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Research Article

Role of Street-Level Outdoor Thermal Comfort in Minimizing Urban Heat Island Effect by Using Simulation Program, Envi-Met: Case of Amman, Jordan

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Abstract: This study determines to what extend does computer modelling and simulation contribute to assessing methods in planning of rural and urban regulations related to lowering the effect of urban heat island. This was achieved by examining global warming and its relationship with urban heat islands and outdoor thermal comfort through relationship, definitions, problem, causes, parameters and mitigation techniques. The aim of the study is to assess urban design aspects, such as height and width ratio, positioning of buildings and provision of shade, and their role in the enhancement of urban microclimate which will have positive effects on both energy use in buildings and outdoor thermal comfort of pedestrians. This was followed by studying Jordan's practices in building regulations for related factors in order to choose parameters to apply in computer simulation program application, theories and experiments, giving out timeless and expense-less solutions and suggestions. Sample of chosen attributes and parameters were applied on a hypothetical typical of residential zone type (C) in the city of Amman, to finalize solutions in possible building regulations and recommendations.

Keywords: Amman, building regulations, ENVI-met

INTRODUCTION

During the period from 1990 to 2020, the urban population in the developing world is expected to increase by about 25-45%, except in Latin America and the Caribbean where the urban population already exceeds 70%. By 2020, the urban population is expected to be greater than the rural population in all parts of the world except sub-Saharan Africa and South Asia (World Bank, 2002).

In 2020, 3.5 billion people in developing countries will live in cities, and Africa and Asia will be predominantly urban, as Latin America already is. Such rapid growth puts high pressure on cities, contributing to urban head islands (Orn, 2002).

Thereafter, the environment is negatively impacted by urbanization. This is caused by the production of pollution, changes in the atmosphere properties, and harmfully impacting soil covers. Table 1 shows General characteristics of the urban climate.

As urban areas develop, changes occur in their landscape. Buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist become impermeable and dry.

These changes cause urban regions to become warmer than their rural surroundings, forming an "island" of higher temperatures in the landscape (EPA, 2006).

Table 1: General characteristics of the urban climate (Johansson, 2005)

Mean air temp	1-3°C warmer (occasionally up to 12°C)
Evaporation	50% less
Pollution	10-25% higher concentrations
Cloudiness	5-10% more
Solar radiation	5-25% less
Mean wind speed	20-50% less
Turbulence	10-50% greater

Heat islands occur on the surface and in the atmosphere. On a hot, sunny summer day, the sun can heat dry, exposed urban surfaces, such as roofs and pavement, to temperatures 50-90°F (27-50°C) hotter than the air while shaded or moist surfaces-often in more rural surroundings-remain close to air temperatures. Surface urban heat islands are typically present day and night, but tend to be strongest during the day when the sun is shining.

In contrast, atmospheric urban heat islands are often weak during the late morning and throughout the day and become more pronounced after sunset due to the slow release of heat from urban infrastructure. The annual mean air temperature of a city with 1 million people or more can be 1.8-5.4°F (1-3°C) warmer than its surroundings. On a clear, calm night, however, the temperature difference can be as much as 22°F (12°C).

Though heat islands may form on any rural or urban area, and at any spatial scale, cities are favoured, since their surfaces are prone to release large quantities

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of heat. Nonetheless, the UHI negatively impacts not only residents of urban-related environs, but also humans and their associated ecosystems located far away from cities. In fact, UHIs have been indirectly related to climate change due to their contribution to the greenhouse effect, and therefore, to global warming (NASA, 2002).

Probably no effect of urban transport attracts more debate than the environmental impact of motorised traffic. In some mega-cities with unfavourable conditions- Santiago, Mexico, Tehran, Dhaka- air pollution is visible as smog and is directly harmful. As motorization gains momentum in the world, an enormous urban population is about to be affected. These effects are not only local (although this is bad enough) but many experts are warning of the serious potential effects of global warming in a world where motorization multiples and is driven by bad engines and poor fuel (Orn, 2002).

However, the city most related to the concepts of smog, Los Angeles, has largely managed to combat it. Even in Bangkok, ill reputed for its notorious traffic problems and air pollution, a turn to the better has been possible (Orn, 2002).

Urban areas act as climate modifiers. Climate elements, such as solar radiation, air temperature, humidity and wind are affected by the urban fabric. Nocturnal urban-rural temperature differences of 6°C or more are common in the centres of major cities. This indicates that the average diurnal temperature rise due to urbanisation may be greater than the estimated 1- 3.5°C rise in temperature due to global climate change over the next 100 years (Johansson, 2005).

