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Ventilation for Energy Efficiency and Optimum Indoor Air Quality
13th AIVC Conference, Nice, France
15-18 September 1992

Poster 20

The Penetration of Gaseous Pollutants Into Buildings in the Case of a Sudden Contamination of the Outdoor Air.

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SYNOPSIS

A sudden contamination of the outdoor air by some toxic gas can have several causes. The primary goal of the investigation was to determine the protection afforded by sheltering indoors. The object of a computational approach was a single family house with two floors. Three different models were utilized as computing tools : MOVECOMP to calculate the infiltration air flows, MULTIC to calculate the contaminant transport inside the building and TDYN to calculate the temperature decay of the building. The variation of the weather parameters was treated using the two-dimensional distribution of the outdoor air temperature and wind speed and a statistical approach. The results show the cumulative distribution functions of the relative doses inside the building for different tightness levels, exposure times and other relevant parameters.

1. INTRODUCTION

A sudden contamination of the outdoor air can be caused by a transportation accident, a sudden emission from an industrial plant, a disaster in a nuclear power plant or even by traffic. The envelope of a building can be utilized as a shelter against the contaminated outdoor air. The protection afforded by sheltering indoors depends primarily on the tightness of the building envelope, the outdoor air temperature and the wind speed. Other parameters, like the leakage distribution, the pressure coefficients, the wind direction and the local environment around the building, have some influence, too. However, the problems involved in sheltering have not been investigated very much [1..3] and there is shortage of useful quantitative knowledge.

The most reliable way to look into the penetration of contaminated air into a building would be to use tracer gas measurements. This would, however, be a very laborious, time consuming and expensive way, and if the effect of the building tightness and the weather statistics were also to be investigated, the amount of work would be enormous. A better way, not as reliable but much more flexible, is to approach the problem using computer models.

2. THE BUILDING

The object of the computational examination is a single family house with two floors and a steep ridge roof. It is not a real, existing building, rather an imaginary one to be used as input data for the calculations. It does, however, represent a common type of house and its leakage characteristics can be fixed on certain levels for calculation purposes. Both floors have five rooms and the floors are connected by stairs. The total floor area of the living space is 140 m^2. No description of the ventilation ductwork is included because it is assumed that in an emergency situation the ventilation is cut off and the ducts are sealed.

For the air infiltration calculations 80% of the envelope leakage area was distributed proportional to the length of the joints. The remaining 20% was placed in the floor and the ceiling to represent pipe and duct passages. The cracks in the building shell had a flow exponent value of 0.65 [4,5,6]. Four different airtightness levels were used for the whole building. The n_{50} value varyed from 1 1/h to 15 1/h, while the distribution of the leakage area and the flow coefficients remained unchanged. The flow coefficients for each level were adjusted using a computational 50 Pa pressurization. The pressure coefficients of the building facades were in situ measured values [7].

For the contaminant transport calculations the building was divided into ten zones. Each room was one zone. The indoor air temperatures of the zones were simply chosen according to the experience gained from measurements in similar situations [8,9]. The temperature difference between adjacent zones, which is the crucial parameter from the viewpoint of the circulating air flows through the open doors and thus the contaminant transport, was chosen to be 0.1 °C. The mean indoor air temperature was 21.0 °C.

3. COMPUTING TOOLS

To calculate the infiltration, exfiltration and internal net air flows, the multizone simulation program MOVECOMP [10] was used. The input data contains a description of the leakage characteristics of the building, the pressure coefficients, the indoor and outdoor air temperatures and the wind speed. The mass balance equations of the system nodes is the basis of the solution. As an output the mass flow rates through the flow paths and the pressures of the nodes are given.

The concentration histories and doses in various zones inside the building were calculated using a computer code MULTIC [11] developed especially for this purpose. The calculation is based on the conservation of mass of the contaminant in the zones. The mixing of the contaminant in each zone is assumed to be complete and instantaneous. The circulating air flows between adjacent zones are calculated using a simple analytical procedure [12]. Some validation of the code has been done [8,9] and it shows that generally the results are satisfactory and the performance of the program can be considered sufficient for the purpose.

4. WEATHER DATA

The most important weather parameters affecting the pressure distribution and the infiltration and exfiltration flows of a building are the outdoor air temperature and the wind speed and direction. The mean two-dimensional frequency distributions of the temperature and the speed values measured in Finland during the years 1961-1980 [13] were used as input data for the calculations. The wind speed was reduced with a coefficient of 0.5 [4,14] to take the effect of the terrain into account.

5. CONCEPTS

The relevant quantity from the health point of view is the dose, which is the integral of concentration over time. The concentrations and the doses in different zones grow at different speeds. The mean dose in the building is defined as the arithmetic mean of the doses in all zones. Further, the concentrations and doses depend on the concentration level outside. Dividing the indoor dose by the outdoor dose gives the relative dose, which does not depend on the outdoor concentration level. Performing both the operations gives the relative mean dose at the moment t:

$$\langle D^*(t)\rangle = \frac{\frac{1}{N}\sum_{i=1}^{N}\left[\int_0^t C_i(t')\,dt'\right]}{\int_0^t C_{out}(t')\,dt'} \tag{1}$$

where N is the number of zones in the building, $C_i(t)$ is the concentration in zone i at moment t, t' is a dummy variable of integration and $C_{out}(t)$ is the outdoor concentration. This relative mean dose is a very central quantity in the presentation of the computed results.

