 | ~~22.0~~→ 22.6 | ~~21.4~~→ 21.7 | ~~22.5~~→ 23.1 |
| **107** | 19.7 | 20.3 | 20.9 | 20.6 | 21.4 | 20.8 | 21.9 |

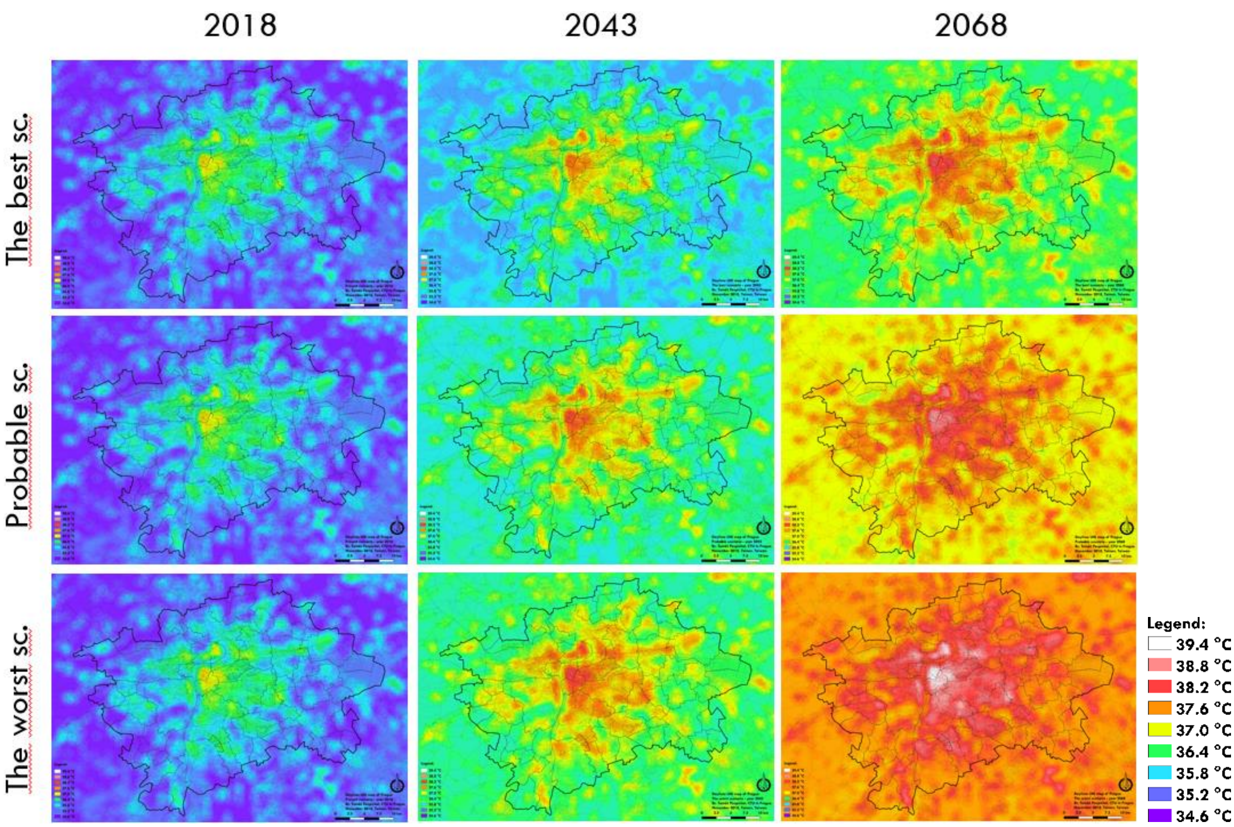
*Tab. 10: Future temperature estimation for the day time*

| **LCZ** | **Default** | **Best scenario** | | **Probable scenario** | | **Worst scenario** | |
|---|---|---|---|---|---|---|---|
| | $\varnothing\Theta_{a,d,max}$ | $\varnothing\Theta_{a,d,max,25b}$ | $\varnothing\Theta_{a,d,max,50b}$ | $\varnothing\Theta_{a,d,max,25p}$ | $\varnothing\Theta_{a,d,max,50p}$ | $\varnothing\Theta_{a,d,max,25w}$ | $\varnothing\Theta_{a,d,max,50w}$ |
| | [°C] | [°C] | [°C] | [°C] | [°C] | [°C] | [°C] |
| **2** | 37.2 | 37.8 | 38.4 | 38.1 | 38.9 | 38.3 | 39.4 |
| **4** | 37.3 | 37.9 | 38.5 | 38.2 | 39.0 | 38.4 | 39.5 |
| **5** | 36.2 | 36.8 | 37.4 | 37.1 | 37.9 | 37.3 | 38.4 |
| **6** | 36.5 | 37.1 | 37.7 | 37.4 | 38.2 | 37.6 | 38.7 |
| **8** | 36.3 | 36.9 | 37.5 | 37.2 | 38.0 | 37.4 | 38.5 |
| **9** | 35.6 | 36.2 | 36.8 | 36.5 | 37.3 | 36.7 | 37.8 |
| **10** | 37.1 | 37.7 | 38.3 | 38.0 | 38.8 | 38.2 | 39.3 |
| **101** | 35.3 | 35.9 | 36.5 | 36.2 | 37.0 | 36.4 | 37.5 |
| **102** | 35.0 | 35.6 | 36.2 | 35.9 | 36.7 | 36.1 | 37.2 |
| **104** | 34.8 | ~~35.4~~→ 35.5 | ~~36.0~~→ 36.2 | ~~35.7~~→ 35.9 | ~~36.5~~→ 37.0 | ~~35.9~~→ 36.1 | ~~37.0~~→ 37.5 |
| **107** | 34.6 | 35.2 | 35.8 | 35.5 | 36.3 | 35.7 | 36.8 |

The calculated maps are shown on the following page. The maps are only illustrative – they have very small scale. All of them are also printed on A3 format and attached in the back of this project.




*Pic. 27: Nighttime UHI of Prague + future scenarios (max. hourly state)*




*Pic. 28: Daytime UHI of Prague + future scenarios (max. hourly state)*

# 7 Methods of remaking the exterior to achieve more favorable conditions

The main goal is to maintain the indoor conditions while not worsening the outdoor climate conditions. Most of present buildings are not prepared for the rising number of hot days and higher maximum temperatures during summer. Without appropriate adaptation of the external environment, the number of refrigeration units in the city can increase. These units would worsen the outdoor conditions even more, also the presence of cooling units greatly aggravates the appearance of the building.

*Pic. 29: Local cooling units on the apartment building in Hong Kong*

The primal step should be focused on improving the conditions in the exterior – reduction of the summer maximus. Since Czech summer temperature conditions are becoming similar to Taiwanese ones, it is suitable to take an example from Taiwanese approach to building design and urban planning.