Heat islands may skew long-term temperature records as urbanization encroaches on weather stations located near the outskirts of town. Consequently, researchers must remove heat island effects from temperature records to accurately estimate climate change. The Intergovernmental Panel on Climate Change (IPCC) has concluded that the impact of urban heat islands on temperature records is "real but local," and has only a negligible effect on regional or global trends. The IPCC also noted that urban heat island effects on local climate appear to include changes in precipitation, clouds, and daily temperature range (Trenberth *et al*., 2007).

This research aimed at finding the optimum urban setting requirements to minimise urban heat islands and reducing its effects which contribute to global warming and climate change.

The second main objective of the reasearch is to achieve best practices in outdoor thermal comfort environment that encourage outdoor activities in proper settings at street level *by studying building height to street width ratios.*

MATERIALS AND METHODS

Due to the increase in energy demand, cost and the scarcity of water, Jordan's Government has established different institutions to address environmental, social, and economic aspects of sustainability. Other non-governmental organizations are working on the same issues to find the best solution to conserve Jordan's water, energy, and the environment. Jordan has identified the role that laws and regulations can contribute to the implementation of best practices for conservation (USAID Jordan, 2010).

Jordan is privileged with an exceptional geographic location and incomparable environmental circumstances; therefore, the use of clean energy sources in Jordan is very low. However, energy use by the residential sector in Jordan is 24% of the total expenditure, which is equal to that of the industrial sector (NERC, 2008).

As the living standard increases, people tend to install heating and/or cooling equipment in order to overcome the problem of poor thermal comfort. For buildings not adapted to the climate, energy use-and consequently costs-will be excessively high and the impact on the environment will be negative. This impact is translated into many forms; one of them is heat island formation.

Field studies: Field studies in numerous cities, mainly in temperate climates, have shown that the magnitude of nocturnal heat islands increases with increasing H/W ratio (reduced SVF) of street canyons. In the day the urban canyon is a good absorber of solar energy and due to the relatively high thermal capacity of urban surface materials, this energy is stored in the fabric and not released until after sunset. The largest urban-rural temperature difference occurs on calm and cloudless nights. Under such conditions, nocturnal heat islands of up to 12°C have been recorded (Johansson, 2005).

Urban microclimate: As for the urban microclimate, studies showed that more shade on the street level is necessary to provide a climate-conscious urban design that takes the hot summer conditions into account. This can be provided through a more compact urban design with higher height-to-width ratios of urban street canyons than those currently applied and through different forms of overhead shading, e.g. arcades and other types of covered walkways. However, the cold season also has to be considered and some wider streets and open public spaces should be designed for solar access. The urban codes of Amman were found to be inappropriate and need to be changed to promote shading of pedestrians (Johansson, 2005).

Almost all studies show that nocturnal urban heat islands are at their largest during dry season. They typically varied by between 2 to 5°C. (Lindqvist and Jonsson, 2005).

Daytime conditions have gained far less attention than nocturnal heat islands, although the former are more important from a human comfort point of view (Johansson, 2005).

Computer simulations: What-if scenarios are fascinating. Aided by computer simulations, they become a tool to test drive multiple virtual models of the building design before wasting any resources on materials (Lee *et al*., 2002).

A model is a simplified representation of the real world (Lave and March, 1993). In one step, the process of exploring iteration can be taken after creating the base case of the model, to perform parametric studies. This is by investigating the microclimate results consequences of various schemes.

Parametric studies are set of measurable factors, such as temperature and pressure that define a system and determine its behaviour and are varied in an experiment.

Numerical models predicting urban microclimate: A large number of numerical models predicting different urban climate variables have been developed. Most Computational Fluid Dynamics (CFD) programmes are complex and require a high level of expertise.

Ali-Toudert (2005) simulated the microclimate of the desert city of beni-isguen (32 N), Algeria using the computer simulation programme *ENVI-met* (Bruse 2006). They found that during hot dry summer conditions, the temperature decreased by about 3°C when the H/W ratio increased from 0.5 to 4 and that north-south streets were slightly cooler than those oriented east-west. Their investigations were restricted to the summer season. Swaid and Hoffman (1990) simulated air temperatures for Tel Aviv (32 N), Isreal, using the *CTTC model* and also found lower air temperatures for north-south than east-west.

