Numerical Prediction of Airflow in a Room with Ceiling-Mounted Obstacles

Svidt, Kjeld

Publication date:
1992

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Svidt, K. (1992). *Numerical Prediction of Airflow in a Room with Ceiling-Mounted Obstacles*. Dept. of Building Technology and Structural Engineering, Aalborg University. Indoor Environmental Technology Vol. R9256 No. 31

INSTITUTTET FOR BYGNINGSTEKNIK

DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITETSCENTER • AUC • AALBORG • DANMARK

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 31

Presented at ROOMVENT'92, Third Int. Conf. on Air Distribution in Rooms, Aalborg, Denmark, September 1992

K. S. CHRISTENSEN

NUMERICAL PREDICTION OF AIRFLOW IN A ROOM WITH CEILING-MOUNTED OBSTACLES

SEPTEMBER 1992 ISSN 0902-7513 R9256

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

INDOOR ENVIRONMENTAL TECHNOLOGY
PAPER NO. 31

Presented at ROOMVENT'92, Third Int. Conf. on Air Distribution in Rooms, Aalborg, Denmark, September 1992

K. S. CHRISTENSEN

NUMERICAL PREDICTION OF AIRFLOW IN A ROOM WITH CEILING-MOUNTED OBSTACLES

SEPTEMBER 1992 ISSN 0902-7513 R9256

NUMERICAL PREDICTION OF AIRFLOW IN A ROOM WITH CEILING-MOUNTED OBSTACLES

K.S. Christensen
Aalborg University, Aalborg
Royal Veterinary and Agricultural University, Copenhagen
Denmark

SUMMARY

In ventilated rooms the air inlet device is often placed close to the ceiling. The air inlet will form a wall jet or a reattached wall jet. The wall jet may be disturbed by ceiling-mounted obstacles such as light fittings or ceiling beams which, in some cases, can cause the air jet to be deflected into the occupied zone.

In this paper numerical prediction of two-dimensional airflow in a room with ceiling-mounted obstacles is compared with the experimental results from the literature. The first part of the paper deals with velocity profiles in a room with non-deflected flow, where it is found that calculated velocity profiles agree very well with experimental results. Thereafter the critical height of an obstacle which deflects the air jet is examined.

NUMERICAL PREDICTION OF AIRFLOW IN A ROOM WITH CEILING-MOUNTED OBSTACLES

K.S. Christensen*
Aalborg University, Aalborg
Royal Veterinary and Agricultural University, Copenhagen
Denmark

INTRODUCTION

In ventilated rooms such as office buildings, industrial buildings or farm buildings, the air inlet device is often placed close to the ceiling. The inlet air will form a wall jet or a reattached wall jet generating a recirculating flow in the room. The wall jet may be disturbed by ceiling-mounted obstacles such as light fittings or ceiling beams which, in some cases, can cause the air jet to be deflected into the occupied zone.

Several authors have presented experimental results describing the influence of ceiling-mounted obstacles. Examples are [1, 2 and 3]. Some authors also presented numerical simulations of air flow in a room containing internal obstacles. Awbi [4,5] has reported good agreement with experimental results for two- and three-dimensional flows with an obstacle placed downstream of the inlet. Berlandier [6] has found that numerical results differed from 10 to 20 percent from experimental results with an obstacle which deflected the inlet air jet. Choi [7] has presented numerical simulation of a large obstacle (30 % of room height) placed in the occupied zone of the room.

In this paper numerical prediction of two-dimensional airflow in a room with ceiling-mounted obstacles is compared with the experimental results presented by Nielsen [3]. First the paper deals with velocity profiles in a room with non-deflected flow, and thereafter the critical height of an obstacle which deflects the air jet is examined.

*The author works at Aalborg University on a research project governed by the Institute of Animal Health and Animal Production at the Royal Veterinary and Agricultural University in Copenhagen. The project is sponsored by the Danish Agricultural and Veterinary Research Counsil.

TEST CASE

The two-dimensional test case is shown in figure 1. The room has a lenght L of three times the height H. The inlet is in the upper left corner of the room and the outlet is in the lower left corner. Inlet height is $h = 0.02\ H$. The inlet jet will form a horizontal two-dimensional wall jet. A ceiling-mounted obstacle of height f is placed in the distance x_f from the inlet. Values of $x_f = 10$, 30 and 60 are used in this paper. Nielsen [3] found the results shown in figure 2 for non-deflected flow with this test case. Velocity profiles were measured in the wall jet downstream of the obstacle in the distance $x = 1.7\ H$ from the inlet and also in the occupied zone in the distance $x = 2.1\ H$ from the inlet.

