Building Envelopes and their Impact on our Urban Thermal Environment

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ABSTRACT

The way we design our buildings and place them in urban areas, affects our outdoor urban thermal environment through large thermal fluctuations, also described as urban heat island effect. The building envelope is the outer layer of the building that interacts most closely with the outdoor climate conditions and impacts the outdoor through diffuse and reflected radiation off its surface onto pedestrian spaces and streets. How the envelope is designed and positioned can have significant impact and should be considered during the building design process. This paper will discuss the methodology adopted to collect field test data and data analysis findings to describe the effects of different design configurations of building envelopes on pedestrian environment.

Field testing was done in various sites in Hong Kong to measure radiant heat flux of sites of varying amounts of 5 main materials: exterior concrete walls, exterior windows, greenery, adjacent open space areas and visible sky. These materials were then extracted through the dissection of fish-eye photographs to isolate and determine ratio of each of the materials, referred to as view factor analysis. The four main view factors used or developed were: sky view factor, sunlit view factor, green view factor, glass view factor. These view factors were studied against the radiant fluxes to find key discoveries of the relationship between short-wave and long-wave radiation and mean radiant temperature (MRT) which is a thermal index used to understand the thermal comfort of a person from net radiant heat loss and gain. Some of the findings are summarized as the more spread apart building or lower height building envelopes may increase short wave radiation however reduce long-wave radiant heat flux meaning less trapped heat within the buildings. Glass buildings performed badly under direct sun, however under indirect sunlight conditions, performed better than opaque concrete building envelopes.

Keywords: *micro-climate, building envelope, view factor analysis*

1. INTRODUCTION

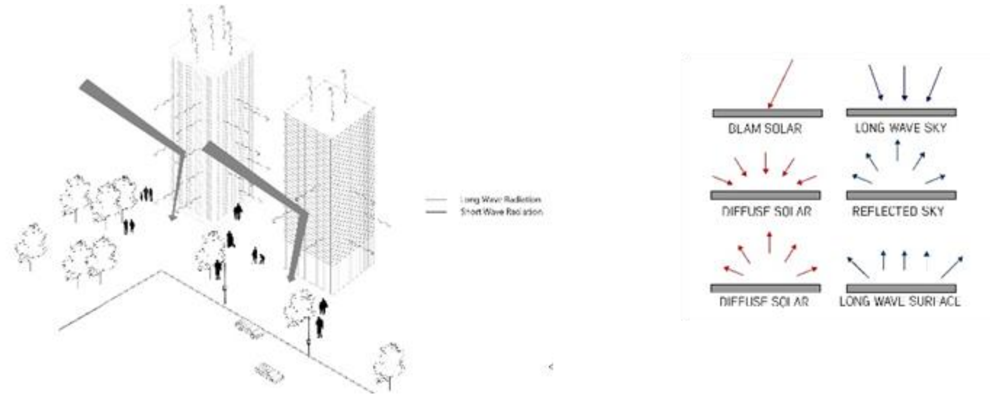
The building envelope is the outer-most interface of the building between the outdoor and indoor environment and in contemporary building design, this separation forms clear demarcation between outdoor as public space and indoor as private space. The impact of the building envelope during the design process is typically considered for indoor thermal comfort. More recently, with increased attention to the effects of buildings on urban environment and climate change, the effect of the building envelope on outdoor urban thermal environment is an emerging research topic and this paper describes research conducted on buildings envelopes in a high density city of Hong Kong.

Buildings affect our outdoor environment through large fluctuations of temperature from stored and trapped heat as observed as urban heat island effect. Research has been conducted on studying the impact of building masses and of urban parks in cities using field measurement and computer simulation methods analysing outdoor thermal environment. It is generally agreed that urban configurations play an important role in the urban thermal balance. This paper describes the field measurement methodology used and a new approach of data analysis through a close examination of view factors and radiant flux to investigate the relationship between building envelope and outdoor thermal environment.