Tools: There are simple tools for measuring effects of urban heat islands and others that are advanced and need special experienced personal to perform. The aim of the following review is to study these tools and reach to the point where we find that the software ENVI-met is the most suitable for this field of study.
Simple tools are the following examples:

- Shade calculation (Shadow)
- Solar absorption (Townscope)
- Mean radiant temperature (RayMan)
- Air temperature, by Cluster Thermal Time Constant (CTTC) model, scale models, and climatic maps.

Advanced tools are the following examples:

- Mesa-scale models (whole city)
- Micro-scale models (street level)
- ENVI-met 3.0

ENVI-met simulation program: ENVI-met was created by Michael Bruse. It is a computer programme that predicts microclimate in urban areas. It is based on a three dimensional Computational Fluid Dynamics (CFD) and energy balance model. The model takes into account the physical processes between the atmosphere, ground, buildings and vegetation and simulates the climate within a defined urban area with a high special and temporal resolution, enabling a detailed study of microclimatic variations. The horizontal model size is typically from 100×100 m to 1000×1000 m with grid cell sizes of 0.5-5 m. The fact that the programme requires limited input data and that the modelling of the urban area is simple, makes it user friendly.

Input data: The input data consists of the physical properties of the urban area of study and limited geographical and meteorological data. The required input data for the buildings are dimensions, reflectivity, U-value and indoor temperature, which are all constant for all buildings. The model uses detailed data on soils, including thermal and moisture properties. Both evapotranspiration and shading from vegetation is taken into account. The required geographical and metrological input data are longitude and latitude, initial temperature and specific humidity, wind speed and direction and cloud cover. Summary of input data concerning Climate data is Latitude and longitude, Wind speed, Initial air temperature and humidity. Summary of input data concerning Urban design data is Urban geometry, Trees, Building material properties and Soil properties.

Output data: The model provides a large amount of output data including wind speed, air temperature, humidity and Mean Radient Temperature (MRT).

Limitations: ENVI-met limitation is that it doesn’t take into account the thermal mass of building envelope, and the indoor temperature has to be constant which is not realistic. This will affect mean radiant temperature and air temperature.

Objectives: There are few user-friendly computer programmes and tools that can predict the influence of urban design on the urban microclimate with good precision. Existing programmes tend to be either too complicated or their output is too limited. This is all on the contrary of ENVI-met program.

The case of Amman: The aim of the study is to define the preferred case for each of the following, considering that the preferred case is the case that has the maximum temperature during winter and minimum temperature during summer:

- The preferred street width for the current Type C residential regulations for street widths.