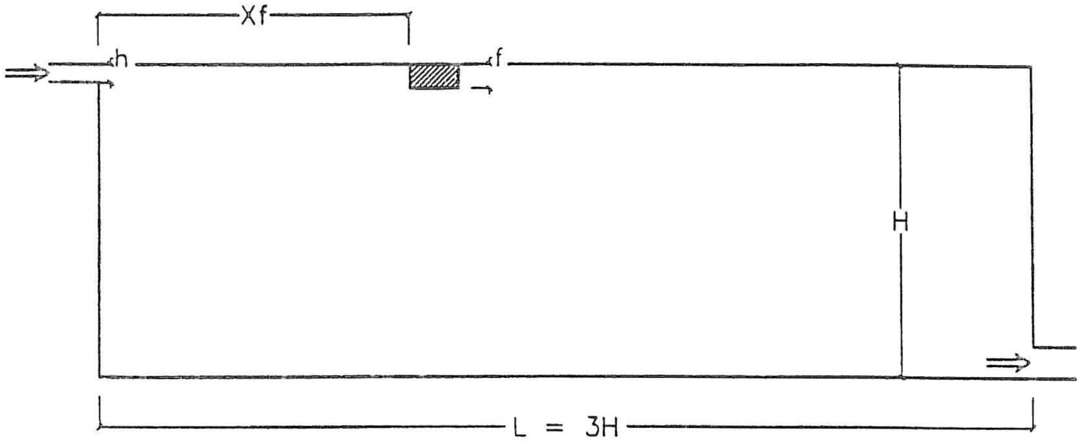


Fig. 1. Geometry of the test case.

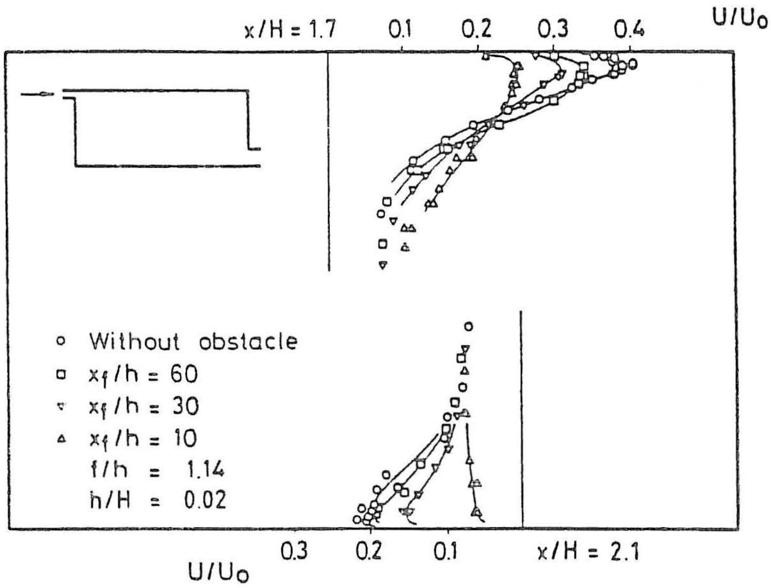


Fig. 2. Experimental results reported by Nielsen [3].

NUMERICAL SIMULATION

The PHOENICS computer code was used for numerical simulation of the air flow. PHOENICS is a general computer code for solving three-dimensional time-dependent fluid flow problems described by equations of the type

$$\frac{\partial}{\partial t}(\rho\phi) + \frac{\partial}{\partial x_i}(\rho\phi u_i) = \Gamma_\phi \left(\frac{\partial^2\phi}{\partial x_i^2}\right) + S_\phi \qquad (1)$$

where ϕ can be any of the unknowns in the governing equations

u_i is the velocity in direction i

ρ is density of the medium

Γ_ϕ is diffusion coefficient of the variable ϕ

S_ϕ is a source term of the variable ϕ

In the present work the programme was set up to solve steady-state isothermal, two-dimensional flow, using the standard k-ϵ turbulence model.

