Simplified Models for Room Air Distribution

Nielsen, Peter V.

INSTITUTTET FOR BYGNINGSTEKNIK
INSTITUTE OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITETSCENTER • AUC • AALBORG • DANMARK

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Research Item No. 1.5 "Simplified Models"

This paper deals with some simplified models for room air distribution. They are part of the preparation phase in the International Energy Agency Annex 20 work: Air Flow Pattern within Buildings, subtask 1.

The following simplified models are used in practice or they are under study.

1. Throw of isothermal jet
2. Penetration depth of thermal jet
3. Maximum velocity in occupied zone
4. ADPI-model
5. Data base model

All measurements and predictions in subtask 1 should be made in such a way that necessary results are obtained for the evaluation of these models.

1. THROW OF ISOTHERMAL JET

The velocity decay in a three-dimensional wall jet below the ceiling in a ventilated room is generally given by:

$$\frac{u_x}{u_o} = K_a \frac{\sqrt{a_o}}{x+x_o} \qquad (1.1)$$

where u_o and u_x are supply velocity and maximum velocity in wall jet in the distance x from the opening, respectively. a_o is the supply area of the diffuser and x_o is the distance to the virtual origin of the wall jet. K_a is a constant.

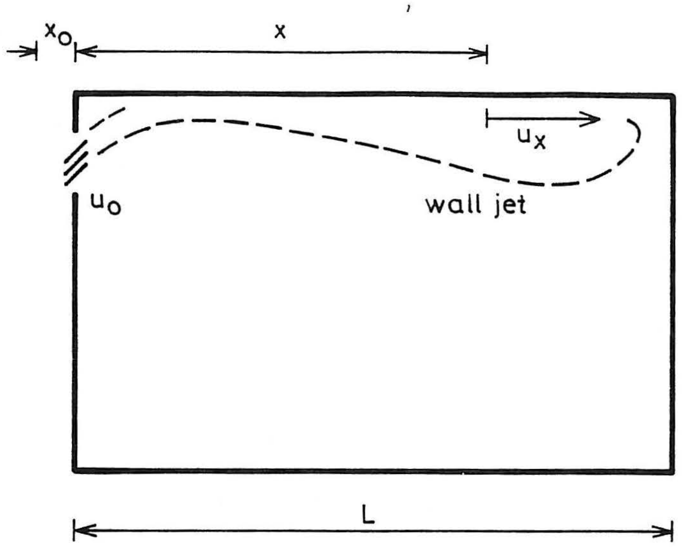

Figure 1.1. Wall jet in a ventilated room.

K_a takes values from 2 to 10 and x_o is about zero, dependent on the actual diffuser.

A length ℓ_{Th}, called the throw, is defined as the distance from the opening where the maximum velocity u_x is equal to 0.2 m/s and equation (1.1) gives:

$$\ell_{Th} = 5K_a u_o \sqrt{a_o} - x_o \quad \text{(m)} \qquad (1.2)$$

The supply area and the supply velocity are selected according to equation (1.2) in such a way that ℓ_{Th} is equal to the room length L or a fraction of the room length, and it is a general experience that resonable velocities are obtained in the occupied zone in the case of isothermal flow.

Necessary measurements

It is necessary to calculate a_o, K_a and x_o for the diffuser (see research item No. 1.2, "Selection of air terminal device") and it is necessary to measure the obtained maximum velocity in the occupied zone as a function of the supply velocity u_o to study the applicability of the model.

Literature

On wall jet:

Rajaratnam, N., Turbulent jets, Elsevier, 1976.

On throw:

Nielsen, P.V. and Å. Möller, New Development in Room Air Distribution. Chapter in "Air conditioning system design for buildings", McGraw-Hill, London, 1983.

Nielsen, P. V., Mathematical models for room air distribution, System simulation in buildings, Proceedings of an International Conference, University of Liege, December 1982.

Air distribution and air diffusion - Laboratory aerodynamic testing and rating of air terminal devices, Draft for international standard ISO/DIS 5219.

2. PENETRATION DEPTH OF THERMAL JET

The penetration depth x_s of a thermal jet is a function of Archimedes number and geometry. It may be used as a part of a dimensioning procedure for an air distribution system.

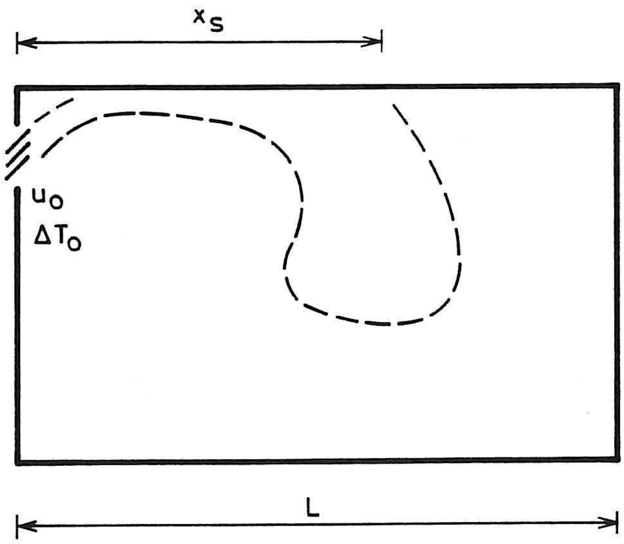

Figure 2.1. Penetration depth x_s of a thermal jet in a room.

A short penetration of the jet results in a flow in the occupied zone with high velocity and low temperature. A minimum value for the penetration depth x_s/L combined with a maximum value for u_o according to a throw ℓ_{Th} = 0.75 L .... L is often a part of a practical dimensioning procedure.