## 7.1 Green roofs and facades

Chapter 3 describes the natural cooling effect of greenery – including green facades and green roofs. The difference between surface temperature of an extensive green roof and dark solid surface (example: SBS waterproofing) was more than 15 °C.

*Pic. 30: Tram depot visible from International Finance Center in Hong Kong*

The strategy of replacing the typical roofs with the green ones is implemented in many cities – Singapore, Hong Kong, Taipei. Apart from adding more green surfaces, it is possible to cool down the streets with sprinkling trucks or building more paddling pools – already built in some parts of Prague like Pankrác neighborhood. Although the truck spraying is effective, it is not admirable thing to look at.

In order to ensure construction of green surface buildings, green surfaces would have to be required in the process of building design. Presently, green roofs are applied when the developer is seeking a certificate declaring the sustainability of the building – it is one of required criterions. These certification systems are SBTooLCZ, BREEAM, LEEDS and others. Construction of a green roof is also encouraged by Czech program of the Ministry of the Environment called „Nová zelená úsporám”. This program offers grant of 500 Kč per square meter - includes renovations and constructions of new homes (19).

It might be helpful to raise public awareness of sustainable development or just increase the given grant. Although, many of buildings in hot city centers (especially historical ones) are under supervision of the Prague City Hall Heritage Department. These building must maintain the traditional look. In a nutshell, the process of replacing typical roofs with the green ones is very complicated.

But there are many other constructions which could replace the original roof with a green roof. For example, bus stops and other „shelters“ could have a green roof/ceiling similarly like the NCKU hospital entrance shading which is shown in the chapter 3 on one of the thermal images. In many cases the existing bus stop does not even have to be rebuilt. The new green roof consists of flower pots which cover the entire area of the ceiling. They are just attached by the current construction. The picture of bus stop in Old Street in London does not show an optimal way how to attach the pots to the construction but it is a matter of design. Surely, there is a way how to effectively fix the pots to the existing structure and to ensure that the new roof will be well serviceable. The bus stop on the Old Street of London is shown in the picture located below.


*Pic. 31: Bus stop on the Old Street in London (20)*

This method is well used even for facades or other vertical constructions. In Taiwan the flower buckets cover big amount of various wall constructions like the acoustic walls near roads and railroads or solid wall fences. Often these walls can be found even in the interiors of building. But its main purpose is obviously different – they serve to improve the visual comfort and to process photosynthesis – still the construction improves the local conditions.

*Pic. 32: Inner green wall in Manila airport and exterior green wall on the hospital fence in Tainan*

## 7.2 Water in the countryside

When discussing green roofs, it would be appropriate to find out if there was as much of precipitation in the future as it is today. Consequently, how much water will be preserved in the countryside. The climate change study from Charles University (17) declares that the precipitation will not significantly change – the reason that Czech Republic is located in the transition zone. Transition zone is a layer between the dry south and the wet north. The global change will cause the dry places to become even drier and the wet places become even wetter. Czech Republic will only struggle with the rain distribution. Although the precipitation will not change, the air will have a tendential to be drier – it is caused by the rising evaporation and the ability of air to accumulate moisture – with higher temperature and steady air moisture, the relative humidity will be reduced.

Only the amount of fallen snow will significantly degrease – that is result of the ice and freezing days loss, increased number of tropical days/nights and increased minimum, average and maximum temperatures. This affect is also caused by the lower land surface reflectivity – when snow cannot create long-time cover, the land will absorb more energy from the Sun and the air temperature will rise. But there still should be the same amount of water kept in the countryside – due to location of Czech Republic in Europe.

Although Czech territory is struggling with drought. The drought effect may be caused by fewer and more intensive raining. The dry soil is not able to absorb all the water from the rain and it is being drifted away.

Water is also not efficiently used. Most of rain water that falls on Czech roofs and other solid surfaces like roads and pavements flows directly into canalization. This water should be collected and used for watering near greenery. There are several ways how to collect the water – underground reservoir lakes, ponds or wetlands. The Ministry of the Environment of the Czech Republic and the State environmental Fund of the Czech Republic encouraged emergence of the new grant program „Dešťovka" (2017). The grant supports owners of family and apartment building to use rain and waste water in homes and gardens. There is also a program called „Dešťovka pro veřejné subjekty" (a similar one dedicated to public entities). This program grants towns, cities, churches and other associations to motivate them to save water. The state can offer 85 % grant for getting an accumulation reservoir, doing reconstructions of surfaces which allow rain water absorption and doing other acceptable solutions to reuse rain water.

So, after the successful implementation of the project in Czech Republic, the water should be used more wisely. But today the drinking water is being used even for flushing toilets.

## 7.3 Wind flow allowance

The wind flow allowance is critical for ensuring the heat can be drifted away from the city. The high air exchange is also needed to get the city rid of the pollution. Even couple of high buildings build close to each other can disrupt the original city air flow.

New apartment buildings (or other high buildings) should be placed parallelly to with the city air flow. If the buildings had to be placed perpendicularly to the air flow, they should not create a blockade. At worst, their height should gradually increase. So, the air flow will not lose its speed rapidly.

*Pic. 33: Freiburg parallel building placement to allow the air continue to the city center (21)*

The urban roughness map in the attachments includes the wind corridor polyline. Since the air flow is mostly going from west to east, the line defines the western area, which should allow the wind speed to permeate the city center. The roughness of this area should remain the same or become less rough. The corridor line was just drawn based on the calculated roughness. There are approaches how to calculate exact wind corridors though. One of the approaches were used in „A simple approach for the development of urban climatic maps based on the urban characteristics in Tainan, Taiwan" study (22). In that project, the least cost path index is used to estimate the ventilation routes.


*Pic. 34: Ventilation routes estimation based on least cost path index (22)*

„LCP were determined using two functions "BCost Distance" and "BCost Path" in "BSpatial Analyst toolbox" of ArcMap which is the primary application used in

ArcGIS. The first function was used to quantify the cost of the grids; in this study, FAI was defined as the cost value. The second function was used to determine the routes with least cost from the results of the first function. Because the set-up wind direction was westerly wind in this study, the route between the starting grid in the west side and ending grid in the east side of Tainan which has the lowest cumulative cost was chosen as the ventilation path." (22)

The roughening of the zone would reduce the air flow that will flow into the city. The colder suburb air helps the city center to reduce the maximum air temperature. The construction of new buildings in this zone would increase the accumulation of warm air in the city center. Even planting more trees there could have a negative influence to the energy balance.

*Pic. 35: Visualization of air flow displacement above high rise buildings in Panama City (11)*

## 7.4 Reduction of waste heat

Waste heat generated by living things or technical devices and released to the environment. Its by-product of another primal activity/process. In the laws of thermodynamics, waste heat is produced by all work processes. It is fundamental that these processes produce some additional heat, since it is not possible to use all input energy and transform into a different form without producing any heat.