Boundary Conditions

At all surfaces of the room logarithmic wall functions were used to determine the value in the first grid node of turbulent kinetic energy k, dissipation ϵ, and the velocity parallel to the wall.

At the inlet a fixed velocity boundary condition was used to set the correct mass and momentum flow. The outlet was defined by a zero-pressure boundary condition which ensures that the continuity equation will be satisfied.

The boundary conditions for the obstacle were set by so-called porosities by defining a zero porosity for the control volumes which contain the obstacle.

Computational Grid

A non-uniform 40 x 19 grid with a fine mesh near the walls and the obstacle was used for the calculations (figure 3).

The inlet height is represented by the three upper cells in the y-direction and the obstacle is represented by four cells in the y-direction and five cells in the x-direction.

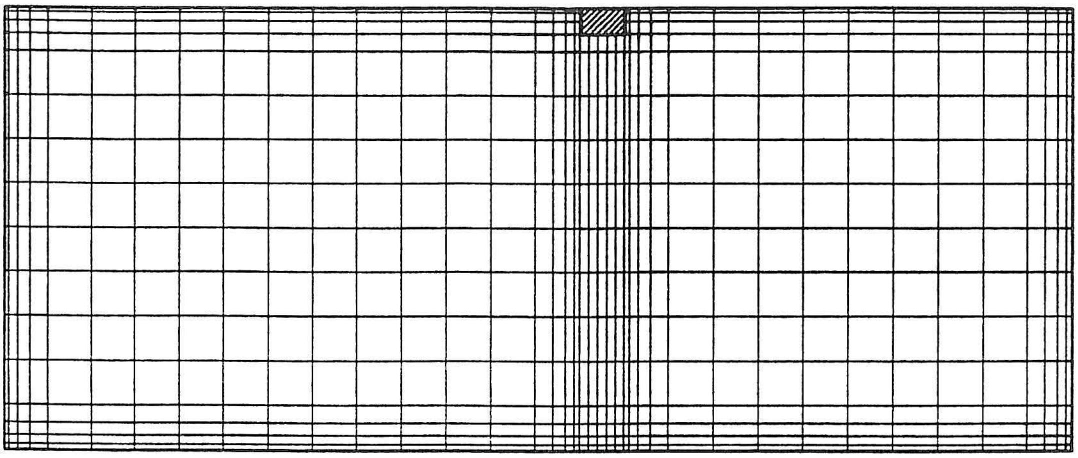


Fig. 3. The computational grid has a fine mesh near the walls and the obstacle (obstacle not drawn to scale).

RESULTS

Figure 4 shows an example of a calculated flow field with non-deflected flow. It can be seen that the inlet wall jet reattaches to the ceiling downstream of the obstacle resulting in *one* recirculation zone in the room.

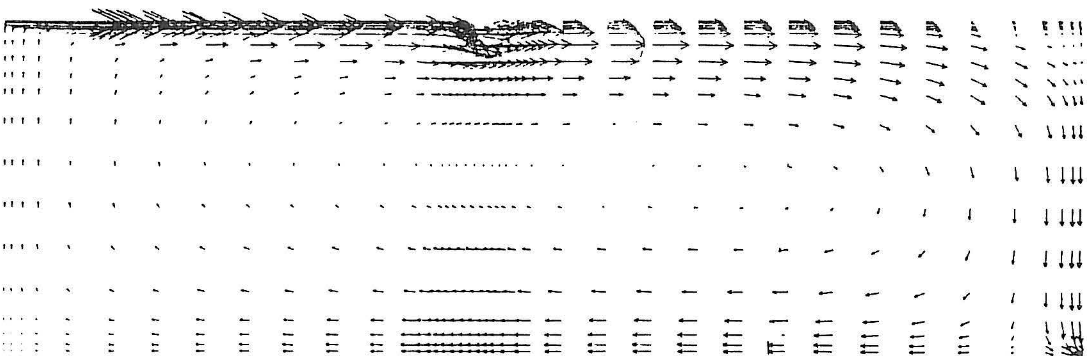


Fig. 4. Calculated flow field in a case with non-deflected flow.

In figure 5 the calculated results are compared with velocity profiles measured by Nielsen [3] for different positions of the obstacle. It can be seen from the figures that in most cases there is good agreement between experimental and calculated results. Only when the obstacle is very close to the inlet ($x_f/h = 10$) there seems to be very little agreement between experimental and calculated results.