2. METHODOLOGY

2.1 Outdoor thermal environment

The outdoor thermal environment is measured by the parameter of mean radiant temperature (MRT) which can be deduced from simulation or through field measurements of temperature and radiation. There are two types of radiation – shortwave (denoted as 'K') and longwave radiation (denoted as 'L') - that are considered relevant and for reasons diagrammed in Figure 1(a) and (b). Shortwave and longwave radiation is within the thermal radiation spectrum and are important parameters to understand how heat travels in our built environment. Shortwave radiation is a measure of how much thermal energy is radiated from the sun to the earth and longwave radiation is a measure of how much thermal energy is emitted from the absorbed shortwave energy from the earth to the atmosphere. In our field measurements the shortwave radiation measured is mainly the diffused solar energy in the atmosphere, and diffused and reflected solar radiation from the buildings and objects such as trees. Longwave radiation measured is mainly the emitted (re-radiated) radiation from buildings and objects.



(a) (b)

Figure 1: (a) Longwave and shortwave radiation diagram of towers in relation with pedestrian and urban space; (b) Shortwave radiation types (in red) and longwave radiation types (in blue).

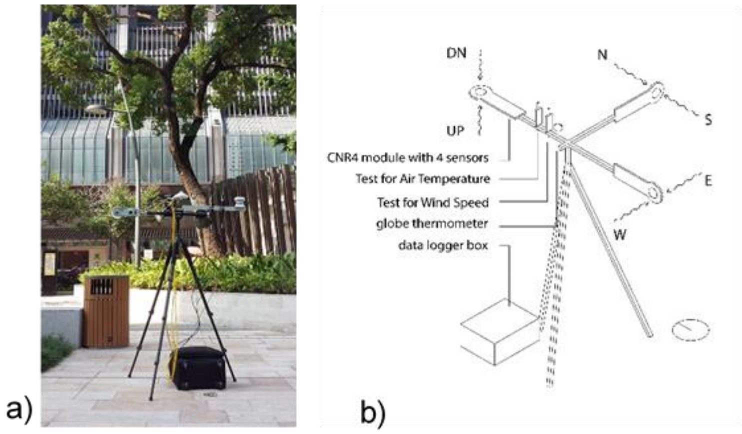


Figure 2: Testing equipment setup for measuring shortwave and longwave radiant flux, temperature, wind speed and humidity.

Thermal comfort parameter – MRT – was calculated based on shortwave and longwave angular factors for a sphere. An integral radiation measurement equipment setup which is one of three common methods of studying the outdoor thermal comfort by researchers was used for this research. A net radiometer (Kipp & Zonen, CNR4) with three integrated pyranometer and pyrgeometer arms was set up at 1.5m above the ground, on a tripod to measure incoming and outgoing shortwave and longwave radiant fluxes within the three-dimension radiation field. The six cardinal points are marked as (N)orth, (S)outh, (E)ast, (W)est, UP and Down where each represents the radiation coming from the noted direction, also shown in the equipment diagram Figure 2b. The Stefan-Boltzmann equation is used to calculate MRT using the measured radiation from six cardinal direction. The CNR4 equipment was used at selected test sites throughout Hong Kong, further described in Section 2.3, and place in shaded conditions to avoid direct sunlight exposure which may cause higher temperature readings due to this exposure.

2.2 View factor analysis

The geometry of the built surfaces and related obstruction of the sky within the city is studied through canyon geometry or sky view factor (SVF), calculated through fish-eye photos, and represents the ratio between radiation received by a planar surface and from the hemisphere radiating environment. Relationships between the air temperature difference and SVF have been studied by means of regression analysis and found to be closely correlated in diverse climates including Hong Kong. For this study, as the focus was identifying how the different vertical building surfaces and materials affected the urban environment, the research began to further dissect the areas related to these factors. The four main view factors identified fundamental were the widely-used SVF, sunlit view factor (SLVF), green view factor (GnVF) and glass view factor (GsVF). SLVF represents the ratio of vertical building surface area receiving direct solar radiation (i.e., cast with direct sun) which then also, inversely counts for the wall areas that are shaded either due to the sun angle or the configuration of surrounding buildings. GnVF, alternately represents the ratio of greenery within the fish-eye lens photo, in order to capture the effect of greenery within the studied hemispheric radiated environment of the urban canyon. GsVF represents the ratio of glass walls receiving radiation within the hemispheric radiated environment. Table 1 shows the visual categorization of these four view factors.

