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INFILTRATION CHARACTERISTICS IN MULTI-FLOOR BUILDINGS

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ABSTRACT

Infiltration or in other words the air leakage in buildings has an important role on heat load calculations. The rate of this loss has been estimated as 20 to 30 % of the total load. The indicated important effect of infiltration on the load calculations needs a reliable method for the determination of air leakeage level in buildings. Meantime, the rate of infiltration has an additional importance at the area of thermal comfort studies which deals with the air quality of enclosed volumes. During this research study, first the mechanism of infiltration and the major components of the phenomena (wind pressure, temperature difference) was discussed together with the theoretical considerations. Later, several conventional engineering approachs and emprical methods was reviewed and compared among each others. At the last part of the paper, the modified DIN 4701 method which is presently used in Turkey, and some other algorithms was applied to some pilot buildings and the predictions was compared with experimental results.

Key Words : Infiltration, Thermal comfort

ÇOK KATLI BİNALARDA İNFİLTRASYON KARAKTERİSTİKLERİ

ÖZET

Binalarda infiltrasyon bir başka deyişle hava sızıntısı, ısı yükü hesaplamalarında önemli rol oynamaktadır. Toplam yükün yaklaşık %20-30 'unu oluşturduğu tahmin edilmektedir. Yük hesaplamalarında infiltrasyonun önemli etkisi, binalardaki hava sızıntısının saptanması için güvenilir metodlara ihtiyaç duyulmasına neden olmaktadır. Aynı zamanda infiltrasyon, kapalı hacimlerin hava kalitesi ile ilgili ısıl konfor çalışmalarında ilave bir öneme sahiptir. Bu çalışmada, ilk olarak infiltrasyon mekanizması, onun oluşmasında etkin rol oynayan rüzgar hızı, sıcaklık farkı gibi ana bileşenler teorik yaklaşımlarla birlikte tartışılmıştır. Daha sonra, çeşitli metodlar birbirleriyle kıyaslanmıştır. Çalışmanın son kısmında ise, Türkiye'de kullanılan geliştirilmiş DIN 4701 metodu ve bazı algoritmalar, pilot binalara uygulanmış ve deneysel sonuçlarla karşılaştırılmıştır.

Anahtar Kelimeler : İnfiltrasyon, Isıl konfor

1. INTRODUCTION

The air leakage through the cracks and interstices around the windows and doors and through floors and walls is called as infiltration and the intentional displacement of air through specified openings such as windows, doors, and ventilators is called as natural ventilation in buildings. The accurate estimation of infiltration and ventilation has an importance on HVAC design either from energy consumption or from indoor air quality point of view. Uncontrolled infiltration and ventilation could cause additional energy losses or unhealthy internal air conditions at terminal levels. The previous research studies in Turkey has shown that approximately % 30 of the total energy losses in buildings is based on infiltration.

Infiltration phenomena mainly is effected from geometric dimensions and orientation of buildings, local climatic and geographic conditions and especially type of the building elements such as doors and windows. Becouse of the large number of parameters involved, infiltration has a very complex structure and it is very difficult to develope a theoretical model for the phenomena. In this research study, first, it was investigated the thoretical background, flow mechanism and major driving forces of infiltration and later, avaible engineering methods and algorithms used in infiltration calculations was discussed and compared with some experimental results.

1. 1 Theoretical Approach for Infiltration and Ventilation

The logic of theoretical modelling of infiltration is based on the estimation of required outputs by using the avaible datas(inputs). In some cases some important datas (inputs) are not avaible and in some other cases the rate of importance of each data on the phenomena can not be determined. The major inputs of common infiltration problems are as follows:

- local climatic conditions
- terrain and shielding datas of building
- details of building structure
- the strategy of ventilation

The required outputs are usually as follows:

- the air change rate of each zones
- air movements in the building
- infiltration based energy losses
- economical analysis

Among the outputs the precise estimation of air change rate of the building is the most important one.