In cities, waste heat is produced by burning of fossil fuel, living activity, transportation, house heating etc. Most of these processes also produce greenhouse gasses which cause the Sun radiation to be reflected back on the Earth's surface.

To improve current and future status, it is needed to decrease the amount of energy which is used in the city. From the point of view of civil engineering, the energy performance of building should be degreased. The impact of climate change in Czech Republic will cause rising of temperatures, especially the coolest and warmest ones. The existing thermal insulation design procedure will be fully functional in the future.

It will be needed to focus on the cooling design more. Initially, passive cooling should be part of house. An attention should be given to a proper shading design, facade design, window/building orientation, ventilation design and choosing a proper material for the construction – with suitable thermal mass and thermal conductivity. The color of the roof should also provide sufficient effectiveness, the cooling system should use natural phenomena like radiation reflection, evaporation, cooling breezes and earth potential.

## 7.5 Reduction of greenhouse gas production

The greenhouse gases reduction goes hand in hand with the temperature reduction. The local greenhouse effect also influences the local place. So, if the city produces a lot of gases, the local greenhouse effect is also more significant.

## 7.6 Alternative solutions

There are many solutions that would be complicated to realize. The example is taken from the Singapore. Some houses offer roof swimming in the pools. The kept water is even more efficient than any greenery. The water also does not make the surface rougher, so the wind flow will not be slowed down. Another example could be CheongGyeCheon stream Project in Seoul. This project transformed one of the busiest traffic roads into city stream.

*Pic. 36: South Korean CheongGyeCheon stream in Seoul (23)*

### 7.6.1 Improving observation network for future climate studies

The ideal tool to improve future climate study in Prague would be an observation network which would consistently measure temperature and humidity. This type of study would provide accurate data on various spots in Prague. From observation it would be possible to create many studies that would lead to the improvement of the city conditions.

In Tainan there is a similar study called „The application of a high-density street-level air temperature observation network" (HiSAN). (24) This study provides very interesting data all over the city. This is an excerpt from introduction of this study:

„The built environment in cities is complex. Accurately evaluating climatic conditions and understanding the relationship between an urban environment and UHI variations cannot be achieved by relying on the meteorological data provided by a few meteorological stations. A network with numerous intensive measurement points, arranged according to the type of urban typology, is required to accurately understand UHI phenomena. In this study, 100 instruments were used to obtain comprehensive meteorological information, such as air temperature and humidity, in Tainan. These instruments comprised a high-density street-level air temperature observation network (HiSAN). In the HiSAN, the measurement points were arranged in different development districts to examine the relationship between thermal conditions and urban development patterns. Using the HiSAN in this study yielded the following advantages: we were able to use numerous stations to observe the distribution of climatic conditions in the study area; an accurate representation of the thermal conditions was achieved because enough stations were distributed in the study area; all instruments recorded data at 5-min intervals every day, enabling the temporal and spatial distribution of the UHI to be presented clearly over the study period." (24)


(a) (b) (c) (d)

*Pic. 37: HiSAN measurement settings: (a) Measuring instrument LOGPRO, (b) radiation cover, (c) radiation cover and poll, and (d) installation schematic diagram (24)*

### 7.6.2 Improving environmental education and raise environmental awareness

Program targeting that promotes awareness of environmental issues would increase interest in sustainable development. This might be the crucial part. If people be interested themselves in improving the environment, it would be easier to promote more green projects – or even just to take a discussion on the topic of sustainability.

Today's issues should be implemented into elementary/high school curriculums. The awareness increasement should be ensured at people of productive age.

# 8 Urban heat island analysis of a selected locality in Prague

This chapter focuses on the outdoor comfort evaluation of selected locality in Prague – the results of this simulation are not binding, they are only for imagination how the real space could be working. For this purpose, the ENVI-met atmospheric model was used. This model includes fluid dynamics computing in selected area. The soil surface, vegetation and building walls and roofs interact with the calculated wind field. The heat between the different surfaces and air is being interchanged.

Secondly, some of the remaking methods are implemented to show their improving effect. Especially the original roofs are switched to green roofs and the surrounding greenery around the settlement is increased.

For this study it would be ideal to pick a locality from the Prague center. But the city center can be difficult to model because of the building geometry and the surface differentiation. It also does not provide many options how to reduce the thermal stress.

Accordingly, a traditional settlement Velká Ohrada in Prague suburbs was picked for this analysis. The settlement is optimal to represent the greenery cooling effect. The locality has also lower roughness – the wind flow will affect more the heat dissipation. The settlement was built between years 1988 to 1993 and it se intended for 12 000-13 000 people. It consists of several buildings which create an open square shape. There are totally 9 „squares" which are placed right next to each other. Their structure is uniform. The roads between buildings able the cars to pass in both directions. These one direction roads between buildings allow the drivers to park on both sides – there are 4 parking lanes between the buildings. Even though, there is not enough of parking space for all the residents.

The space in middle of the square shape is filled with greenery, play grounds, sandboxes and courts. There are several pavements, most of them are made of concrete bricks. The roads are made of concrete as well.

## 8.1 Simulation description

The simulation needed the space in ENVI-met to be modeled. In order for the simulation to provide trusted data, the modeling principles given by ENVI-met website (25) have to be followed. One of the restrictions is the model height. The

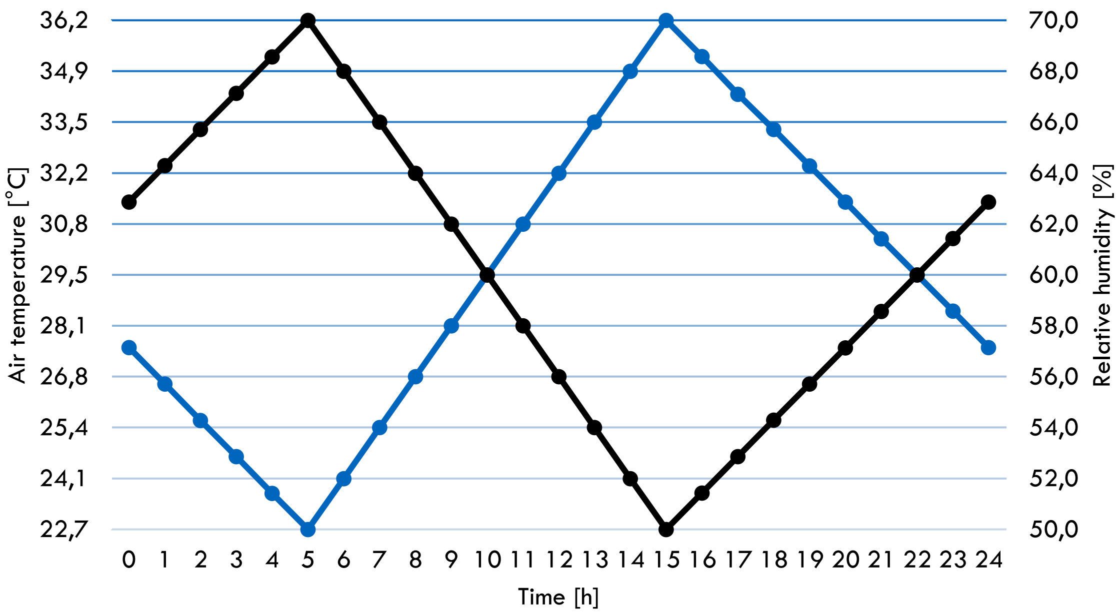
ENVI-met model requires the height of space to be two times bigger than the larges object. Even though the ENVI-met does not specify how far the building should be from the boundary of space, it is advisable not to it right on the edge. The buildings were placed at least 5 m away from the model border. Also, the empty space leading from the wind direction is 10 m long – to provide the air to reasonably interact with the housing estate.

