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A Parameterization for the Sensible Heat Exchange between Urban Canyon and The Atmosphere

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ABSTRACT; This paper investigates the behavior of the sensible heat exchange between the top of the canyon and outside atmosphere using a numerical model together with available field measurement data in a mid-latitude city. It was found that the heating characteristic of the urban canyon has close relationship with the narrowness index and outside wind velocity. The increase of the narrowness index and consequently, reduction of the sky-view factor leads to the reduction of sensible heat exchange between urban canyon and outside atmosphere. The increase of outside wind velocity makes the sensible heat exchange between the street canyon and outside atmosphere larger, and consequently cooler the urban canyon. A parameterization scheme was established which permits the evaluation of the sensible heat exchange between urban canyon and outside atmosphere based on the narrowness index, outside wind velocity and latitude of the city.

KEYWORDS: Narrowness index, Sky view factor, Fictitious surface, Urban Lid, Mid-latitude.

1 INTRODUCTION

The distinct thermal climate of the cities is comprehended as the ensemble of the effects of physical process and features inherently in built-up environment [1]. Urban climate research has carried out in two distinct scales, those are urban boundary layer and urban canopy layer [4]. At the mesoscale the Urban boundary layer derives many of its characteristics from the interaction with the Urban Canopy Layer beneath. This urban boundary layer grows in depth with the distance from the upwind edge of urban areas [6]. The urban canopy layer extends vertically between the level of zero net heat flux in the ground upto an arbitrary upper level, this upper level is a fictitious surface known as urban lid, within this upper level all the structure of the urban surface contributing to the energy storage and it is situated slightly above the roof level [9]. This conceptual classification has been established through observational support recently [4]. The complexity of the urban canopy layer generates an unlimited number of micro climates that prevents its study at the scale of city. Thus instead of studying the whole urban canopy layer, in the microscopic approach it has been considered the smallest division of canopy layer which has common structural characteristics known as urban canyon [3,4] . The top of urban canyon and together with roof level yields the boundary condition for the overlying urban boundary layer [6]. Although realistic process-response models must consider for fluxes across this roof level interface, but a major deficiency in the literature to make link between two scales of activity. The urban structure interms of its energy budgets has been examined by field and modelling techniques.

Radiation conditions, especially within the canopy layer of inner cities are complicated by the change of horizon, which affects the duration of sunshine and insulation by the urban surface materials and radiate interactions occurred between buildings and front streets. This interaction is determined by narrowness index of the urban canyon, which is the function of total height of the houses and width-orientation of the front street. The role of this narrowness index in urban climate is very important, which changes the physical environment and leads to alterations of energy exchange and thermal conditions, in comparison with the pre-urban state [4,5,7]. Furthermore, the atmosphere in the urban canyon absorbs the direct heat energy from the sun in addition to the heat energy reflected by the buildings. This phenomenon makes the albedo of the city lower and consequently increases the urban canyon temperature [2,5]. The proportion of the area covered with impermeable materials such as concrete and asphalt is higher in the urban area, this makes the latent heat flux smaller and hence the urban temperature is elevated . The narrowness index of city describes the sky view factor for the

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infrared radiation and the surface temperature pattern of the city is dependent on narrowness index & its regional temperature within the city. A rectangular canyon has chosen as adequate model of a city street which represents a common form within diverse city structure.

This parametric research has been attempt to focused on the one component of energy budget of the UBL/UCL exchange by considering that thermal exchanges occur across the interface separating by the street and affected by the mean wind flow from the overlying atmosphere. Our emphasis is on the spatial diversity of the output of sensible heat flux at the top of canyon as the prime causes of the vertical changes of temperatures.

This paper is directed at describing the formulating, logic and results of a parameterization scheme designed to evaluate the sensible heat exchange between top of urban canyon and urban boundary layer with relation of narrowness index, mean wind outside canyon and latitude.

2 SENSIBLE HEAT EXCHANGE AT THE TOP OF URBAN CANYON

2.1 The Sensible heat Flux at the top of canyon

Assuming that the energy involved in advection, canyon air temperature change and radiative flux divergence is small in comparison with the surface source terms, then the sensible heat flux through the canyon top is estimated [1,8] as follows-

$$H_t = \left[(H_e + H_w)n + H_f\right]/(1 + 2n) \tag{1}$$

where H_e, H_w, and H_f are the sensible heat flux at the east,west and street of the canyon which was determined by numerical model, n is the narrowness Index of street canyon which is estimated as follows-

$$n = \frac{z_b}{w_s} \tag{2a}$$

where w_s is the width of the interfacial front street of the wall in meter, z_b is the height of the building and it is estimated [2] as follows:-

$$z_b = bx_p + c \tag{2b}$$

where b is the height of the building in meter, x_p is the number of story and c is the height of basement of floor(m). For determining the effect of narrowness index considered various height and number of story of the building, which was computed by the equation 2a & 2b. For the parameterization scheme we consider the height of one story of the building is 4m, height of floor basement is 1m and number of story 2-13.

