A PARAMETERIZATION SCHEME FOR THE SENSIBLE HEAT EXCHANGE BETWEEN THE STREET CANYON AND THE ATMOSPHERE USING THE RELATIONSHIP NARROWNESS INDEX AND WIND VELOCITY

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ABSTRACT

This paper investigates the behaviors of the sensible heat exchange between the top of the canyon and outside atmosphere using a numerical model together with available field measurement data. 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 street 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 street canyon. A parameterization scheme was established which permits the evaluation of the sensible heat exchange between street canyon and outside atmosphere based on the narrowness index and outside wind velocity.

Key Words: Narrowness index,Sky view factor,Fictitious surface,Urban Lid

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 (Swaid, 1990). Urban climate research has carried out in two distinct scales, those are urban boundary layer and urban canopy layer (Oke,1976). At the mesoscale the Urban boundary layer (UBL) derives many of its characteristics from the interaction with the Urban Canopy Layer (UCL) beneath. This UBL grows in depth with the distance from the upwind edge of Urban areas (Mills, 1992). 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 (Kerschgens And Kraus, 1989). This conceptual classification has been established through observational support recently (Taesler,1981). 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, this layer is divided to common structures known as urban canyon (Aida,1982; Aida and Gotoh,1982; Arnfield,1976; Oke,1976; Nunez and Oke,1976; Oke,1981; Yoshida,1990). The top of urban canyon and together with roof level yields the boundary condition for the overlying UBL (Arnfield,1982). 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.

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 street 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 (Oke,1977).

The variation of sensible heat flux determines the rate of warming and cooling of the air due to the convergence and divergence of sensible heat flux (Arya,S.1988). In practice, canyon walls exchange radiation with the street and with the atmosphere, which affects their surface temperature and near surface climate(Roth et al 1989). Surface temperature relates with the net radiation. This radiation depends on the sky view factor as well as narrowness index. Because this limit expresses the extent of openness of canyon surfaces to the sky radiative sink and solely dependent on narrowness index (Oke,1981,1988). 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.

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 and mean wind outside canyon.

2. Sensible Heat Exchange at the top of Street 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 (Nunez and Oke,1976) and (Swaid,1992) as follows:

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

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 (Kaempfert,1949) as follows-

$$n = z_b / w_s \qquad 2(a)$$

where z_b is the height of the building and it is estimated (Yamashita et al 1990-91) as follows:-

$$z_b = bx_p + c \qquad 2(b)$$

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 2(a) & 2(b). 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:

The model employed is simple and can not be handled in full range of conditions found in cities. 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

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

The boundary condition is described below:

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

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 total 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;

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

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, Ta 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 (Swaid,1992);

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

where hc is the convective heat transfer coefficient and is estimated (Swaid,H.1992)

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

u is the characteristics mean wind velocity ,here we considered ambient wind flow pattern 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 (Swaid,1992; Vu *et al*,1994).

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 Hanna,1992; Yoshida *et al*,1990; Nunez *et al*,1976. 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. One of the important reason is that field measurement components were effect of 3-D but this model is 2-D. From the figure(1) it is seen that in the peak hour time the model net radiation is 695w/m^2, conduction heat flux is 487.0 w/m^2 and sensible heat flux is 208 w/m^2 where as field results are 735w/m^2,510 w/m^2 and 225 w/m^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^*

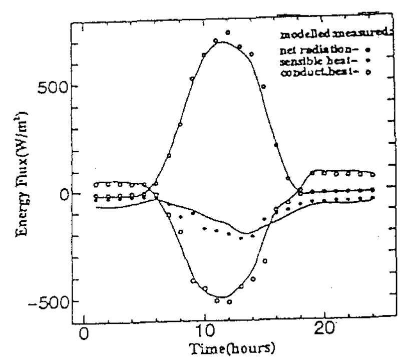

Fig-1 Diurnal variation of energy balance components with measured(points) and modelled(curve) at the top of urban canyo

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 narrowness Index. Figure-2(a) & 2(b) show the diurnal integral of sensible heat flux at the top of canyon at various narrowness index (n) and wind velocity. This results were obtained by numerical model and equation (1). From the figure it is seen that H_t is the function of $H_t = H_{t0}(n,u)$. Sensible heat exchange at the top of canyon is inversely proportional to n and directly proportional to mean wind velocity and when $2.06 \le n \le 2.2$ then H_t is zero and H_t is negative for any value of n more than $n \ge 2.2$. 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.