There are two calculated simulations. Their purpose is to observe how will the outdoor thermal conditions change – in order to changing original roof surface to green roof and adding more trees to the residential area. The number of trees will be increased to approximately twice. There will be no more grass area added on the ground area, only the existing open green areas will be filled with trees. In other words, the tree and bush density will be increased. The first simulation captures the original state on 8th August 2018 – the same date and hour which was used to calculate the thermal map in chapter 6. The following picture captures the real situation, model no. 1 and the new model – model no. 2.


*Pic. 38: Velká Ohrada settlement in Praha 13 (13), model no. 1, model no. 2*

The lowest air temperature in this area is 22.7 °C at 5 am., the relative humidity is 50 %. The highest one reached 36.2 °C at 3 pm, the relative humidity is 70 %.

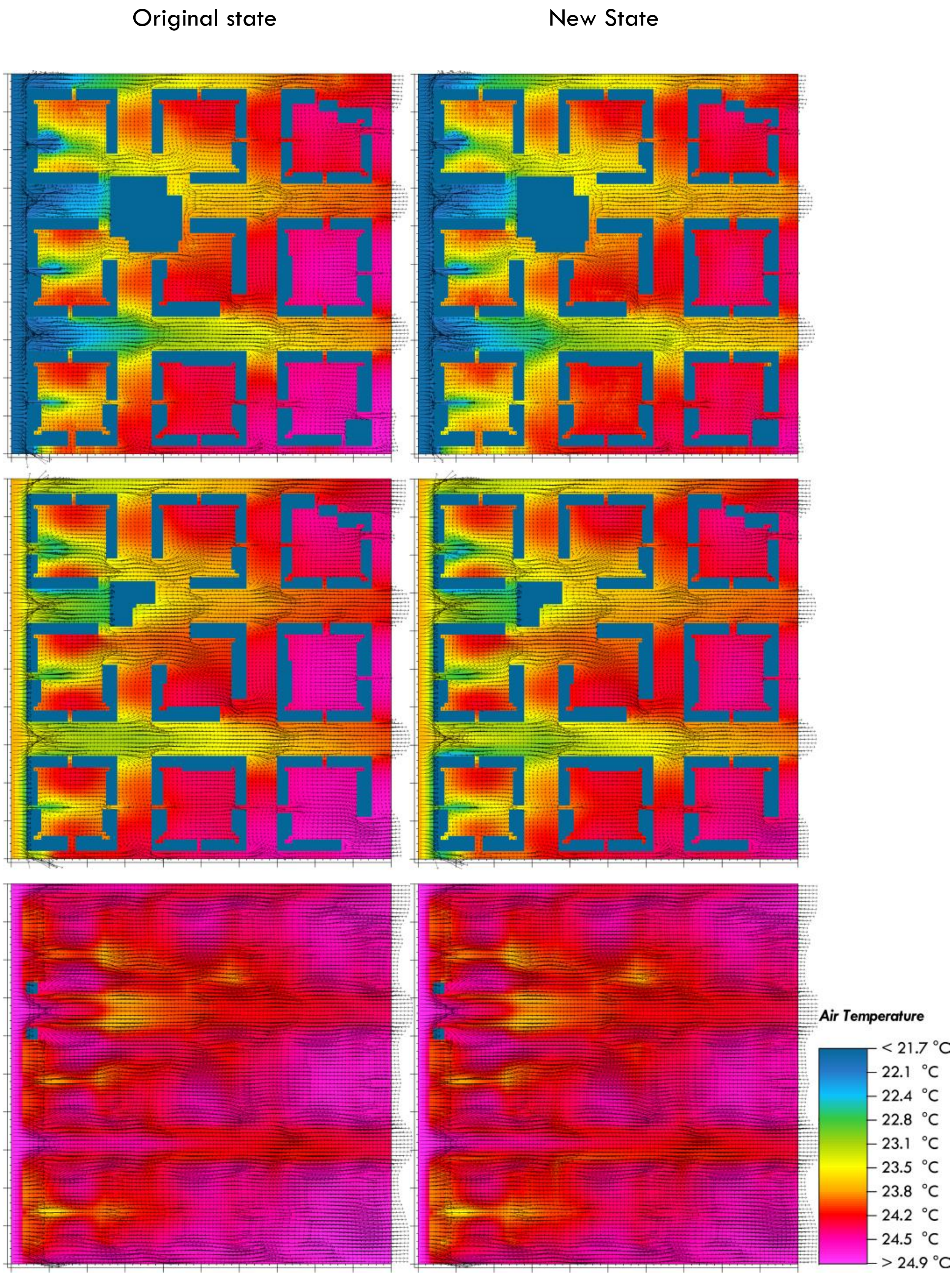
The roughness was set to 0.25 [-]. The wind speed in 10 m height was determined 2.5 m/s – average airflow. The wind blows from the west to the east. The following graphs show simplified temperature and humidity assumption used in the simulation. The following graph shows the simple forcing data used for both simulations – air temperature and relative humidity. Both curves estimation was based on minimum/maximum temperature/humidity in concrete hour.