2.2 Parameterization of Sensible Heat Flux at the top Canyon

It is the interest to examine and to compare the variability and the magnitude of components of the energy budget for canyon top. This discussion will detailed followed by a detailed consideration of parameterization of Sensible heat flux at the top of canyon.Before that a description has been presented below on numerical model.

2.2.1 Numerical Model Description

In this numerical model the subsurface temperature profile is allowed to adjust to the computed substrate heat flux density and it is estimated by one dimensional Fourier equation, which is solved by finite difference Crank Nicholson scheme. The equation is as

$$\rho c \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial z^2} \tag{3}$$

The boundary conditionat the outside surface is described below:

$$-k \frac{\partial T}{\partial z} = S(1 - \alpha) + R_{Ln} - H \tag{4}$$

where ρc is the volumetric heat capacity of the surface material , k is the thermal conductivity of the surface, T is the surface temperature, S is the downward short-wave radiation, α is canyon surface the albedo, R_{Ln} is the net absorbed infrared radiation and H is the sensible heat

The second term of R.H.S of equation 4 R_{Ln} is estimated from the following equation [7];

$$R_{Ln} = \varepsilon_i \sigma \left[\sum_{\substack{j=1 \\ i \neq j}}^{N} \varepsilon_j \psi_{ji} T_j^4 + \varepsilon_a T_a^4 \psi_{sky-i} - T_i^4 \right] + \varepsilon_i \sigma \sum_{\substack{k=1 \\ k \neq i}}^{N} \sum_{\substack{j=1 \\ j \neq k}}^{N} \psi_{ki} (1 - \varepsilon_k) \psi_{jk} \varepsilon_j T_t \quad (5)$$

Where i is the receiving surface, j and k are the emitting surfaces to the i, T_j, T_i, T_k are the surface temperatures, $\varepsilon_i, \varepsilon_j, \varepsilon_k$ are the surface emissivities and ε_a is the atmospheric emissivity, T_a is the atmospheric temperature. Last term of the equation (5) is assumed to be negligible in the 2-D canyon analysis. First and second terms are incoming infra-red radiation's from the environment and from the sky respectively. Third term is outgoing infra red radiation from the surface and last term is that of alternate regions. Sensible heat flux for the canyon facet is estimated as [1];

$$H = h_c (T_a - T_i) \quad (6)$$

where h_c is the convective heat transfer coefficient and is estimated [1]

$$h_c = 5.7 + 4.1u \quad (7)$$

u is the characteristic mean wind velocity , here considered as that of ambient wind as air flow is accelerated just above the roof level outside of the canyon, which direction is parallel to the street of canyon from any side and which is controlled by narrowness index [1,8]

2.2.2 Energy Balance at the top of Canyon

Figure 1 shows the diurnal variation of energy balance component on a fine day during summer. Canyon facets are as asphalt street and concrete wall of the symmetrical building. The energy balance component at the top of canyon estimated by numerical model and followed the formulation procedure of [1,3,9] The results were tested against field data, but cannot be exercised fully because the information available from urban field studies is slightly deficient and some input characteristics are estimated by best estimates. The magnitude of the energy balance components are slightly different in comparison with field results, but pattern and trends are in the good match. From the figure 1 it is seen that in the peak hour time the model net radiation is 695wm^{-2}, conduction heat flux is 487.0 wm^{-2} and sensible heat flux is 208 wm^{-2} where as field results are 735wm^{-2}, 510 wm^{-2} and 225 wm^{-2} respectively. In the day time the ratio of sensible heat flux is 0.299Q^* in model and 0.31Q^* in observation results. For the comparison , here we consider n value is the same as the field value which is 0.94. Here net radiation is denoted by Q^*