2.3 Site and testing

There were 12 sites selected within Hong Kong for field testing, each site having characteristics of typical and comparable building envelope types and material, and urban configuration (i.e., building layout). To further quantify this range, a design of experiment matrix was developed (Table 2) that represents the range in each view factor for all the sites selected. This method allowed the research team to ensure that the pool of tested sites had conditions to study the effect of the four view factors on the urban thermal environment. From the 12 sites, about 85 data point were collected and multiple regression analysis was conducted to study the relationship between the various view factors and longwave, shortwave radiation and MRT. Most of the testing was conducted in the months of April to September 2015 and during clear to overcast days.

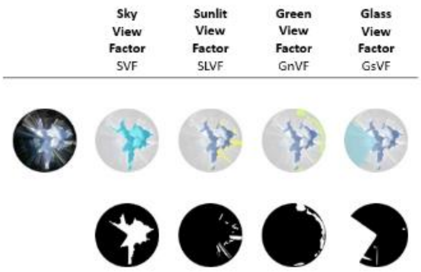


Table 1: Segmentation of the fish-eye lens photo into sky view factor, sunlit view factor, green view factor and glass view factor.

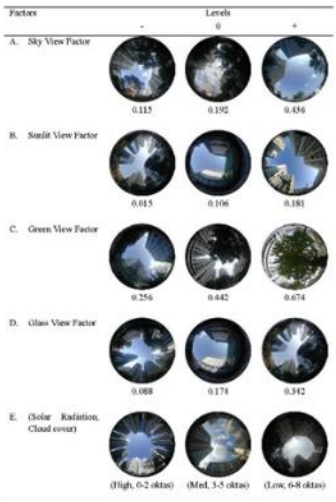


Table 2: Five factors and levels, urban fabric experiment (based on fish-eye photos toward sky)

3. RESULTS AND DISCUSSION

The multiple regression analysis of shortwave (K) and longwave (L) against the four view factors: SVF, SLVF, GnVF and GsVF are shown in the following Tables 3, 4, 5, and 6 respectively. Five minutes mean values were used to determine the data points from 4 to 6 sites per view factor regression analysis.