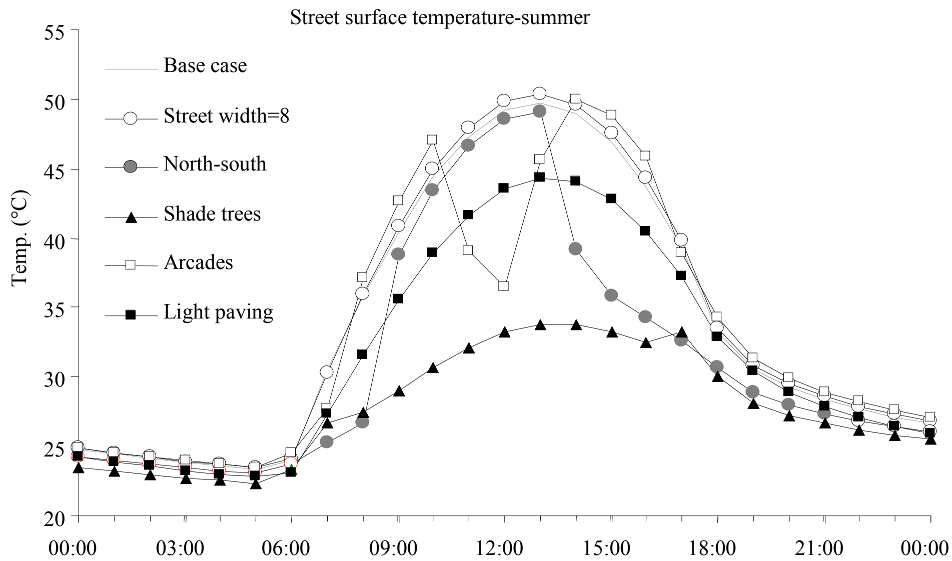

Fig. 1: Street surface temperature, summer time, between all cases

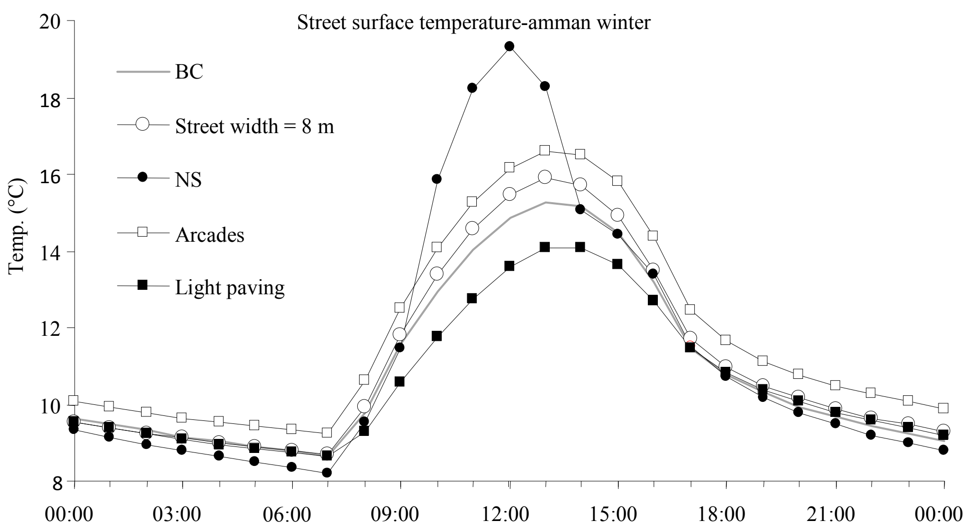

Fig. 2: Street surface temperature-winter case, between all cases

- The preferred building height for the residential type C.
- The best location for trees on the street that might contribute to improving street climate.
- The best street/building height ratio for pedestrian streets
- Suggesting modification in the current setbacks that will result in improved thermal conditions in the urban areas.
- The preferred street orientation for the residential sector type C.

The results can be used for some of the commercial buildings regulations.

Geography: Amman is known to have a wide variation of landscape components, hills and valleys, even and uneven land, therefore, different variations of climate are experienced all over Amman throughout the year. The lowest part of Amman is presented by the amphitheatre station down town with altitude of 730 m above sea level, and the highest (approximately) is presented by Jordan University station, 980 m above sea level, where the case study zoning will be applied. Figure 1 and 2 for an overview of the city of Amman.

Climate: Being on a high altitude, with 35°E longitude and 32°N latitude, climate can be cold to very cold in winter and warm to hot in summer, with south-west and south winds through the year, and quite a good amount of rain fall compared to the hot-arid climate of Jordan. The data collected was taken for the Jordan university station, which has the same altitude and nearly the same latitude as the newly built areas in Amman city that

Table 2: Climate Data for University of Jordan Station (Metrological Department, Jordan, 2005)

Station	Amman, universty of Jordan											
Source	Meteonorm, Jordan climate handbook									Latitude	32	°
Data collected	Tala Awadallah									Longitude	35	
										Altitude	980	m
	Solar radiation											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sunshine		h/day										
Real	5, 10	5, 90	7, 00	8, 30	10, 40	11, 90	12.10	11,40	10,00	8,40	6, 70	5, 00
Max.	10, 13	10, 86	11, 84	12, 84	13, 68	14, 09	13.87	13,14	12, 16	11,16	10, 32	9 ,91
	50%	54%	59%	65%	76%	84%	87%	87%	82%	75%	65%	50%
	MJ/m^2 day											
Radiation	11, 03	12, 96	17, 70	22, 0	26, 80	30, 70	32, 70	27, 29	24, 20	19, 25	13, 90	10, 54
Temperature	°C											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Extreme max	24.0	25.1	26.3	33.0	39.0	38.3	39.0	41.5	39.0	34.6	28.0	24.8
Mean max	10.1	11.5	15.0	20.2	25.2	28.1	29.5	29.6	28.3	25.1	18.2	12.4
Mean	6.40	7.40	10.2	14.6	18.9	21.9	23.6	23.6	22.2	19.0	13.1	8.40
Mean min	2.70	3.20	5.40	8.90	12.5	15.7	17.7	17.6	16.0	12.8	8.00	4.30
Extreme Min	-8.3	-4.5	-6.5	-1, 5	1.40	4.50	8.50	8.80	4.50	3.40	-2.0	-4.8
	mm/month											
Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	346	285	234	268	54	0	0	0	5	92	204	305
Average	110	98	87	25	5	0	0	0	0	10	48	90
Mini	74	64	58	18	3	0	0	0	0	8	31	58
	%											
Humidity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean max	79	74	67	58	51	50	52	54	56	56	64	75
Average	74	96	62	53	46	45	47	49	51	51	59	70
Mean min	69	64	57	48	41	40	42	44	46	46	54	65
	Direction and speed: m/s											
Wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Direction	SW	SW	SW	S	S	S	S	S	S	S	SW	SW
Speed	2.6	2.6	2.5	2.5	3.0	2.0	2.2	2.0	1.9	2.2	2.2	2.4

applies Greater Amman Municipality regulations. The values were put in a certain excel sheet template as in Table 2.