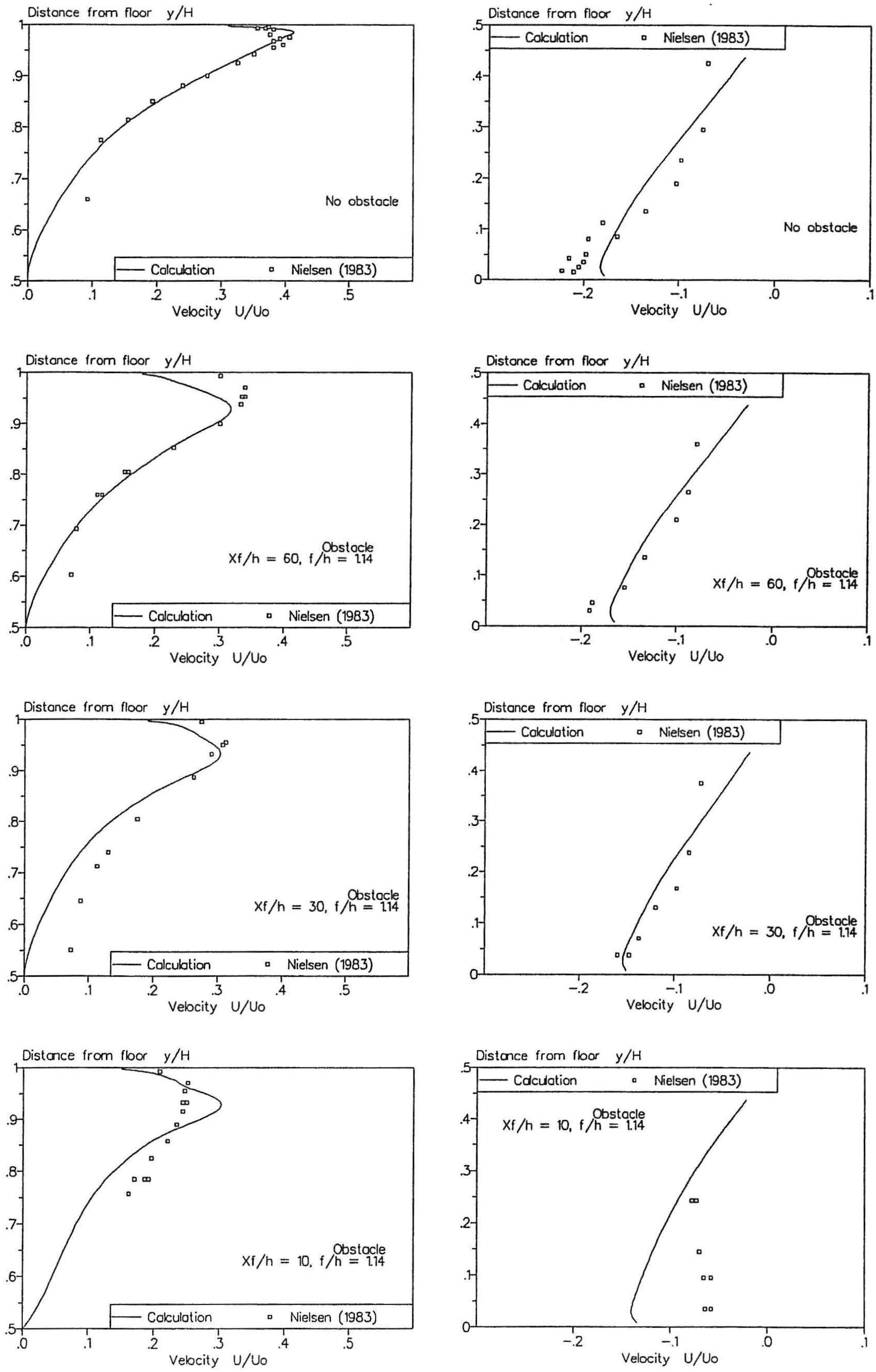


Fig.5. Calculated and measured velocity profiles in the jet (left) and in the occupied zone (right).

At certain combinations of the height of the obstacle and its distance from the inlet, the air jet will be deflected into the occupied zone. Figure 6 shows the calculated flow field for two different combinations of obstacle height and position resulting in deflected and non-deflected flow, respectively.