The two-dimensional frequency distribution of the outdoor temperature and wind speed, which was used as input data, contains approximately 200 pairs of values for a one-year period. To be able to present the results of the calculations in a compact form, a statistical approach has to be utilized. The cumulative frequency of the computed relative mean dose values $F(\langle D^*(t)\rangle)$ is the quantity used in this context.

6. RESULTS

An example of the cumulative frequencies of the relative mean dose is presented in Fig.1. Here the location by which the weather data is determined is Helsinki, Finland. The period for the weather data is one year. All inner doors are wide open. Four different levels of air tightness and five different exposure times t=1h, 3h, 6h, 12h and 24h were

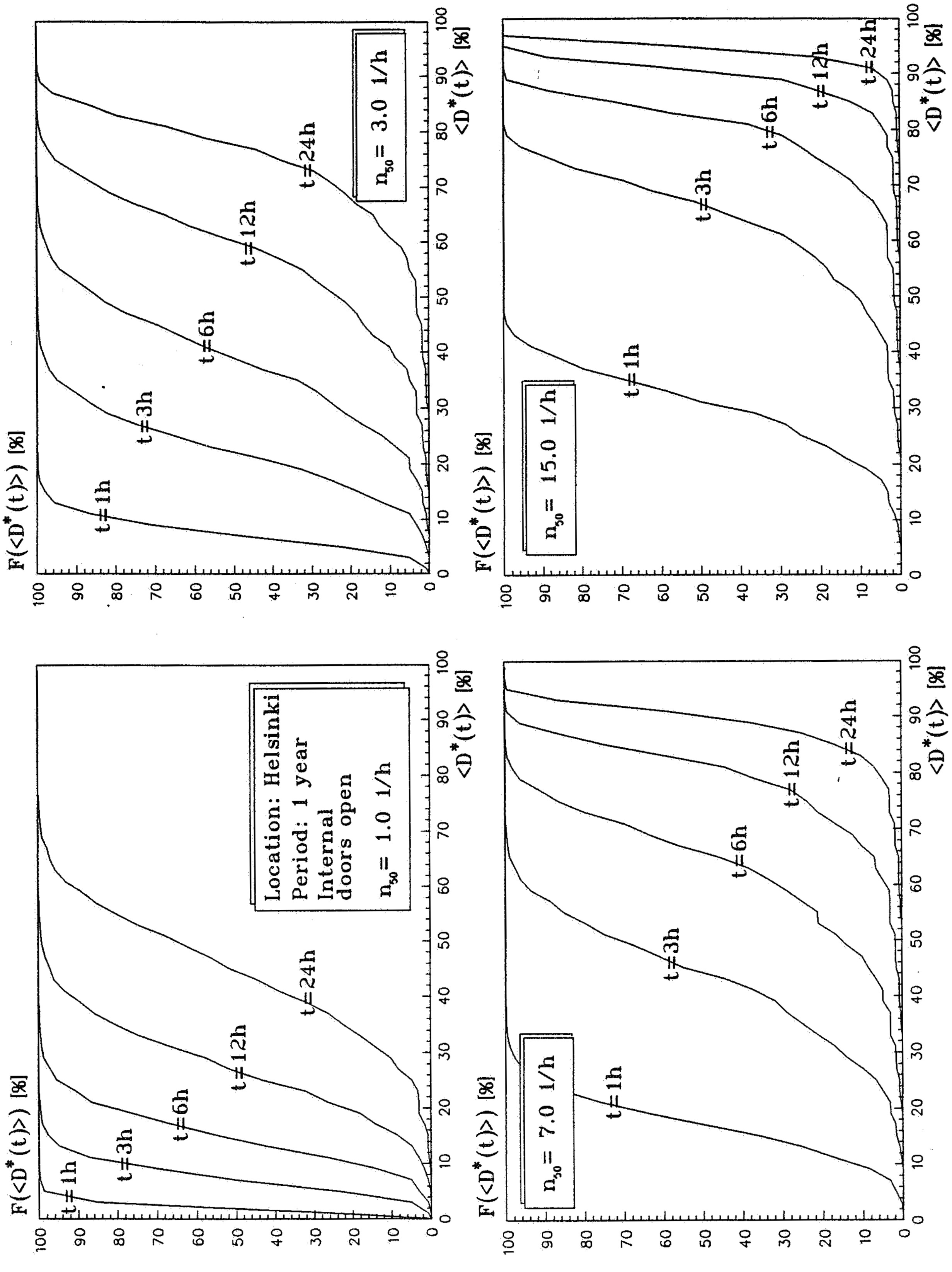

Fig.1 The cumulative frequencies of the relative mean dose.