1. 2 The Major forces of Infiltration

The major forces of infiltration are as follows:

- time dependent climatic conditions and variations
- terrain and shielding of building
- dimensions and types of openings such as external doors and windows
- mechanical ventilation

2. THE CALCULATION METHODS OF INFILTRATION

There are several methods for the calculation of infiltration. These methods can be classified in two main groups.

1. Empirical methods
    - The air change method
    - The reduction of pressuration
    - The Regression technics
2. Theoretical methods
    - The network methods
        - Single zone structure
        - Multi zone structures
    - Simplified theoretical methods

The simplified theoretical methods are the ones which developed by research centers and the most well known of this algorithms are; ELA (Lawrance Berkeley Laboratory Equivalent Leakage Algorithm)(Liddament, 1988a), NBS (National Bureu of Standarts)(Walton, 1982), and NRC (National Research Council of Canada)(Sander, 1974).

3. THE THEORY OF INFILTRATION

The rate of air flow into and out of the building due to either infiltration or natural ventilation depends on the magnitute of the pressure difference betweeen the outside and inside of the structure and on the resistance to flow of air offered by openings and interstices in the building. The pressure difference exerted on the building enclosure by the air may be caused either by wind or by a difference in density of air inside and outside. The effect of difference in density is often called chimney or stack effect. The pattern of air flow through any part of the structure depends on both the pressure difference and the area of openings. When the pressure difference is the result of wind pressure, air will enter the building through openings in the windward walls and leave through openings in the leeward walls. When the pressure is caused by the indoor-outdoor temperature difference, the flow will be along the path of least resistance from inlets at lower levels to outlets to higher levels in a heated building.

3. 1. The Flow Mechanism

It is difficult to develope an exact formulation of air flow mechanism in buildings. The phenomena is also become more complex when the infiltration takes place. For an exact formulation, it is necessary to define a seperate equation for each crack or interstices in the building. In order to develope an applicable and acceptable method, it is needed to make some assumptions and simplifications.

For an applied typical pressure difference, the type of flow is the function of geometric dimensions of the duct. In reasonably wide flow paths (ventilation outlets, cracks and interstices around the poor constructed windows and doors) the air flow can be considered turbulent and defined by general orifice equation;

$$Q = C_d \left(\frac{2\Delta P}{\rho}\right)^{1/2} \tag{1}$$

If the air flow length of cracks and interstices are reasonably longer than the air flow cross section, the orifice equation has to be modified. This is valid for poor constructed doors and windows which, viscosity is very effective on the flow. The air flow in this kind of media should be considered laminar and the anology of laminar flow in tubes should be used for definition.

$$Q = \frac{\Delta P}{8\mu L} \Pi r^4 \tag{2}$$

In practice, the air flow through cracks can occur both ways as defined in equations (1) and (2). The combined form of equations (1) and (2) is known as "power law" and expressed as follows,

$$Q = k(\Delta P)^n \tag{3}$$

3. 2. The Driving Forces Of Infiltration

3. 2. 1. Wind effect

Wind within in lower regions of earth`s atmosphere is characterised by random fluctuations in velocity which, when arranged over a fixed period of time, poses a mean value of speed and direction. The strength of the wind is also a function of height above ground, this function being dependent on surface or terrain roughness, and on the thermal nature of athmosphere(thermal stability).

On impinging the surface of an exposed rectangular building, wind deflection induced a positive pressure on the upwind face. The flow seperates at the sharp edge of the building, giving rise to negative pressures along the sides. The air, which enters the building from the upwind surface leaves the building from the other surfaces. That is why, wind is considered one of the major forces of infiltration.