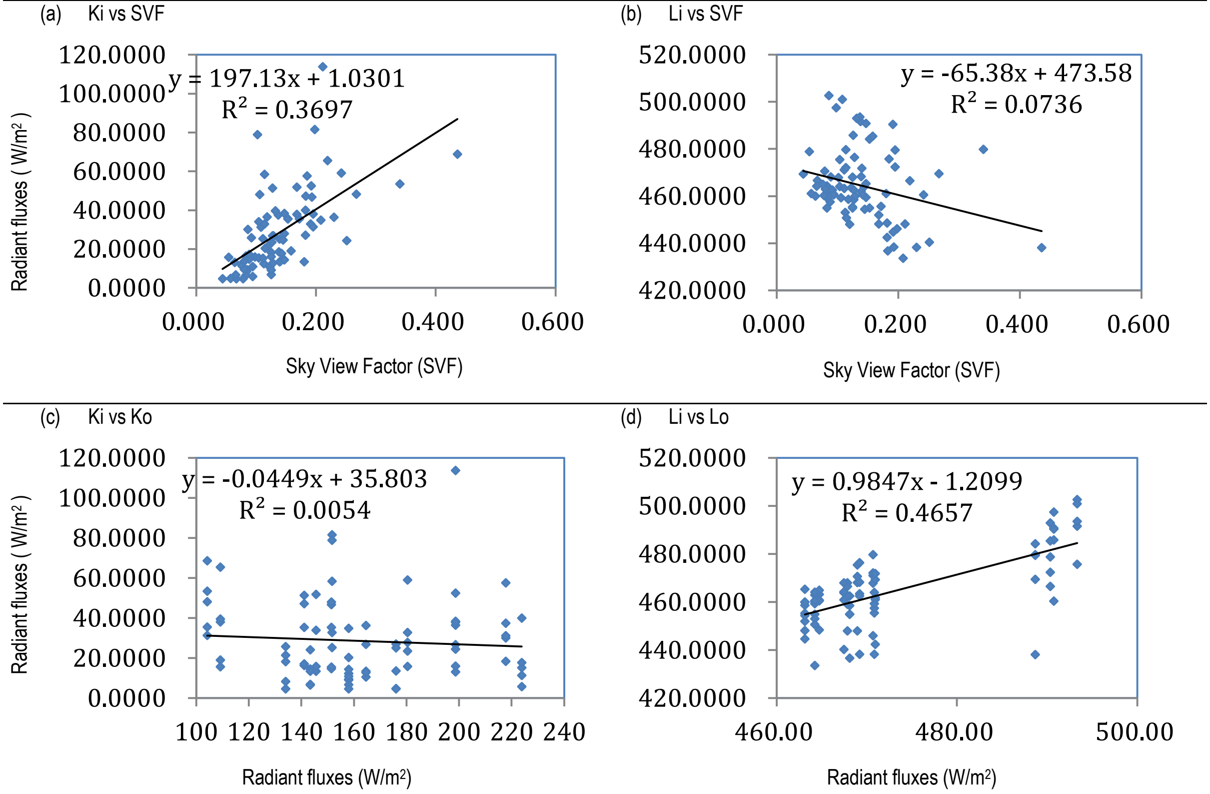


Table 3: Scatter plots for radiant fluxes using 5-min mean values against SVF.