The building sector in Jordan: During the development process Jordan has invested a considerable amount of its scarce financial resources in the construction industry, building houses, hotels, banks, schools, etc. for both the public and private sectors. It is expected that this sector will expand even more in the coming years due to the growing need for good quality housing in Jordan for the expected population of about 6 millions by that time. The construction sector accounts for 15% of the GDP and about 10% of the labour force. The Building activity in Jordan measured by the area licensed for construction grew by 26.4% between January and July 2000 over the same period in 2007 reaching 2,757,500 m^2. This is mainly attributed to residential buildings (Department of Statistics, 2008).

This can contribute to further urbanization and growing of the city, which will for sure contribute to urban heat island effect. Furthermore, when temperatures rise during the day and they don't have to time to cool at night, the urban environment will not be hospitable for pedestrians to enjoy the outdoors inside the city, without any outdoor thermal comfort.

Urban zones and regulations: The following material is extracted from "Building Regulations and Zoning in Amman" Amman Municipality:

Building materials: Reflective materials that might upset the surrounding neighbours or might present hazard to public safety are forbidden. Not more than 20% of the exterior elevations are allowed to be painted with colours other than the colour of stone or white.

Building setbacks: Table 3 shows the regulations of buildings for residential building sector, setbacks, width of street facade and maximum building percentage on the plot.

Residential buildings height: Subject to any special provisions indicated on the structural or detailed drawings, the building height in the housing sectors will be limited to four floors apart from the roof provided that the building will not be higher than 15 m above the ground floor's tile level.

Table 3: Greater Amman municipality regulations

Sector	Area (m^2)	Width street façade (m)	Setback Front	Setback Side	Setback Back	Maximum building percentage
Housing area						
Sector A	1000	25	5	4.0	7.0	39
Sector B	750	18	4	4.0	6.0	45
Sector C	500	15	4	3.0	4.0	51
Sector D	300	13	3	2.5	2.5	51

Table 4: Base case and other cases to compare results

Case Name	Type	Street width	Sidewalk finish	Building height	Street orientation
Base case	Residential type C	12 m	Light	4 floors 12 m	West-East
Case street 8	Residential type C	8 m Ratio = 1.5	Light	4 floors 12 m	West-East
Case street orientation	Residential type C	12 m	Light	4 floors 12 m	North-South
Case trees effect	Residential type C-Trees added at the sidewalks	12 m	Light	4 floors 12 m	West-East
Case sidewalks colour	Residential type C	12 m	Extra Light	4 floors 12 m	West-East
Case with arcades	Residential type C	12 m	Light	With arcade	West-East

Balconies are not allowed to exceed the building line that was granted a permit except for the architectural projection and these should not exceed 0.75 m from the building line for buildings below street level.

Computer simulation: Based on the regulations mentioned above and on the information from the municipality about street widths, the following model was adopted as prototype to be used for Urban Simulation.

Climate data: Climate data including temperatures, wind speed and direction, solar radiation and rainfall from Jordan Climatologically Data Handbook was used in the simulation. August was chosen to be studied for the summer season and January for the winter season. A special software was used to simulate climate data of Jordan, and the exact location of Amman, to be able to use it in the ENVI-met program.

Comparison between different cases: The model adopted for residential buildings is based on a type C residential zoning, this type was chosen because it is the most common type specially for area that were recently regulated, taken the inflation in land prices this type became common as it provides the minimum area that can be used to build proper residential building and at the same time is economical because of its low area. The street width for the base case will be 12 m; street widths of 16 and 20 will be compared in order to identify the best street width that will provide the most acceptable street climate. A Street surrounded by eight residential plots will be used as a model for simulation; Table 4 includes a description for the original case and the different cases that will be studied. Data will be measured for the central point in the middle of the street.

Modelling: According to the method of the study, different cases were created to test the assumptions mentioned above in addition to the performance of the suggestions to be used in the subject urban model, the main goal was to use available and affordable materials and techniques.