*Pic. 39: Graph of forcing data used for simulation in ENVI-met*

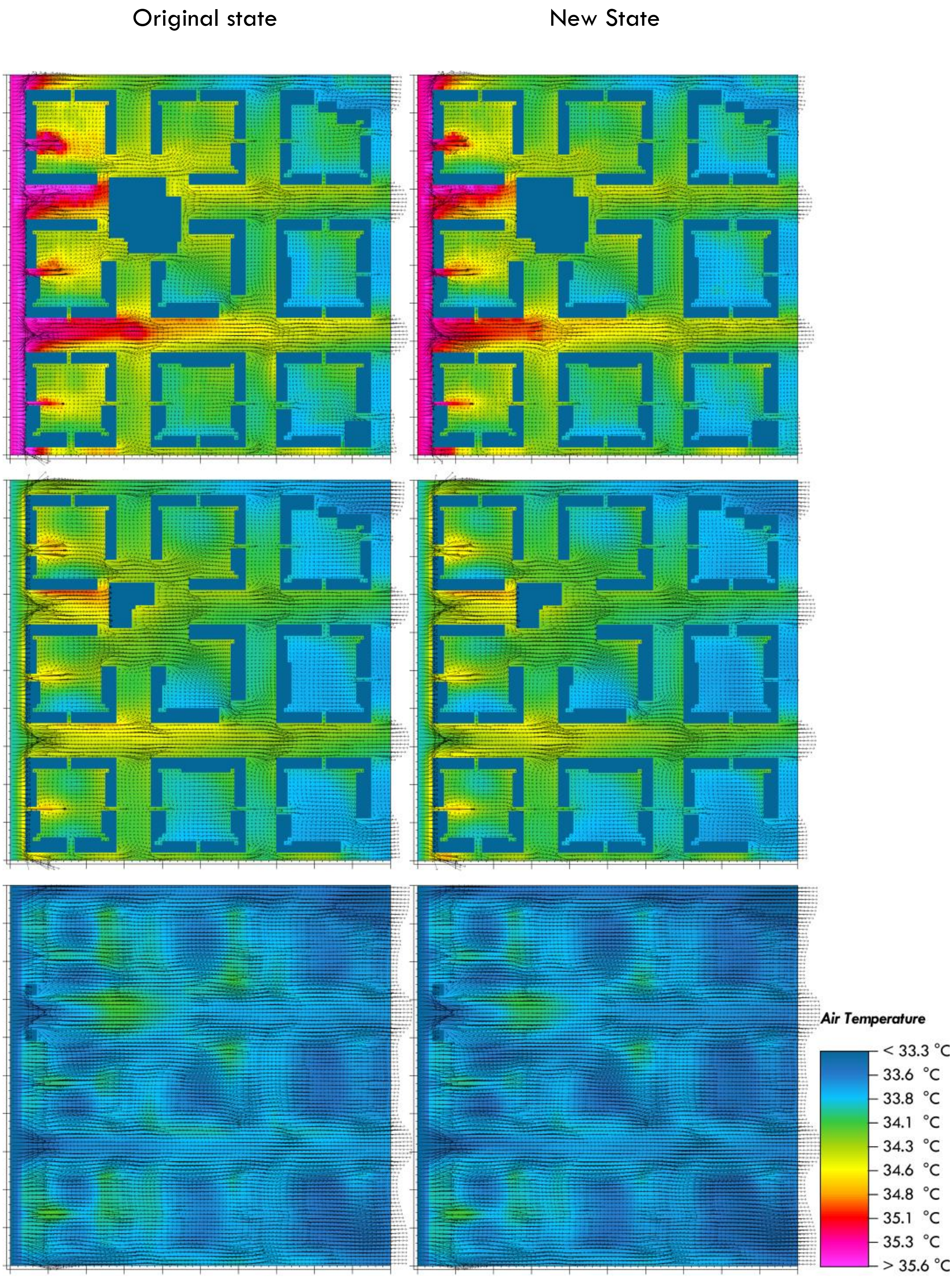
The following distribution maps show temperature distribution in the housing estate. The left maps describe the original state and the right ones describe the new state with green roofs and added greenery. There are three representing cuts – the first one is taken 1 m above ground level, second one is taken 11 m above the ground and the last one is taken 27 m above the ground. The 27 m high level is mostly above all the rooftops.

## 8.2 Results of 5 am. simulation




*Pic. 40: Temperature distribution for 8th August 2018 (5 am) in 1 m, 11 m and 27 m height (25)*

## 8.3 Results of 3 pm. simulation




*Pic. 41: Temperature distribution for 8th August 2018 (3 pm) in 1 m, 11 m and 27 m height (25)*

## 8.4 The conclusion of the simulation

In the 3 am. simulation, it is clear that the entering colder air becomes warmer. There is a lot of energy accumulated in the apartment buildings. The heat is retransmitted back to the exterior. On the other hand, the wind flow with combination of greenery helps to cool down the housing estate in the afternoon. In certain places, the air velocity has decreased. The temperature differentiation between the original and the new state is slightly visible. The map may be slightly distorted due to temperature rounding. To compare temperatures between original and new case, it would be advisable to do a separate legend for each height. But that could be confusing when comprising temperatures in different heights. Although, the images show reduction of maximum temperatures. The average temperature is also lower. The temperature difference is compared in the next table. The positive sign represents temperature decrease.

*Tab. 11: Differences between max. and min. temperatures after optimization*

| Time | Cut height [m] | $\Theta_{o,min}$ [°C] | $\Theta_{n,min}$ [°C] | $\Delta\Theta_{min}$ [°C] | $\Theta_{o,max}$ [°C] | $\Theta_{n,max}$ [°C] | $\Delta\Theta_{max}$ [°C] |
|---|---|---|---|---|---|---|---|
| 5:00 am. | 1.0 | 21.73 | 21.74 | **-0.01** | 24.73 | 24.55 | **0.18** |
| | 11.0 | 22.41 | 22.50 | **-0.09** | 24.76 | 24.60 | **0.16** |
| | 27.0 | 23.53 | 23.47 | **0.06** | 24.88 | 24.88 | **0.00** |
| 3:00 pm. | 1.0 | 33.67 | 33.66 | **0.01** | 35.88 | 35.61 | **0.27** |
| | 11.0 | 33.65 | 33.61 | **0.04** | 34.97 | 34.85 | **0.12** |
| | 27.0 | 33.35 | 33.33 | **0.02** | 34.14 | 34.11 | **0.03** |

(These data are illustrative only.)

# 9 The effect of climate change to the energy building concept

The purpose of this chapter is to take a discussion over the energy design of a building – in response to climate change and the location of concrete building in the environment. The standard deviation from mean hourly maximum temperature in the city center is 1.9 °C at night and 1.2 °C in the day (chapter 5).

In the year 2068, the city center hourly maximum temperature will be much higher than today's mean hourly maximum in Prague. The city center temperature will be 3.6 °C (1.9 °C + 1.7 °C) higher at night and 2.9 °C (1.2 °C + 1.7 °C) higher in the day. The suburbs in Prague will be hotter as well. But there will be 0.0 °C deviation from the average temperature. The only impact is caused by climate change – without the UHI effect. These values are valid for the probable scenario. The task is to describe the change of the inner comfort and to describe the building's ability to respond to the temperature changes.