Hence H_t can be written from the result and the above relation is as follows:

$$H_t = \left[\lambda\left(\frac{1}{n^2} - \frac{1}{n_0^2}\right)u + \beta\right]\Delta T \quad (8)$$

where ΔT is the temperature difference with air at that imaginary surface, n_0 is the narrowness index when sensible heat is equal to zero and which can be written as at day time $2.06 \le n_0 \le 2.2$,but at night time after sunset there is no any effect of n_0 because 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 of a large cavity as well. So we can functionize the coefficients as follows:

From the equation (8) the coefficient of λ is the function of wind velocity and n'values which is as $\lambda = \lambda_0(u,n)$ and the coefficient of β is the function of narrowness index which is as $\beta = \beta_0(n)$,hence the functional equation for λ has given below:

$$\lambda = \lambda_0 e^{\lambda_1 k n u} \quad (9)$$

λ_0, λ_1 of the above equation are depend on the mean wind velocity and it shows in the Figure-3(a): From the figure it is evident that λ_0 and λ_1 are the inversely proportional to wind velocity except λ_1 is lower when $0 \le n \le 0.5$ as the causes are lowest value of n does not effected by mean wind velocity only it follows the general pattern of flow due to small canyon.

In equation (9) k is the constant of proportionality for the simplicity of our equation considered it is equal to

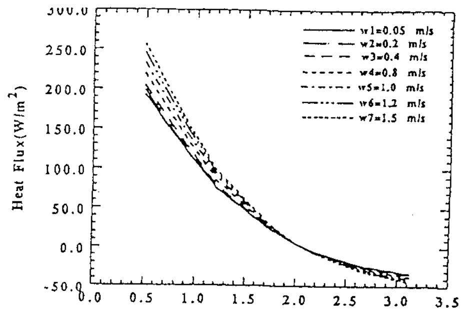

Fig-2(a) The Sensible heat flux at top of Urban Canyon with different mean wind scale in terms of n' values at day time

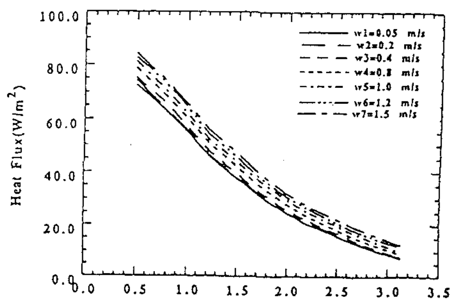

Fig-2(b) Sensible heat flux at the top of Urban Canyon with different mean wind velocity scale in terms of n'values at night time

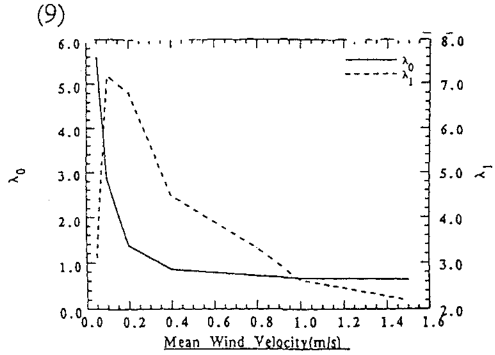

Fig-3(a) Parameters for the main parametric coefficient λ in day time unity. Than the coefficient of β of equation (8) is functioned as the following:

$$\beta = \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \beta_4 x^4 + \beta_0$$

where $x=kn$, when $0 \le n \le 1$ and $x=k\,1/n$ when $n \ge 1$
The values of $\beta_1, \beta_2, \beta_3, \beta_4$ and β_0 are -25.721,59.9829,-59.5514,26.5265,-4.4704 and 7.5948 respectively ,hence our final parametric equation for the $6 \le t \le 18$ is as

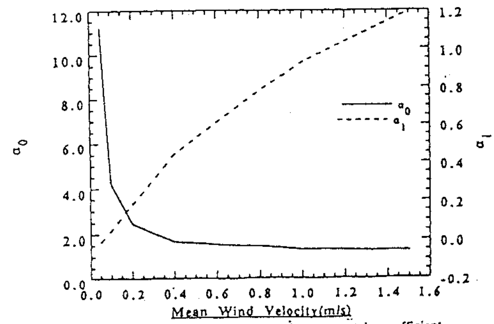

Fig-3(b) Parameters for the main parametric coefficient α in night time

$$H_t = \left[\lambda_0 e^{\lambda_1 knu}\left(\frac{1}{n^2} - \frac{1}{n_0^2}\right)u + \left(\beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \beta_4 x^4 + \beta_0\right)\right]\Delta T \qquad (11)$$