The flow field was calculated for seven different heights and positions of the obstacle and it was determined whether the flow was deflected or non-deflected. In figure 7 the obtained results are compared with the experimental results made by Nielsen [3]. It appears that the calculated results tend to be non-deflected in more cases than the experimental results. In the cases where Nielsen found that the flow could be either deflected or non-deflected the calculation resulted every time in a non-deflected flow.

The explanation may be that in the latter cases there exist two different flow field solutions from which only the non-deflected solution was obtained in the present work. It is possible that the solution with deflected flow could be obtained by using another initial flow field for the calculations but this assumption was not further investigated.

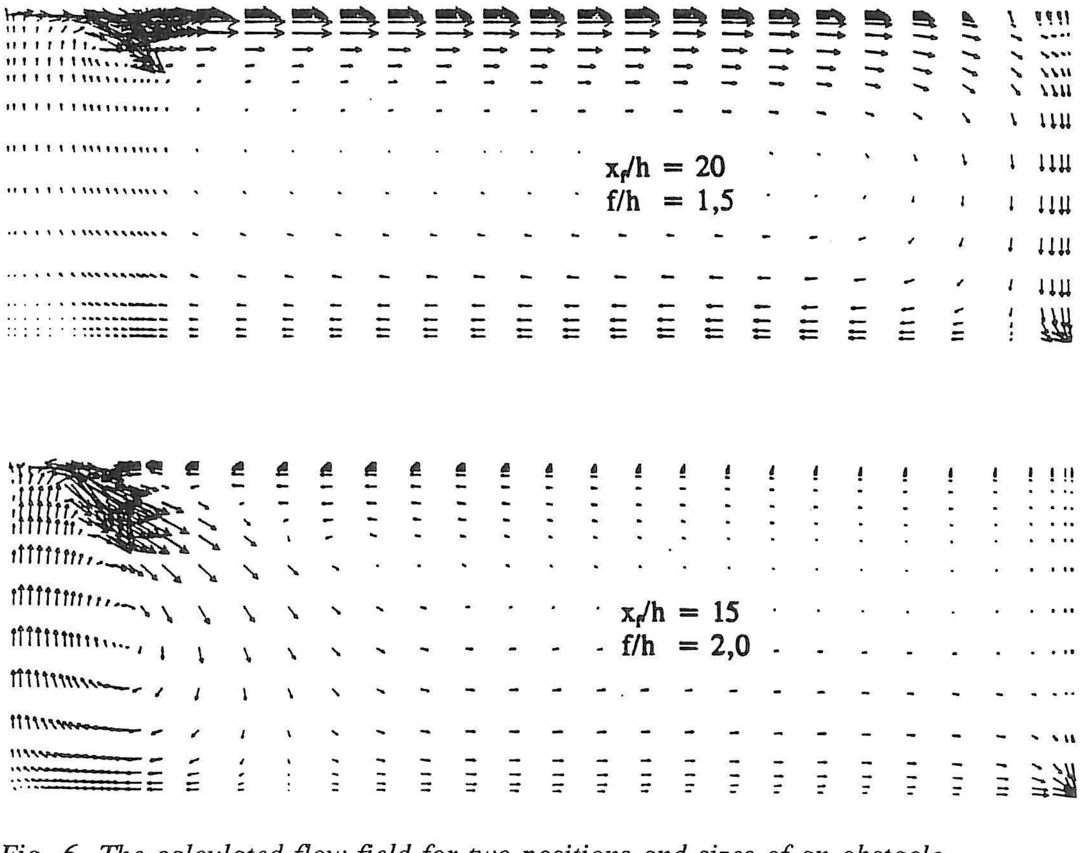
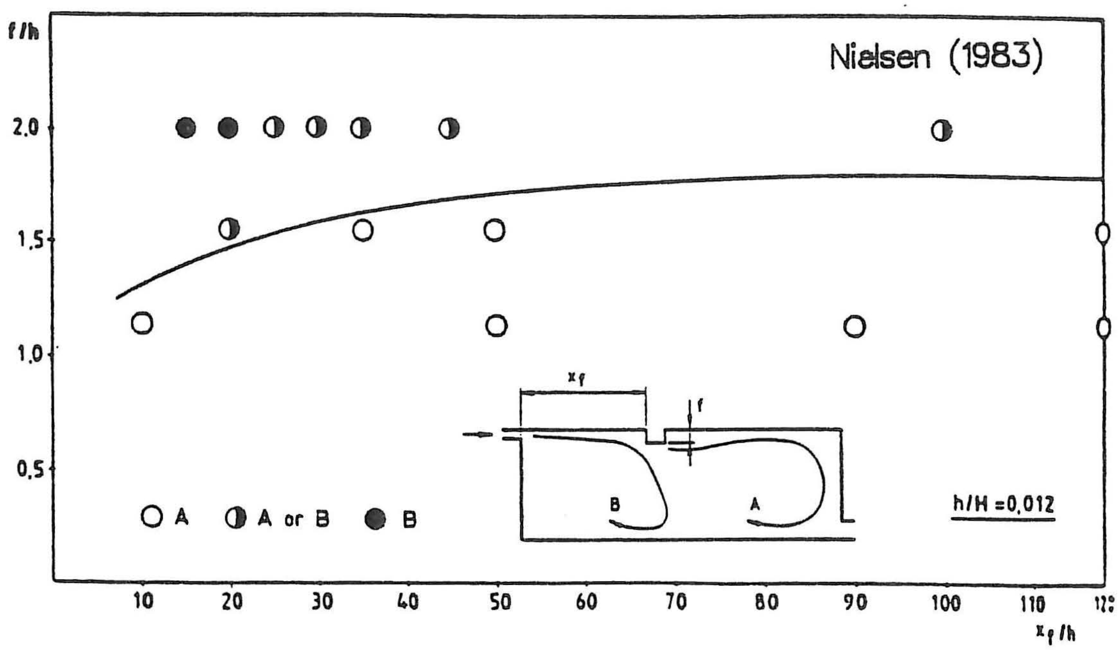