According to the climate change study (17), model simulations show an increase in average, maximum and minimum temperatures. The warming in Czech Republic is the biggest in winter and summer period. But from the civil engineering point of view, it is more important to focus on the summer period. The winter warming will not cause significant troubles but exact opposite. Example: The energy consumption will be reduced, the condensation risk of some constructions will be reduced, there will be less freezing.

Although, for purpose of this thesis, it possible to assume an overall steady increase in temperature by the defined values. Generally, the need for cooling energy increases and the energy demand for heating is reduced. Since cooling is more energy intensive than heating, we can expect an overall rise of costs. Reducing the need for cooling can be prevented heat from entering the interior. This heat gain prevention is often called a passive cooling. With passive cooling, there is a reduction in excess internal heat in the interior. The amount of heat produced by the cooling units is reduced as well. So, the external cooling unit will not transfer as much heat to the exterior as it would without the passive cooling. This will result in internal comfort without influencing the outdoor urban comfort.

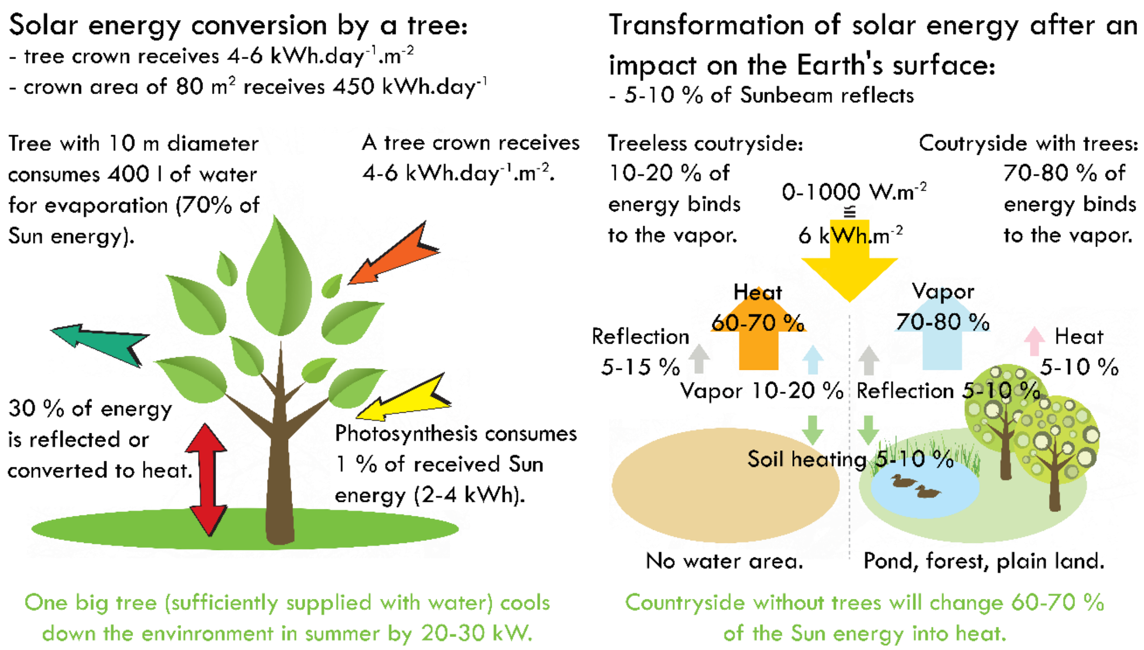
## 9.1 Passive ways to reduce thermal stress

### 9.1.1 Green roofs and facades

The significance of green roofs and facades was already described in chapter 3 and chapter 7. The directly shined dark construction may have around 15 °C higher surface temperature than other directly shined green construction (in hottest daily hour). The surface temperature of directly shined green construction responds to the surface temperature of shaded solid construction. Accordingly, especially the shined building surfaces should be covered with greenery. The purpose is to reduce the emitted longwave radiation to surrounding area and to degrease the heat transfer through envelope of a building.

#### 9.1.1.1 Other greenery

As well as it was mentioned in the previous chapter, it is appropriate to plant greenery especially around south side of a house. Grown trees also provide natural shading. Especially delicious trees are appropriate. In summer they shade building and in winter the leaves fall of. So, the tree does not prevent Sunshine to enter the interior. The greenery lowers the temperature due water retention and evaporation. The cooling effect is described by the following picture.




*Pic. 42: Greenery cooling effect (26)*

### 9.1.2 Constructions

The main problems of overheated buildings is the way they are designed, built and operated. The overall rise of temperatures will be especially noticed at buildings with:

- high thermal conductive windows,
- inappropriate window shading,
- leaky joints of structures,
- constructions with low coefficient of thermal conductivity,
- constructions with a short phase shift ≈ low thermal capacity.

All the factors have significant influence to the building living comfort, especially when they are combined together.

In Taiwan, the thermal capacity of structures is often visible as a disadvantage. Example: Sun shining on a concrete rooftop heats up the construction which subsequently transmits the heat into the interior. The temperature is high in the day and night, so there is a little space to cool the construction down. That's why is there a tendency to design structures with low thermal capacity.

The problem would be solved with insulating the walls and roof from an exterior side. Insulation would lower the temperature on the external area of the concrete roof. The concrete temperature would be slightly higher than the inner air temperature, which would help to cool the building more efficiently. The only construction, which reliably works without insulation, is a floor on the ground. In hot climates, the cool ground helps to cool down the inner space. In these cases, it would be ideal if buildings had more constructions adjacent to the soil.

In a nut shell, the thermal capacity can be very helpful to improve the interior comfort and lower the cooling energy consumption. The ideal phase shift (The time it takes for the thermal impulse to get from one side of the structure to the other.) should take at least 9 hours – especially in climates with big temperature fluctuations. Consequently, phase shift significance is more visible in Czech Republic than Taiwan. The structures in Taiwan are mostly made of concrete or bricks. On the other hand, Czech structures are made of a variety of different materials. The lower phase shift can be observed at structures made of lighter materials – like wooden constructions. To improve the overall thermal capacity of the wooden constructions, wood fiber boards are usually added in two layers.

#### 9.1.2.1 Windows

When building an energic effective house, emphasis must be placed on the design of the windows. Inappropriate window design can be a critical impact on the entire building. In terms of heat transfer, they are a weak building element. In summer period they may let undesirable amount of heat to the interior. In winter the heat is transfer through the window is greater than transfer though other construction. Especially, the roof windows (in sloping roof) are very problematic. Today most of them already have insulating triple glass. More important is a design of the window frame, its placement to the roof and correctly made thermal bonds. The frame is often embedded in the adjacent wall to lower the heat lose. Despite these disadvantages, windows are needed because of the daylight supply. There is also a psychological aspect of having windows – to be able to see outside. In winter period the Sun supplies the house with heat gains.