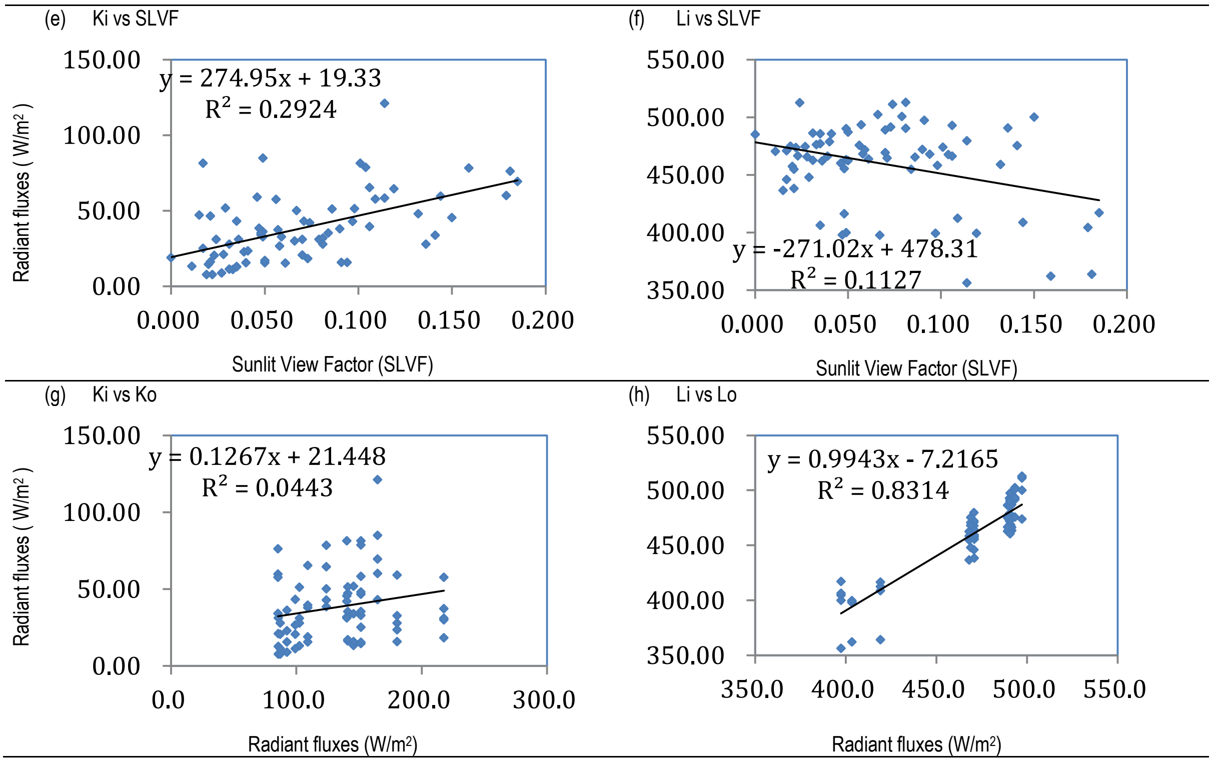


Table 4: Scatter plots for radiant fluxes using 5-min mean values against SLVF

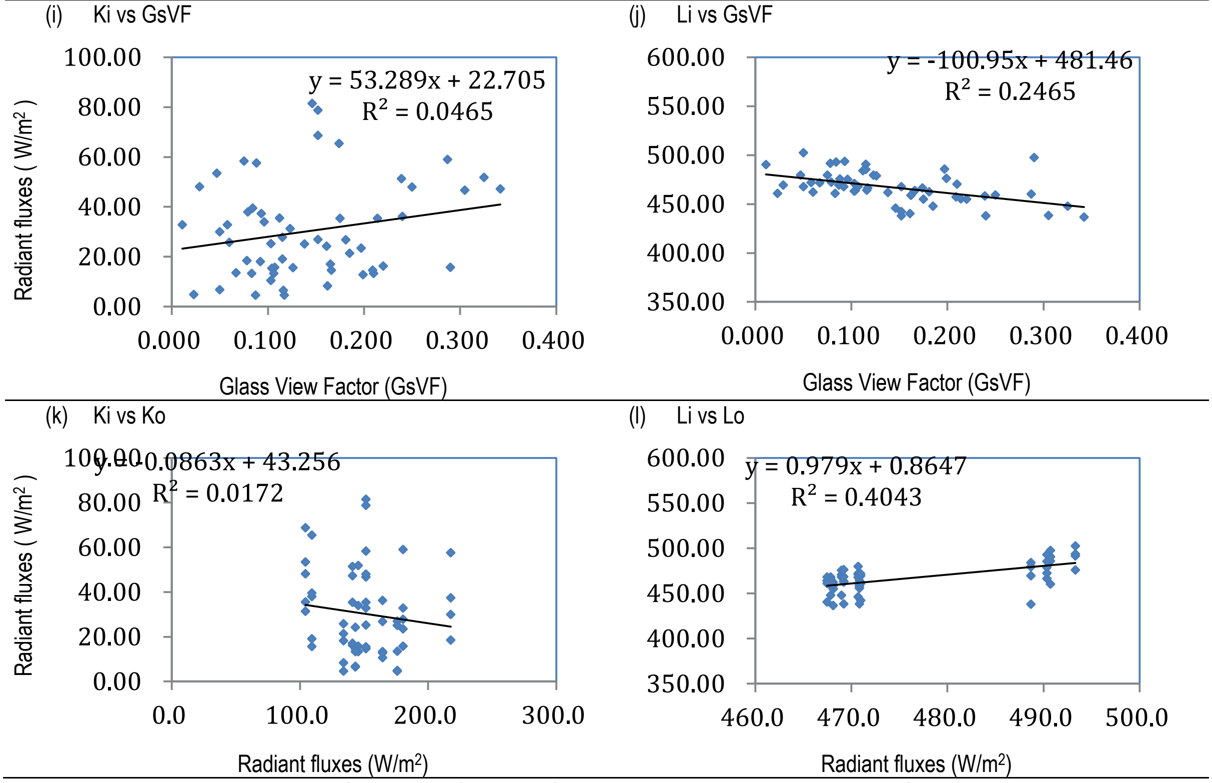


Table 5: Scatter plots for radiant fluxes using 5-min mean values against GsVF

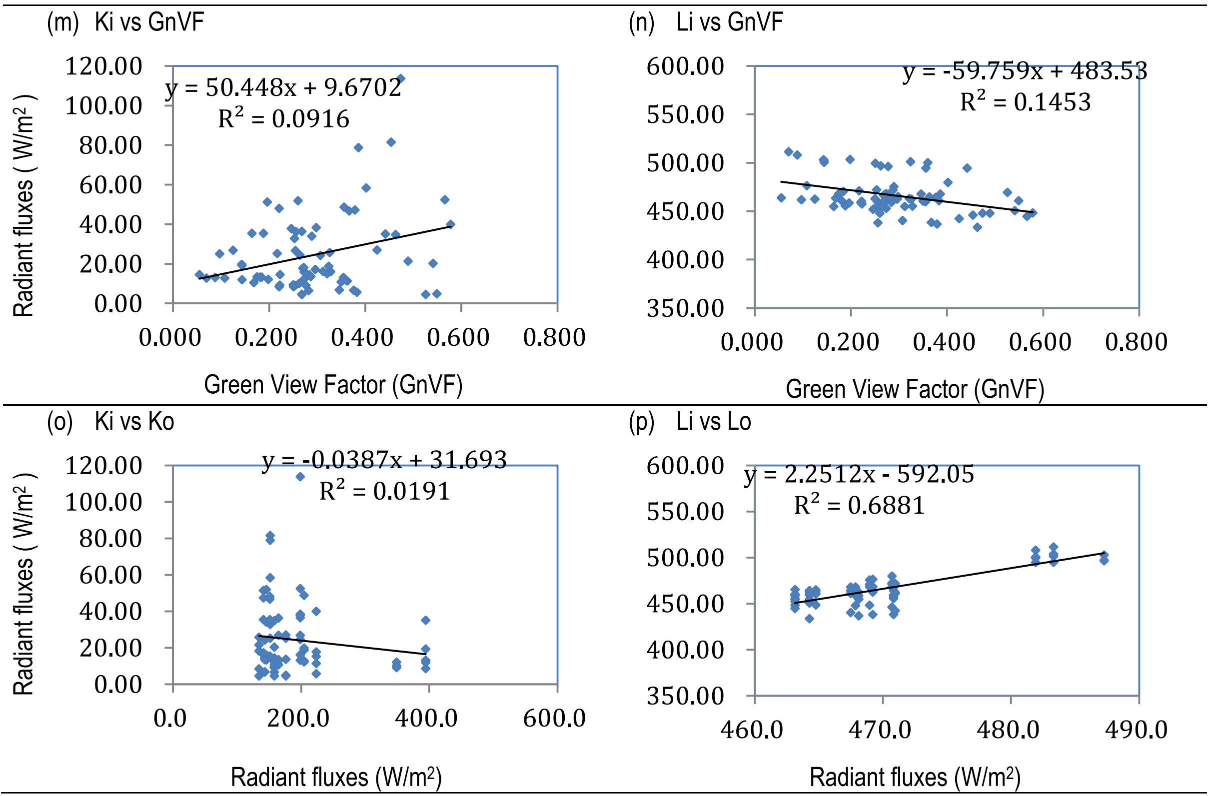


Table 6: Scatter plots for radiant fluxes using 5-min mean values against GnVF

To summarize the regression analysis above in terms of shortwave and longwave radiation, the relative strength table (Table 7) was produced to get a better comparison insight of how sunlit area (SLVF), greenery density (GnVF) and glass wall surfaces (GsVF) can affect shortwave radiation effects (K) and longwave radiation effects (L) for every increase or decrease in visible sky (SVF).