Fig. 6. The calculated flow field for two positions and sizes of an obstacle.



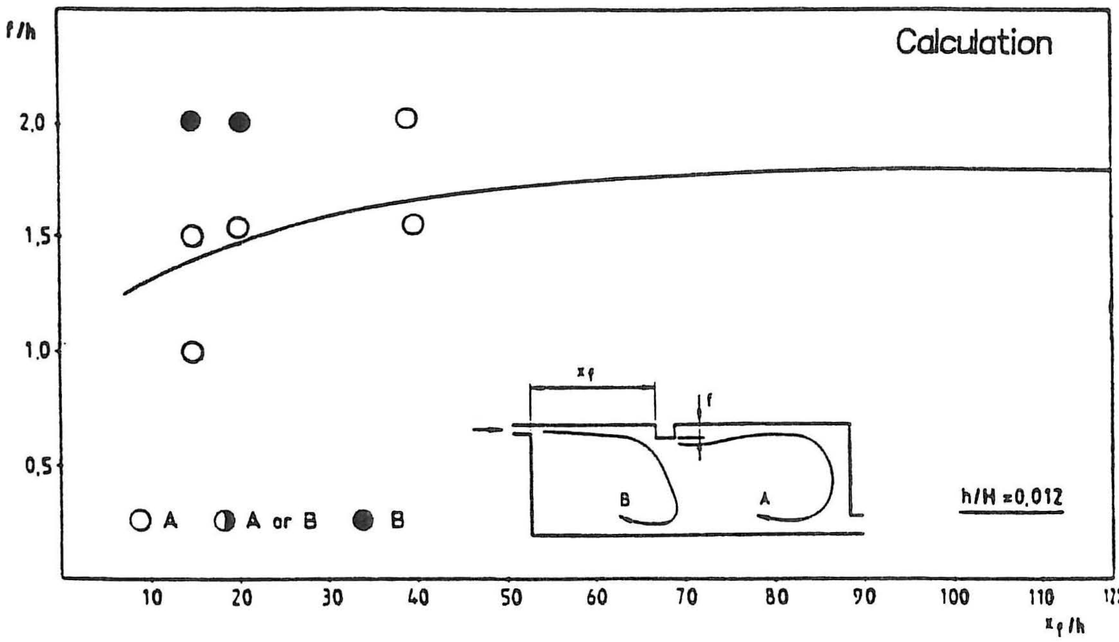


Fig. 7. Experimental and calculated results for different combinations of obstacle height and position.