The climate change will cause reducing heat loses through windows in winter with existing structures. In other words, todays windows will work effectively in future winters. In summer period, the heat gains will increase. That's why it is needed to pay attention to the shading design more. Nevertheless, the shading must not reduce the amount of daylight illumination below the minimum allowable value.

#### 9.1.2.2 Shading systems

In term of reducing heat stress in buildings, we need to design an effective way of shading. Shielding can be external of internal. However, the biggest disadvantage is a reduction of light coming to the interior. There are many types of shading construction on a market. The most common are the external jalousies and blinders. The advantage of this systems in the ability to electrically operate the blinder angle. The shader angle can help us reach optimal indoor conditions. Some todays systems are able to operate independently. They are controlled based on the required illumination and thermal comfort in the interior. In Taiwan, these controllable shadings are very common. Although, there are also other unchangeable shadings. Sometimes the building itself (its shape) reduces the direct shining.

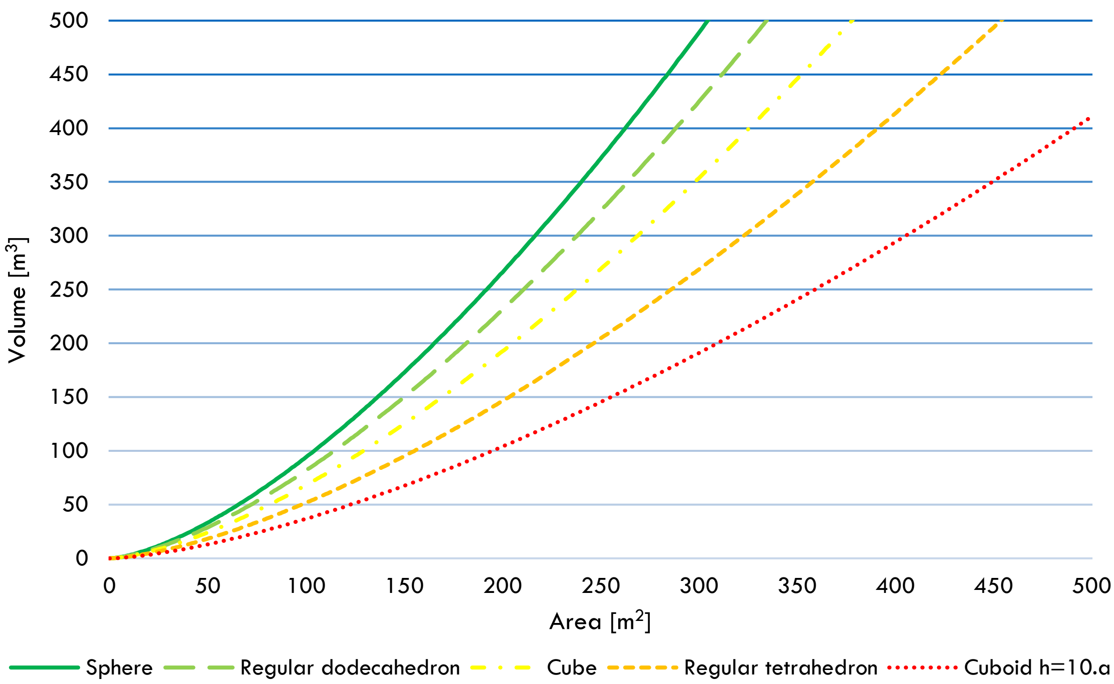
One of interesting facade systems is Shang Kai Steel system. This system uses ordinary metal sheets to create design shading facades. The metal sheet is cut and stretched. The holes will create a rhomboid shape.

Although, this system is not controllable – the construction is consistent. Sheet metal stripes prevent the direct radiation to permeate to the interior. Especially in summer period, the reflection efficiency will rise – because of the higher altitude of the Sun. In winter, the horizontal stripes allow the radiation to permeate (When there is no greenery, which would cover the facade.). Theoretically, this system could be used in Czech conditions as well. Since the deciduous plants will lose the leaves in the autumn period.

*Pic. 43: Shang Kai Steel facade system (27)*

### 9.1.2.3 Shape

The shape of building itself can be very important in terms of heating/cooling. Buildings that are more structured have more dividing structures. It is advisable to have as small outer surface as possible with the larges possible volume. In other words, the surface-to-volume ratio should be as low as possible. The following graph compares the surface-to-volume ratio of selected shapes. The graph shows that round shapes are much more efficient when designing an energy-efficient building.




*Pic. 44: Surface-to-volume ratio graph comparing simple geometry shapes*

### 9.1.3 Passive cooling

Because of climate change and overall population growth, there are more and more cooling systems every day. These systems are necessary to ensure the operation of data centers, food cooling, cooling of housing units etc. In the apartment houses they improve living conditions, so people are heathier and more effective. Although, in 30 years, the energy consumption should raise by 500-600 %. With larger energy demand, the production of greenhouse emissions also grows. That is a good reason to find other passive solutions, which would help us provide appropriate living conditions.

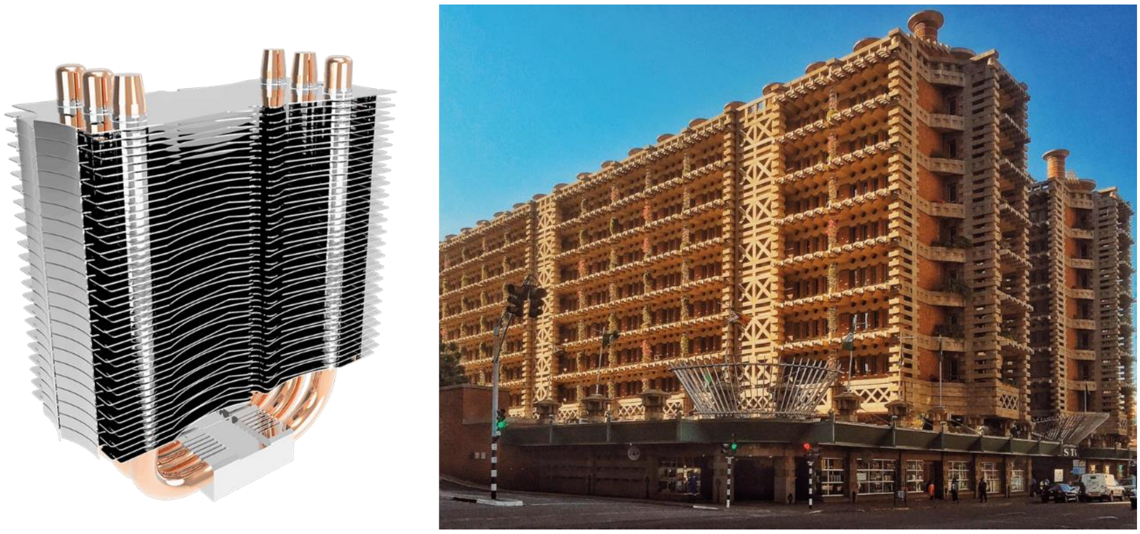
#### 9.1.3.1 Night cooling

This chapter is dedicated to night cooling. Night cooling a type of natural ventilation. The main strategy is to take away the heat accumulated in the inner constructions. After a hot day, the inner constructions need to be cooled down to guarantee better thermal conditions during the following day. The potential of natural ventilation allows us to avoid using mechanical device to power the air exchange. In other words, there is no other heat creating device, which would heat up the living space. This strategy can be used when the night temperature is sufficiently lower then the inner constructions temperature.