The penetration depth for a three-dimensional wall jet is given by:

$$\frac{x_s}{\sqrt{a_o}} = K_{sa} K_a \left(\frac{u_o^2}{\Delta T_o \sqrt{a_o}}\right)^{0,5} \tag{2.1}$$

where ΔT_o is temperature difference between return and supply. K_{sa} is a constant dependent on parameters outside the wall jet, such as room dimensions, location of thermal load etc.

Necessary measurements

Wall jet constants as $\sqrt{a_o}$ and K_a. Measurements of $x_s/\sqrt{a_o}$ versus $u_o^2/\Delta T_o \sqrt{a_o}$ and measurements of PPD in the room (Predicted Percentage of Dissatisfied).

Discussion

Study the connection between e.g. x_s/L and PPD at constant throw ℓ_{Th} = 0.75 L .... 1.5 L.

Literature

On penetration depth:

Nielsen, P.V. and Å. Möller, Measurements on Buoyant Wall Jet Flows in Air-Conditioned Rooms. "Room Vent 87", Stockholm, 1987.

On PPD:

Fanger, P.O., Thermal Comfort, McGraw-Hill, New York, 1973.

3. MAXIMUM VELOCITY IN OCCUPIED ZONE

The maximum velocity in the occupied zone u_{rm} is proportional to u_L in case of isothermal flow where u_L is the velocity in the wall jet of length L (u_L = 0.2 m/s for ℓ_{Th} = L).

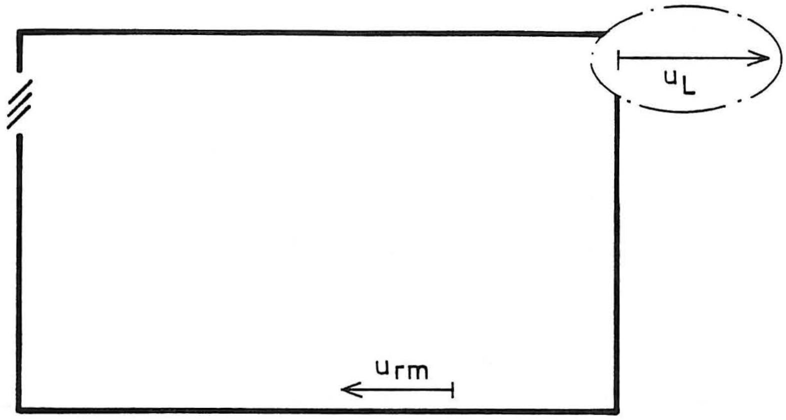

Figure 3.1. Sketch of room with "location" of u_L and u_{rm} (u_L can only be calculated).

It is interesting to study the relation

$$\frac{u_{rm}}{u_L} = \text{func}\left(\frac{\text{width of jet}}{\text{width of room}}, \ldots\right) \qquad (3.1)$$

$\frac{u_{rm}}{u_L}$ is equal to ~ 0.7 for two-dimensional flow and it seems to be equal to ~ 0.3 when the jet width is small compared to the width of the end wall.

x and u_x are replaced with L and u_L in equation (1.1) and both sides are multiplied with equation (3.1)

$$u_{rm} = u_o \cdot \text{func}(\ldots) \cdot K_a \frac{\sqrt{a_o}}{L + x_o} \qquad (3.2)$$

Equation (3.2) is a direct description of the maximum velocity in the occupied zone. Therefore, it is interesting to study the relation (3.1) by measurements and by predictions.

Equation (3.2) may be an easy way to summarize predictions for different supply openings and different room lengths (dimensions) in case of isothermal flow.

Necessary measurement

Wall jet measurements as in model 1 and 2 but especially some measurements of wall jet width and height in front of the opposite wall before the deflection.

Measurements of the maximum velocity in the occupied zone u_{rm}.

Literature

On u_{rm}/u_L - model (two dimensional):

Nielsen, P.V., Mathematical models for room air distribution, System simulations in buildings, Proceedings of an International Conference, University of Liege, December, 1982.

On u_{rm}/u_L - model (three-dimensional):

Nielsen, P.V., Ventilation of working areas (In Danish), Statens Byggeforskningsinstitut, SBI-rapport 128, 1981.

4. ADPI-MODEL

The Air Distribution Performance Index is an index which compensates a high air velocity with high temperature and thus it takes some account to thermal comfort. Results show that maximum ADPI is found for constant values of ℓ_{Th}/L in the level of 1.5 to 2.0. This is high values for an air distribution system in Europe, and it may be interesting to study the connection between ADPI, PPD and ℓ_{Th}.

Necessary measurements

ADPI and PPD-distribution. It should further be mentioned that thermal comfort is dependent on the turbulent level in the occupied zone. This level should be measured both for some comparisons with predictions but also for the evaluation of the PPD-level.

Literature

On ADPI e.g.:

Nevins, R.G. and P.L. Miller, Air Distribution and Thermal Comfort, Build International, 6, 1973.

On turbulence level and thermal comfort:

Fanger, P.O., A.K. Melikov, H. Hanzawa and J. Ring, Air Turbulence and Sensation of Draught, Energy and Buildings, 12, 1988.

5. DATA BASE MODEL

All predictions and measurements for the entire subtask 1 job are collected in a data base. The access to the data base is arranged in menus:

- Geometry of room
- Location of supply opening
- Momentum flow (the momentum flow from a diffuser is the most important information)
- Heat source location in case of thermal flow
- Archimedes' number
- Reynolds' number
- ....
- ....

It might perhaps be easier to find a solution in the data base instead of generating a new prediction.

The calculated results in the data base may be adjusted by measured values.

Situations which are not contained in the data base may be found by interpolation. It is possible to use models as "Penetration depth of thermal jets" and "Maximum velocity in the occupied zone" as a structure for interpolation in the data base.