CONCLUSIONS

The prediction of isothermal, two-dimensional airflow in a room with a ceiling-mounted obstacle has been made using a general CFD-code. Good results were obtained with a rather simple representation of the inlet and the obstacle.

In cases with a small obstacle, which did not cause a permanent deflection of the air jet, calculated velocity profiles showed good agreement with experimental results measured in the reattached wall jet and in the occupied zone.

It is more complicated to predict the critical height and position of the obstacle which will cause a permanent deflection of the air jet. The calculated results agreed with experiments in cases with definitely deflected flow or definitely non-deflected flow, but further work is necessary in order to handle special cases where the obstacle height and position are close to the critical values.

REFERENCES

[1] Sölner, G. and Klinkenberg, K. "**Leuchten als störkörper im Luftstrohm.**" (Lighting fixtures as obstacles in air flow), Heizung, Lüftung/Kli.matechnik Haustechnik, 23, No. 4, 1972.

[2] Holmes, M.J. and Sachariewicz, E. "**The effect of ceiling beams and light fittings on ventilating jets.**" Laboratory Report No. 79, HVRA 1973.

[3] Nielsen, P.V. "**Air diffusion in rooms with ceiling-mounted obstacles and two-dimensional isothermal flow.**" 16th international congress of refrigeration, Paris 1983.

[4] Awbi, H.B. "**Application of Computational Fluid Dynamics in Room Ventilation.**" Building and Environment, Vol. 24. No. 1, pp 73-84, 1989.

[5] Awbi, H.B. and Setrak, A.A. "**Air jet interference due to ceiling-mounted obstacles.**" RoomVent '87, International conference on engineering aero- and thermodynamics of ventilated rooms, Stockholm 1987.

[6] Berlandier, P., Rapp, R., Serieys J.C. and Cunin, J.C. "**General feature of a two-dimensional isothermal mean flow inside a ventilated room with a wall mounted obstacle.**" Progress and trends in air infiltration and ventilation research, Finland, 25-28 september 1989.

[7] Choi, H.L., Albright, L.D. and Timmons, M.B. "**An application of the k-ϵ turbulence model to predict how a rectangular obstacle in a slot-ventilated enclosure affects air flow.**" Transactions of the ASAE, Vol 33(1), January-February 1990.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 1: C. E. Hyldgård: *Aerodynamic Control of Exhaust.* ISSN 0902-7513 R8712.

PAPER NO. 2: Per Heiselberg, Peter V. Nielsen: *The Contaminant Distribution in a Ventilated Room with Different Air Terminal Devices.* ISSN 0902-7513 R8713.

PAPER NO. 3: Peter V. Nielsen, L. Evensen, Peter Grabau, J. H. Thulesen-Dahl: *Air Distribution in Rooms with Ceiling-Mounted Obstacles and Three-Dimensional Flow.* ISSN 0902-7513 R8714.

PAPER NO. 4: Peter V. Nielsen, Åke T. A. Mõller: *Measurements on Buoyant Wall Jet Flows in Air-Conditioned Rooms.* ISSN 0902-7513 R8715.

PAPER NO. 5: Peter V. Nielsen: *Numerical Prediction of Air Distribution in Rooms. Status and Potentials.* ISSN 0902-7513 R8823.

PAPER NO. 6: Peter V. Nielsen, Åke T. Mõller: *Measurements on Buoyant Jet Flows from a Ceiling-Mounted Slot Diffuser.* ISSN 0902-7513 R8832.

PAPER NO. 7: Peter Kofoed, Peter V. Nielsen: *Thermal Plumes in Ventilated Rooms - An Experimental Research Work.* ISSN 0902-7513 R8833.

PAPER NO. 8: Peter V. Nielsen, Lars Hoff, Lars Germann Pedersen: *Displacement Ventilation by Different Types of Diffusers.* ISSN 0902-7513 R8834.

PAPER NO. 9: Per Heiselberg, Peter V. Nielsen: *Flow Conditions in a Mechanically Ventilated Room with a Convective Heat Source.* ISSN 0902-7513 R8835.

PAPER NO. 10: Peter V. Nielsen: *Displacement Ventilation in a Room with Low-Level Diffusers.* ISSN 0902-7513 R8836.