The efficiency of night cooling depends on the air temperature at night. In Czech Republic, an average cool night in August has around 8 °C. So, it is very convenient to use this method. At Tainan, the difference between heated interiors and outdoor night temperature is not that big. An average cool night in August has temperature around 24 °C. The cooling air would have to be collected from cooler areas in the city, for example parks, rivers, ponds etc. Air intake through the soil could also be used for cooling the outdoor temperature.

#### 9.1.3.2 Surface area increasement

The night cooling effect can be increased by adding more surface area to the facade. The efficiency of heat transfer through the convection improves. Similar strategy is common in mechanical engineering. The following picture shows the analogy of transferring the heat from CPU to the heatsink. The cooler allows the air go through and reduce the heat stress. The building in the photo is a the Eastgate center in Harare, Zimbabwe.



*Pic. 45: Improving the effect of heat removal by increasing the facade area – CPU analogy (28) (29)*

Thanks to this strategy, the night cooling effect is increased. In the morning, the temperature inside the building is lower than it would be with flat facade. This building also uses effective way of ventilation which helps to maintain the comfort level. Even when power supply is shot down, the building is still operative.

Although this strategy is more preferable to hot climates. Construction like this would not is not suitable to cold climates because of lack of thermal insulation. Insulation would lower the leak of heat in the external environment. These ribbed structures would have to be inside the interior, which would be ventilated during the night by accessing the air to go through.

#### 9.1.3.3 Night sky cooling

Another passive way how to gain cold is from the sky. The heat is transferred by conduction, convection and radiation. It is possible to use radiation between the Universe and Earth to cool down the environment. This phenomenon is visible especially after cloudless nighttime. Even though the air temperature is not under the freezing-point, some surfaces may be covered with layer of ice. It is due to radiation from the sky – because the average temperature of Universe is above the absolute zero. So, the surfaces are able to cool under the freezing-point.

However, in the day time, solar radiation will counteract the effects of this phenomenon. In presence, new materials which would reflect the Sun radiation are under development.

### 9.1.4 Wall surface color

The color of the facade also increases the negative effect on the thermal balance. It is advisable to prevent the direct impact of the Sun rays on the surface of the building. The surface of the wall should have a high reflectance color. Ideal is a white color or other light shades.

### 9.1.5 Lowering of inner energy gains in hot season

Another measure that can be applied in the summer to reduce heat gains is lowering the inner gains. The inner gains consist of individual internal heat sources – occupation, lighting, office equipment, ventilators, warm surfaces, water steam production and others. In other words, it is ideal to cook less, not to use many electrical devices and light the space with light bulbs which produce less waste heat like LED lightning.

# 10 Conclusion

The analysis of the Prague heat island was calculated using a local climate zone study. Thermal maps estimation was made based on the data provided by NETATMO company (14). Characteristic zone deviation from mean temperature in Prague was set for every local climate zone. Based on these deviations, it was possible to produce interpolation maps. These maps show probable temperature distribution in Prague area during the hottest day/night hour in a year.

Following this method, the temperature distribution maps were also produced for future scenarios. There are totally 6 future scenarios – best/probable/worst possible case for year 2043 and year 2068. The temperature change forecast for this study was taken over from climate change study from The Charles University in Prague (17). The future scenarios also contemplate the decline of plain land – data were provided by Czech Statistical Office (2). The +50 years probable scenario shows significant increasement of temperatures in the city. The average deviation is around +1.7 °C.

Subsequently, methods of remaking exterior were described. The goal of this transformation is to achieve more favorable conditions. The following UHI studies served to verify the effectiveness of these methods. The number of trees was doubled in the settlement. Ordinary roof surfaces were replaced by green ones. The temperatures in the housing estate in 1 meter above the ground dropped by 0,27 °C during the day and 0,18 °C during the night. The study confirmed the improvement of living conditions.

A discussion over effective energy design of buildings was made by comparing the climate, approach to engineering and executed UHI analysis. Energy design strategy in the Czech lands will change especially due to overall temperature increasement. Taiwanese approach of reducing heat stress was explored. Taiwanese attitude toward building design is mainly influenced by the permanent heat stress. Although, the buildings thermal comfort must be maintained in both summer and winter. Not all the local techniques are appropriate to Czech climate, only some of them were implemented to the Czech energy design. Though it is possible to combine different methods to find new energy saving solutions.

The climate change will not significantly influence today low-energy or passive buildings. However, in the future we need to pay more attention to the summer condition design. Attention needs to be paid to proper window choice, size and location. All outer walls should be highly heat insulating. The constructions thermal capacity should resist the temperature fluctuations. The building surrounding area should contain a lot of greenery, ideally the greenery is also implemented to the construction itself. Great impact on thermal stability also has shield design. All the windows should have a proper shading system which will reduce the number of sunrays going to the interior and maintain sufficient illumination in the interior. In winter period the windows should also let the sunray go through to use the passive shining for heating. In summer there are methods how to cool the interior passively as well. Especially, night cooling is efficient in our climate – the night and day temperature differs greatly.

Currently in the Czech Republic, there is not enough paid attention to the impact of climate change on a building design. Climate change will become stronger and influence our living conditions more than ever. This is critical because more than half of today's population live in cities. Average person spends probably more than 85 % of time inside of buildings. Urban environments need to be developed rationally to reduce the negative impact of climate change and improve the living conditions of people both outdoors and indoors. These studies are part of tomorrows sustainable solutions which needs to be implemented to secure dignified life for today and future generations.

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## List of used software

1. Autodesk – AutoCad 2018
2. Microsoft office 2016 – Word, Excel, Powerpoint
3. SAGA GIS – System for Automated Geoscientific Analyses
4. Esri – ArcGIS – GIS software used for urban calculations
5. QGIS 3.2.3 – GIS software used for urban calculations, editing platform
6. Adobe Systems – Adobe Acrobat 2017
7. ENVI-met V4.4 – Urban microclimate calculations

# Attachment list

32. Velká Ohrada temperature distribution at 3 pm. in 27 m height, original st.
33. Velká Ohrada temperature distribution at 3 pm. in 27 m height, new st.

# Picture list

# Table list