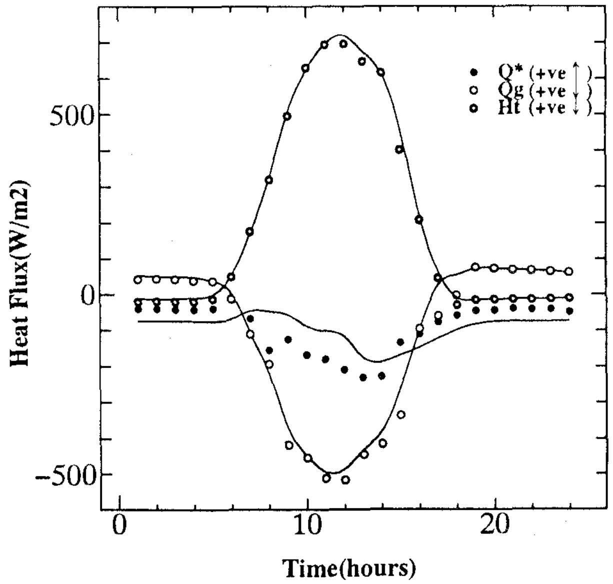

Figure 1 Diurnal variation of energy balance at the top of mid-latitude canyon, field(symbol) and model(line).

2.2.3 Parameterization of Sensible Heat Flux

The objective of this study is the investigation of parametric representation of H_t in terms of *n*, *l* and *u*. The diurnal integral of sensible heat flux at the top of canyon at various narrowness index, latitude and outside mean wind velocity at day(peaking at 13 hr) and night time(0 hr) has been shown in figure 2. This results were obtained by numerical model and equation 1. From the figure it is seen that H_t is inversly proportional to *n* and directly proportional to *l* & *u* at day time, but at night it is inversly proportional to *n* and *l*. For some values of *n*, H_t is zero and negative, the reasons are as, (i) air temperature dominate the underlying area below the top of canyon.(ii) due to increase of *n* decrease the view factor of sky effects on the infrared surface temperature.(iii) decreased loss of heat by turbulence due to stagnation in deep canyon.

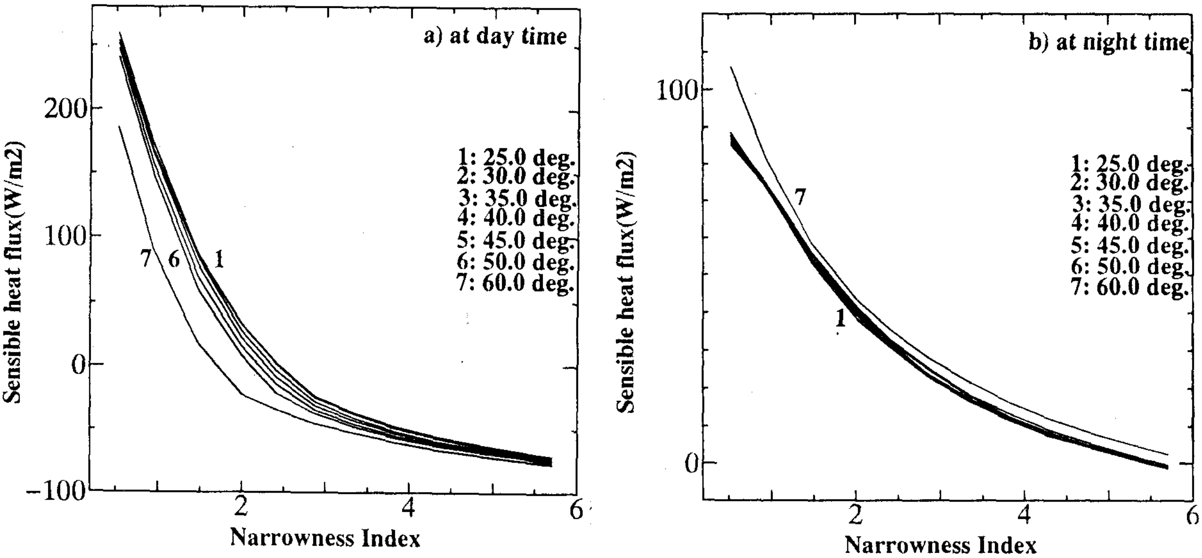

Figure 2 Diurnal variation of sensible heat flux at the top of mid-latitude canyon with u=1 m/s a) day time and b) night time

From the generalised result and the above relation H_t can be written as follows-

$$H_t = \left[\alpha\left(1/n^2 - 1/n_0^2\right)u + \beta\right]\Delta T \qquad (8)$$

$$\alpha = f(n,l,u) \qquad (9)$$

$$\beta = f(n,l) \qquad (10)$$

where ΔT is the air temperature difference at that imaginary surface, this temperature difference decreases to a minimum around 0600 JST and its magnitude increases rapidly during the morning hours peaking around 1300-1400 JST, near the time of maximum R_{Ln} (equation 5) n_0 is the narrowness index when sensible heat is equal to zero α and β are the parametric coefficients. From the equation 9 it is evident that α is the function of *n*, *l* and *u*. In equation 10 it has shown that the coefficient β is the function of *n* and *l*. With the effect of nocturnal heat island, canyon facets below the canyon top is warmer than the surroundings air temperature as canyon facets release heat and the effect of pro-found heat pumping from the building through air cooler and effect of anthropogenic heat release due to combustion of automobile. Hence sensible heat flux is positive at night time in a large n' as well. The functional relationship of α with mean wind velocity has been shown in the figure 3. In the figure 3 the coefficient of α is divided into two distinct part, such as δ_0 and δ_1,those are receprocal of each other.