In general, it is observed that relative to the static pressure of the free wind , the time averaged pressure acting at any point on the surface of building may be represented by the following equation (Walton, 1982).

$$P_w = \left(\frac{\rho}{2}\right) C_p V^2 \tag{4}$$

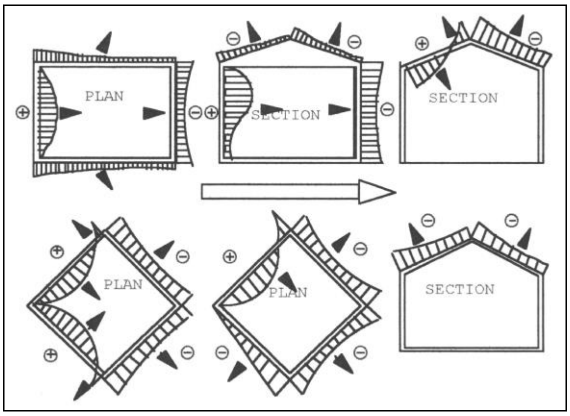

Figure 1. Wind pressure distribution on building surfaces

Since the strength of wind close to the earth`s surface is influenced by the roughness of the underlying terrain and the height above ground, a reference level for the wind velocity must be specified for use in wind pressure calculations. For general purpose, the reference level is the building height.

As a rule, "on site data" is rarely avaible and therefore, it is used the climatological data which is taken from the nearest meteorological station. However it is essential that such measurements has to be corrected for the difference between measurement height and the building height and for intervening terrain roughness. The suitable correction of these effects can be represented as follows (Liddament, 1988b)

$$\frac{V}{V_m} = \frac{\alpha z^{\beta}}{(\alpha z^{B})_m} \tag{5}$$

Some typical values for a,ß coefficients are as follows, (Liddament, 1988b)

Type of location	α	β
Rural areas	0.10	1.30
Seperate buildings on flat areas	0.15	1.0
Small cities and villages	0.20	0.85
Industrial areas	0.25	0.67
Metropolitan areas	0.35	0.47

3. 2. 2. Turbulent Fluctuations

The turbulent nature of the atmospheric wind results in corresponding fluctuations to the wind induced pressure distributions. However, these transient departures from the mean pressure distribution are random and they are usually neglected in mathematical modelling studies (Liddament and Allen, 1983).

3. 2. 3 Stack Effect

The stack effect arises as a result of differences in temperature and hence air density between the interior and exterior of the building. This produce an imbalance in the pressure gradients of the internal and external air masses, and creates a vertical pressure difference. When the internal air temperature is higher than that of the outside air mass, air enters through openings in the lower part of the building and escapes through openings at the higher level. This flow direction is reverse when the internal air temperature is lower than that of the air outside. The level at which the transition between inflow and outflow occurs is defined as the neutral pressure plane. In practice, the neutral plane is assumed occurs at the midheight of the building (for symmetrical buildings). The pressure gradient due to stack effect in buildings can be estimated by the following equation,

$$P_s = -\rho_o g 273 (h_2 - h_1)\left(\frac{1}{T_o} - \frac{1}{T_i}\right) \quad (6)$$

3. 2. 4. Combined Wind and Stack Effect

Air infiltration calculated from wind and stack effect acting alone can not be summed directly to obtain a combined air infiltration rate. Experimental observations shows that, the combined air infiltration rate is obtained by adding the corresponding infiltration values in quadrature.

$$Q_T = (Q_W^2 + Q_S^2)^{1/2} \quad (7)$$

4. EXPERIMENTAL STUDIES

One of the basic experimental methods used in infiltration rate predictions is tracing gas method. This method generally can be classified in two main section:

(a) Tracing gas decay method (TGDM)
(b) Tracing gas contant concentration method

In this research study, the TGDM method was preferred and CO_2 was used as tracing gas and it`s variation in concentration with time was monitored on site using detector tubes (Drager tubes).