Shortwave radiation increases by all four elements of sky, sunlit wall area, greenery and glass independently by a ratio factor of 1, 0.7, 0.1 and 0.3 respectively. However, the effect of greenery seems to be quite minimal and can be considered negligible in respect to shortwave radiation reflected and diffused from building envelope wall areas receiving direct sun exposure. Shortwave radiation is more significantly affect and increased by:

- More visible sky
- More concrete wall area receiving direct sunlight
- More glass wall area

Although shortwave radiation is considered a significant factor, longwave radiation results provide a better conclusion of how building envelope impacts the thermal environment.

Longwave radiation is affected differently from shortwave radiation in that increases in sunlit wall area causes increase in longwave radiation by ratio of 1:0.5. For elements of sky, greenery and glass decreases in these ratio factors by –1, -0.2 and -0.5 respectively causes increase in longwave radiation. This means that more densely packed built environments where sky visibility is reduced will increase longwave radiation. Reducing the amount of greenery will increase longwave radiation. Reducing glass within the building envelope surface (therefore increasing the amount of concrete building envelope material) in shaded conditions, will increase longwave radiation. To reduce longwave radiation the following could be deduced:

- More visible sky
- Reduce amount of concrete wall area receiving direct sunlight
- Increase greenery
- Increase glass wall area in shaded orientations (i.e., such as north, northeast and northwest facing walls).

Increasing the amount of sky visible in an urban open space between buildings is a positive attribute for psychological human comfort and reducing longwave radiation, therefore although it increases the amount of shortwave radiation due to the direct sunlight entering the open space, the key is to reduce the allow space to let the shortwave radiation reflect and diffuse away beyond the open space.

	SVF (+1 unit)	SLVF (+1 unit)	GnVF (+1 unit)	GsVF (+1 unit)
Shortwave radiation, K	1 1 1	0.7	0.1	0.3
Longwave radiation, L	-1 -1 -1	0.5	-0.2	-0.5

Table 7: Relative strength of view factors and their effect on increases in shortwave and longwave radiation.

The final relative strength matrix summarizes the effects of thermal radiation on pedestrians due to orientation and layout of building envelope, cast sunlight on building envelope, greenery and glass envelopes.

4. CONCLUSION

The results indicate that the thermal environment is mostly affected by the positioning of the building envelope in respect to the canyon geometry and amount of direct solar radiation received by the building envelope. This can be translated to mean that having more sky visible between buildings where building envelopes are smaller masses (lower building) or more spaced apart will allow for relief of shortwave and longwave radiation trapping, which in turns means the MRT will experience less rise. Allowing more sky to be experienced by the pedestrian, also alleviates the urban heat island effect. The wall area receiving direct solar has significant impact on affecting both shortwave and longwave radiation. Greenery affects longwave radiation and should be considered a material to combat the effects of large thermal mass (concrete) receiving direct solar and re-radiating out to the environment increasing MRT.

REFERENCES

[1] Arnfield, AJ (1982) An approach to the estimation of the surface radiative properties and radiation budgets of cities. Physical Geography 3:97-122.

[2] Giridharan, R, Lau, SSY, Ganesan, S, Givoni, B (2007) Urban design factors influencing heat island intensity in high-rise high-density environments of Hong Kong. Building and Environment. 42: 3669-3684.

[3] Svensson, M (2004) Sky view factor analysis – implications for urban air temperature differences. Meterological Application 11 201-211.

[4] Thorsson, S, Lindberg, F, Eliasson, I, Holmer, B (2007) Different methods for estimating the mean radiant temperature in an outdoor urban setting. International Journal of Climatology. 27:1983-1993.