Dotted line for δ_0 shows the trend of natural convection, because value decreases with the increases of wind velocity. But solid line for δ_1 shows that α is the exponentially increase with u .

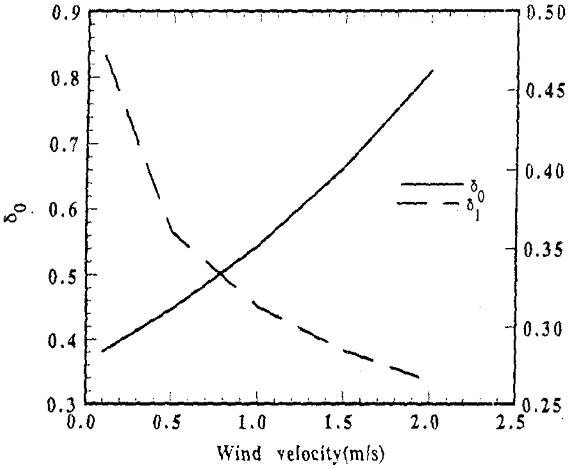

Figure 3 Coefficient of α parameterised with mean wind velocity(m/s).

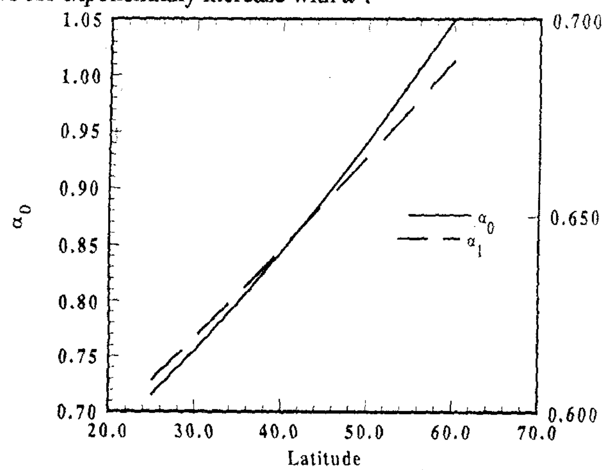

Figure 4 Coefficient of α parameterised with mid-latitude option in various wind velocity.

Figure 4 depicts the functional relationship with one of the geographical condition mid-latitude on the coefficient α . Where shows that α_0 and α_1 exponentially increases with the latitude and also increased the magnitude with the of wind velocity.

Figure 5 shows that the coefficient α increases with the increase of narrowness index and magnitude varies with the latitude and wind velocity. But coefficient β exponentially decreases with the incraese of n and magnitude also decreases with latitude. In figure 5, α_1,α_2,α_3,α_4 and α_5 show the wind effect on coefficient α

n_0 is the function of time and latitude. The functional relationship of n_0 is given in equation 11, in which, coefficients σ_0, σ_1 and σ_2 are function of l only. Those functional relationship have been shown in figure 6.

$$n_0 = \sigma_1(\cos 2\pi t/24) + \sigma_2(\cos 2\pi t/24)^2 + \sigma_0 \qquad (11)$$

where σ_0, σ_1 is the inversly proportional to l and σ_2 is the directly proportional to l .

From dimensional analysis it is found that coefficient of α is similar with volumetric heat capacity. The units of α and β are $Jm^{-3}K$ and $Wm^{-2}K$ respectively.

Figure 7 shows the generalised final result of equation 8 together with the numerical model and field experiment data [3]. Eventually it is seen that parameterised result is the best fit with model and quite closer to the field data than the equation 1. This parameterisation equation may applicable for the real situation.

3 CONCLUDING REMARK AND FUTURE WORK

The sensible heat exchange between urban canyon and outside atmosphere is strongly depends on narrowness index latitude and outside wind velocity. Our parameterization scheme has been established to formulate the relationship between these quantities. But in real case,the sensible heat exchange also depends on the time of the day. Its diurnal pattern we should consider in further study. The results of computation using these functional relationship reveals that it can give reasonable estimation of sensible heat exchange between the street canyon and outside atmosphere, since this relationship is rather simple it might be applicable for the real situation and convinient for practical use.