During the experiments, the test space was been reached to an initial concentration of CO_2 approximately 2000 ppm. This was done by releasing a short burst of carbon dioxide from a gas cylinder. Measurement period was 1.5 to 2 hours. After obtaining the gas concentration variation due time (C_t), the infiltration rate was determined by using the following equation,

$$V\frac{dC_t}{dt} = -Q(C_t - C_e) + F_t \quad (8)$$

If it is assumed that the infiltration rate is time dependent over the period of the measurement than, both sides of the equation (8) can be integrated over the total measurement period and then arranged to give (infiltration rate Q):

$$Q = \frac{V\left[\int_{t=0}^{t=tm}\frac{F_t}{V}dt - \int_{t=0}^{t=tm}dC_t\right]}{\int_{t=0}^{t=tm}\left[C_t - C_e\right]dt} \quad (9)$$

Experimental studies was carried out at Gaziemir Emlakbank site in Izmir. Measurements was taken at three different level of apartment houses for plastic and wood constructed doors and windows. During the experiments the CO_2 concentration was measured at 5, 10, 15, 30 and 90 th minutes. Meantime, the wind velocity at room and roof level and the indoor and ambient temperatures was also recorded.

5. RESULTS AND CONCLUSION

The main aim of this research study is to compare the present infiltration calculation methods among each others and discuss the results with experimental measurements.

Due to this aim, the modified DIN 4701 was applied to typical 8 floor building and the results shown in Figure 2 and 3 were obtained. As it would be seen from the figures, none of the mentioned engineering methods used for infiltration rate prediction give satisfactory results compared with the experimental studies.

Either from the building components or from geometric and climatological point of view , these methods has to be developed and the reliability widely analysed for local conditions.

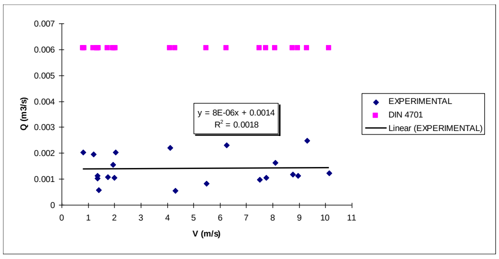

Figure 2. Variation of Infiltration due to Wind Velocity (Plastic Frame Window Construction)

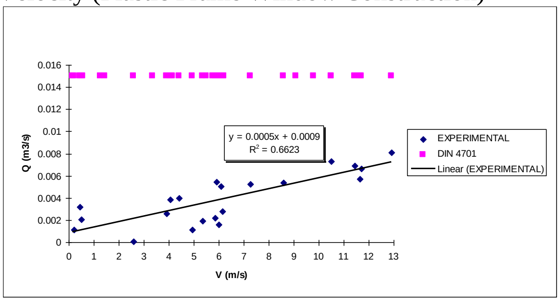

Figure 3. Variation of Infiltration due to Wind Velocity (Wood Frame Window Construction)

6. NOMENCLATURE

Q : Air flow rate (m^3/s),
P : Pressure difference (Pa)
C_d : Discharge coefficient
p : Density (kg/m^3)
L : Length of flow (m),r: radius (m)
µ : Dynamic viscosity (N s/m^2)
k : Proportionality constant (m^3/s per Pa pressure difference)
n : Exponent of flow (0.5< n < 1)
P. S : n = 0.5 for fully developed turbulent flow, n = 0.5 for fully developed laminar flow, n = 0.65 for practical purpose (1)
P_w : surface pressure due to wind (Pa)
C_p : Pressure coefficient (experimetally determined)
V : Mean wind velocity at datum level (m/s)
a, ß : Coefficients for terrain rpoghness
z : Datum height(m)
V : Mean wind speed at datum height (m/s)
V_m : Mean wind speed at meteorologicalstation (m/s)
T_o : Ambient temperature (K)
T_i : Indoor temperature (K)
h_1, h_2 : Level of openings (m)
Q_T : Combined infiltration (m^3/s)
Q_W : Infiltration due to wind (m^3/s)
Q_S : Infiltration due to stack (m^3/s)
Ce : External concentration of tracer (CO_2)
F(t) : Production rate of CO_2 by occupants.
Q : Infiltration rate (m^3/s)

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