Previous studies proved that using night ventilation and avoiding day ventilation in hot arid climate will lower the inside temperature in the building during daytime in summer, and thus will lead to more energy saving for cooling purposes. So this study used the method of night ventilation whereby the infiltration rate where increased during night time and reduced during day time in summer.

Constant building materials, internal loads, u-values and surface properties for the buildings were used. Also, the climate data is constant for all the case to be inside the City of Amman.

The simulation was done for the 15 of July as the average day of the hot season, representing summer and the 15th of January as the average cold day representing the winter season.

Analysis: After conducting data entry of input data in the simulation software ENVI-met, results were compared for each case alone with the base case for both winter and summer seasons.

Figure 1 for the summer case results and Fig. 2 for the winter case results.

RESULTS AND DISCUSSION

From the temperature differences through all case all through the day and night, it was found that there is big variations in air temperatures within the city, both in summer and winter.

Summer case results: It is found from graphs that light paving and shading with trees reduced the air temperature by 2 to 15 degrees in the middle of the street, which will contribute to outdoor thermal comfort, while the worst case scenario was the base case.

Winter case results: North-South axis organisation of the street had the maximum temperature in the middle of the street in winter, while the shading of trees is excluded from the study cases because of the assumption of using deciduous trees.

CONCLUSION

After the analysis of the case study and literature reviews, a number of opportunities, conclusions and recommendations, the following attributes are recommended for the success of outdoor thermal comfort and urban heat island effect mitigation:

- Reducing the temperatures in street scale can contribute to decreasing urban heat island effect on a micro scale, and global warming on a macro scale.
- Taking into account the results of the study concerning the orientation of proposed pedestrian streets in Amman; it is objective to choose north-south axis paths for converting into pedestrian streets. On the other side, Rainbow Street in downtown Amman is an east-west Axis Street; but it is successful and comfortable to walk in. This can be for the narrowing of the street and variation in widths which may give it interest experience for the pedestrian and users of the street.
- Although Al-Wakalat Street in Swefieh, Amman is a north- south axis road, it wasn't successful. This may be caused by the H/W ratio achieved in it with a value of 1, which means that the height of the buildings adjacent to the path is equal to the width of the path, which is negative for the outdoor thermal comfort.
- It may be a good idea to convert Al-Hamra Street in Sweifieh into a pedestrian path, although it will be wiser to take other elements into consideration when making this decision.
- It is recommended to choose locations of pedestrian streets to be enclosed between parallel strips of buildings that have good reflective materials on their facades so it doesn't absorb heat that gets emitted at night time which is the time that people use the pedestrian walks in summer.
- It is recommended to choose locations of pedestrian streets to be enclosed between parallel strips of buildings that have high H/W ratio that does not exceed a certain limit to avoid urban geometry effect in absorption and reflection, and benefit from the time of shading of the pedestrian street, which will keep the pavement surfaces from getting over heated.
- It is recommended that further simulations using ENVI-met software can be done on outdoor thermal comfort of streets between commercial tall buildings in order to decide H/W ratios, optimum orientation and optimum shading techniques (using trees or shading devices) that can be positive for improving outdoor thermal comfort.
- It is recommended that further simulation using ENVI-met software can be done on further studies concerning vegetation type, height and location to conclude the optimum vegetation that can reduce heat and be cost effective.
- It is recommended that further simulation using ENVI-met software can be done on types of pavement material ranging from dark to light, soft to hard, smooth and rough, to measure the effect of them on reducing heat and choosing the optimum material.
- It is recommended in places where it is not possible for pedestrian walks creation, to design arcades in buildings. They are optimum solutions in commercial buildings, where we find no waste areas and no lose in investment and cost. On the contrary, this will increase revenues of commercial shops adjacent to the arcade where people are encouraged to walk because of the outdoor thermal comfort underneath the arcade. These are solutions for commercial areas.
- Distances can be narrowed between buildings in newly regulated plot of lands. This can encourage outdoor activities; at least for residents of buildings in their own backyards.
- In order to improve outdoor thermal comfort, there should be no front setbacks in order to achieve H/W proper ratio.
- Adequate planning and paying attention for outdoor thermal comfort by caring for pedestrian and outdoor activities can contribute to decreasing energy use and air pollution, and will mitigate urban heat island effects and dangers of global warming.
- It is encouraged to provide pathways and pedestrian walks with overhead shading to protect against solar radiation in summer by using shading devices, shading trees and canopies or arcades and galleries in commercial buildings.

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