This imaginary surface is very important for the energy preservation process within the canyon where people lives. Furthermore this is the transition station for the meterological elements exchange between below the urban canopy layer and atmosphere, it is the lower boundary of urban boundary layer.

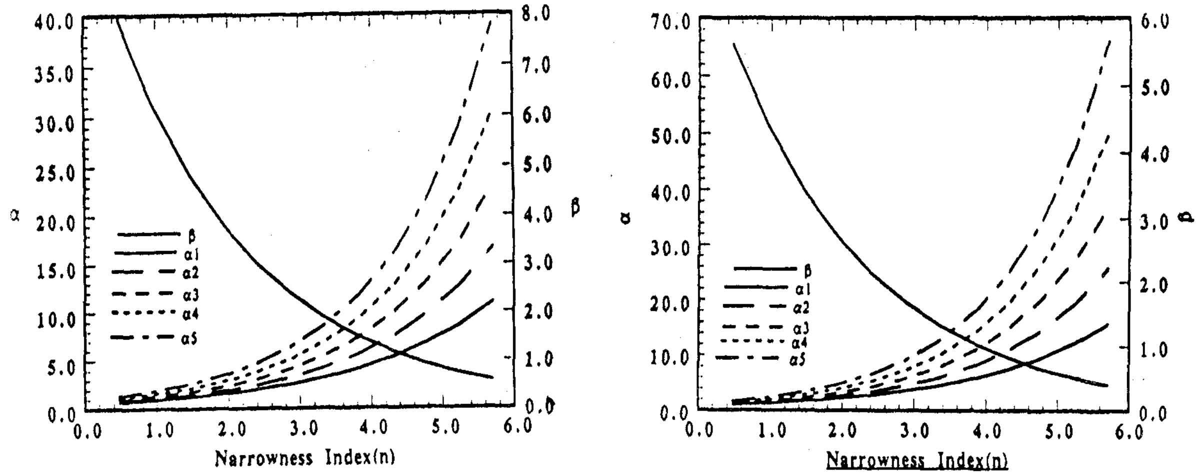

Figure 5 Coefficients parameterisation of sensible heat flux at the top of mid-latitude canyon, a) 25.0 deg b) 45.0 deg.

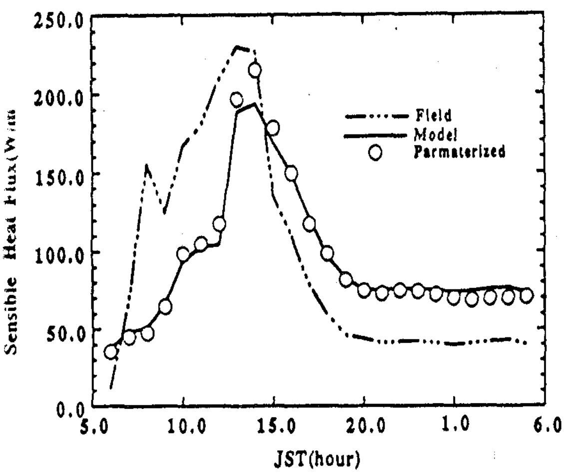

Figure 7 Diurnal variation of sensible heat flux at the top mid-latitude canyon, field(dotted line), model(line) parameterisation(symbol).

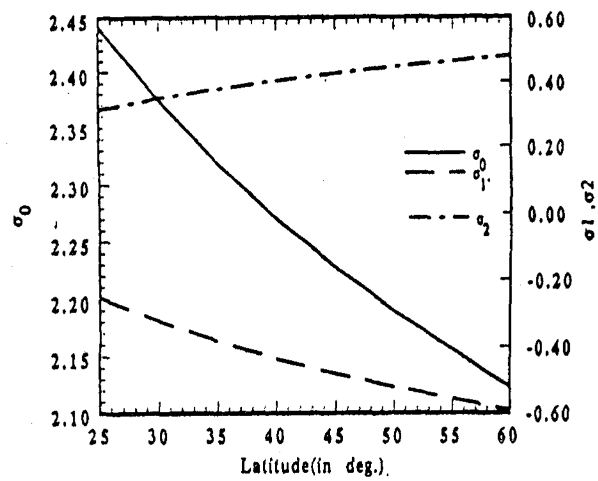

Figure 6 Coefficients for the generalisation of n0 in mid-latitude canyon.

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