From the figure 2 (b) it is evident that at night there is no any effect of n_0 than parameterized equation after sunset from $18 \le t \le 6$, then equation(11) can be rewritten as -

$$H_t = \left[\alpha_0 e^{\alpha_1 kn/u}\left(\frac{1}{n^2}\right)u + \left(\gamma_0 + \gamma_1 \log n\right)\right]\Delta T \qquad (12)$$

The coefficient of α in equation (12) can be functioned as the following:

$$\alpha = \alpha_0 e^{\alpha_1 kn/u} \qquad (13)$$

Where the expression is almost similar with equation (9) but variable output is quite different which is directly proportional to narrowness index n but inversely proportional to wind velocity u,but in day hours it is directly proportional to both n and u. Figure-3(b) shows the coefficients value of α_0, α_1 in terms of various mean wind velocity.

From the Figure-3(b) it is evident that α_0 is the inversely proportional to u and α_1 is the directly proportional to n. The cumulative results of λ and β for day time, α and γ for night time have been shown in the figure-4(a) & 4(b) in terms of narrowness index,showing wind effects.It is seen that both λ and α increases with the narrowness index and wind velocity but β decreases with the increases of n and γ increases with n . For the Coefficient γ proposed functions expression is as follows and result shows in the figure-4(b)

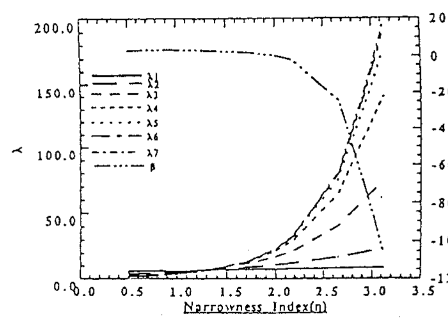

Fig-4(a) Coefficients for the parameterization of Sensible Heat Flux in different wind velocity to the top Urban Canyon at day time

$$\gamma = \gamma_0 + \gamma_1 \log(n) \qquad (14)$$

Where the value of coefficients γ_0 and γ_1 are as 5.2711 and 2.4976 respectively.

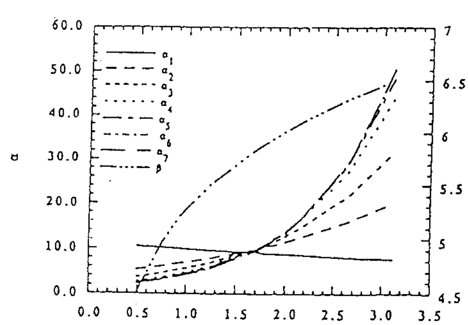

Fig--4(b)-Coefficients for the parameterization of Sensible Heat Flux at the top of Urban Canyon at night time

Figure (5) shows the result of Equation (11) and equation (12) together with the numerical model and field experiment data(Yoshida *et al* 1990-91).Eventually,it is seen that parametrized result is quite closer to the field value than the result of equation (1). This parameterization equation may applicable for the real situation.

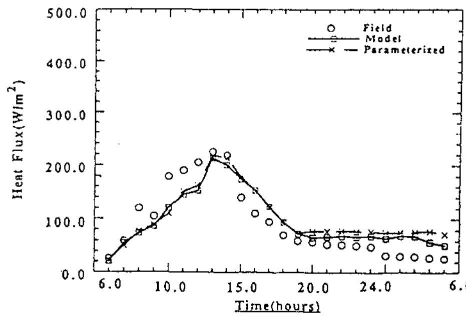

Fig--5 Diurnal variation of sensible heat flux at the top Urban Canyon results from Field(symbol),Model(line) and Parameterization(dotted line)

3.0 Concluding remark :

The sensible heat exchange between the urban canyon and outside atmosphere is strongly depends on narrowness index and outside wind velocity. Our parameterization scheme has been established to formulate the relationship between these quantities. 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.

In the same way need to parameterized of other components of energy budget and using one dimensional fourier equation it can possible to find out the term ΔT of equation (11) and (12). 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 meteorological elements exchange between below the canopy and atmosphere. On the other hand it is the boundary condition of UBL.

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