PAPER NO. 11: Peter V. Nielsen: *Airflow Simulation Techniques - Progress and Trends.* ISSN 0902-7513 R8926.

PAPER NO. 12: M. Skovgaard, C. E. Hyldgaard & P. V. Nielsen: *High and Low Reynolds Number Measurements in a Room with an Impinging Isothermal Jet.* ISSN 0902-7513 R9003

PAPER NO. 13: M. Skovgaard, P. V. Nielsen: *Numerical Prediction of Air Distribution in Rooms with Ventilation of the Mixing Type using the Standard K, ε-Model.* ISSN 0902-7513 R9042.

PAPER NO. 14: P. Kofoed, P. V. Nielsen: *Thermal Plumes in Ventilated Rooms - Measurements in Stratified Surroundings and Analysis by Use of an Extrapolation Method.* ISSN 0902-7513 R9043.

PAPER NO. 15: P. Heiselberg, M. Sandberg: *Convection from a Slender Cylinder in a Ventilated Room.* ISSN 0902-7513 R9044.

PAPER NO. 16: C. E. Hyldgaard: *Water Evaporation in Swimming Baths.* ISSN 0902-7513 R9045.

PAPERS ON INDOOR ENVIRONMENTAL TECHNOLOGY

PAPER NO. 17: H. Overby, M. Steen-Thøde: *Calculation of Vertical Temperature Gradients in Heated Rooms.* ISSN 0902-7513 R9046.

PAPER NO. 18: P. V. Nielsen, U. Madsen, D. Tveit: *Experiments on an Exhaust Hood for the Paint Industry.* ISSN 0902-7513 R9146.

PAPER NO. 19: L. Germann Pedersen, P. V. Nielsen: *Exhaust System Reinforced by Jet Flow.* ISSN 0902-7513 R9147.

PAPER NO. 20: P. V. Nielsen: *Models for the Prediction of Room Air Distribution.* ISSN 0902-7513 R9148.

PAPER NO. 21: M. Skovgaard, P. V. Nielsen: *Modelling Complex Inlet Geometries in CFD - Applied to Air Flow in Ventilated Rooms.* ISSN 0902-7513 R9149.

PAPER NO. 22: M. Skovgaard, P. V. Nielsen: *Numerical Investigation of Transitional Flow over a Backward Facing Step using a Low Reynolds Number $k - \varepsilon$ Model.* ISSN 0902-7513 R9150.

PAPER NO. 23: P. Kofoed, P. V. Nielsen: *Auftriebsströmungen verschiedener Wärmequellen - Einfluss der umgebenden Wände auf den geförderten Volumenstrom.* ISSN 0902-7513 R9151.

PAPER NO. 24: P. Heiselberg: *Concentration Distribution in a Ventilated Room under Isothermal Conditions.* ISSN 0902-7513 R9152.

PAPER NO. 25: P. V. Nielsen: *Air Distribution Systems - Room Air Movement and Ventilation Effectiveness.* ISSN 0902-7513 R9250.

PAPER NO. 26: P. V. Nielsen: *Description of Supply Openings in Numerical Models for Room Air Distribution* ISSN 0902-7513 R9251.

PAPER NO. 27: P. V. Nielsen: *Velocity Distribution in the Flow from a Wall-mounted Diffuser in Rooms with Displacement Ventilation.* ISSN 0902-7513 R9252.

PAPER NO. 28: T. V. Jacobsen & P. V. Nielsen: *Velocity and Temperature Distribution in Flow from an Inlet Device in Rooms with Displacement Ventilation.* ISSN 0902-7513 R9253.

PAPER NO. 29: P. Heiselberg: *Dispersion of Contaminants in Indoor Climate.* ISSN 0902-7513 R9254.

PAPER NO. 30: P. Heiselberg & N. C. Bergsøe: *Measurements of Contaminant Dispersion in Ventilated Rooms by a Passive Tracer Gas Technique.* ISSN 0902-7513 R9255.

PAPER NO. 31: K. S. Christensen: *Numerical Prediction of Airflow in a Room with Ceiling-Mounted Obstacles.* ISSN 0902-7513 R9256.

Department of Building Technology and Structural Engineering
The University of Aalborg, Sohngaardsholmsvej 57. DK 9000 Aalborg
Telephone: 45 98 15 85 22 Telefax: 45 98 14 82 43