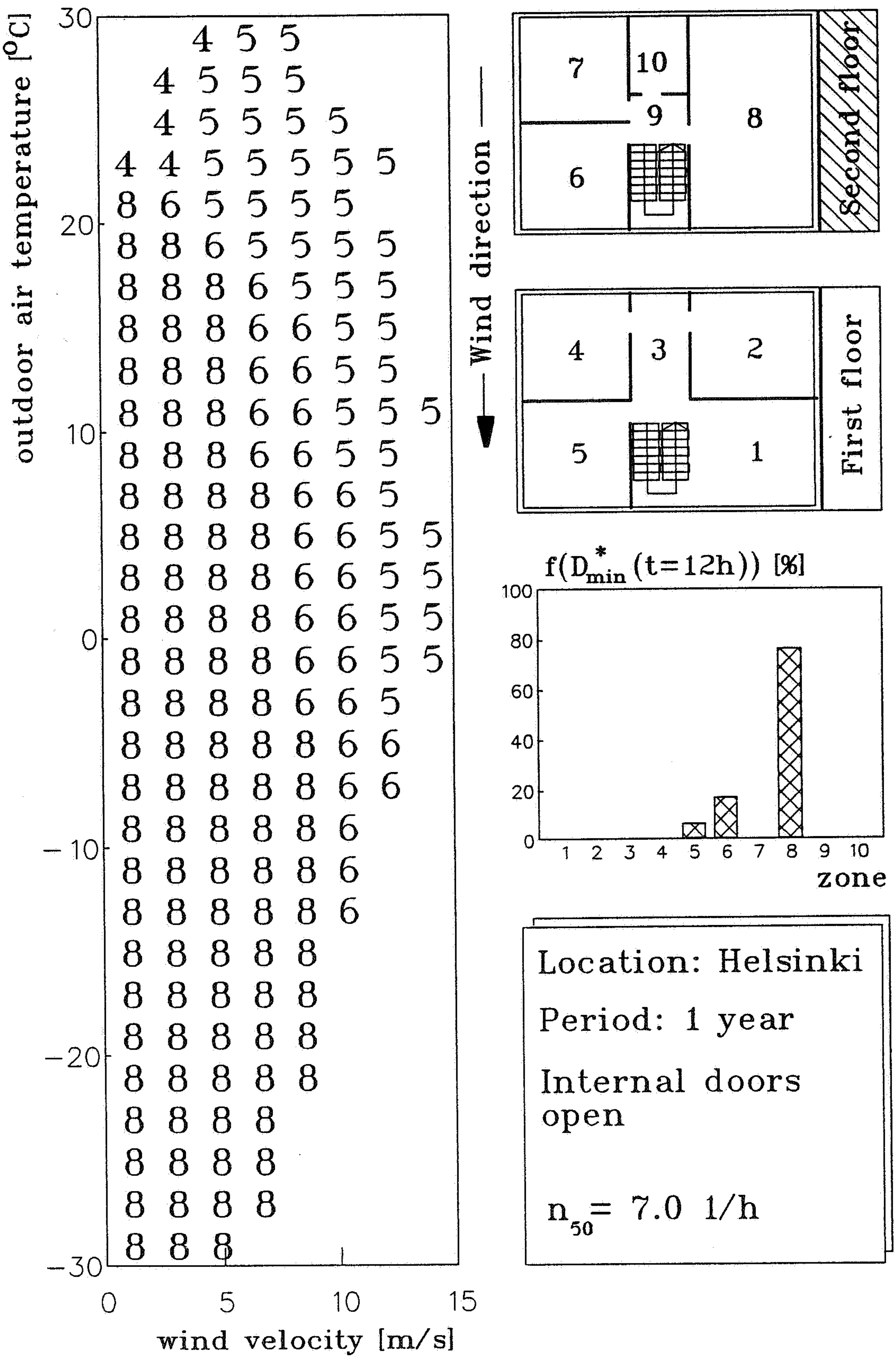

Fig.2 The location of the minimum dose, an example.

used. The cumulative frequency can be interpreted as the probability when the relative mean dose does not exceed the value on the abscissa. If the period is not one year but e.g. January, the frequency curves shift to the right because the temperature difference between indoors and outdoors is larger.

The occupants, when sheltering indoors, should try to minimize the dose by moving into the zone where the lowest concentration occurs. Here, besides the outdoor air temperature and wind speed, the direction of the wind and the status of the inner doors are also of importance. The tightness of the building, on the other hand, does not play an important role in this context. Fig.2 gives an example of the location of the minimum dose values after 12 hours' exposure. A more thorough presentation of the results is given in the reference [15].

7. CONCLUSIONS

From the viewpoint of sheltering, the tightness of the building holds a key position. In a leaky building, depending on the exposure time, the doses are from two to fifteen times as much as in a tight building. By closing the inner doors and choosing the correct location inside the building, the occupant can decrease the dose in favourable conditions by 50% compared with the mean value. This does, however, require knowledge of the local wind direction.

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