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PAPER 9

USE OF STATISTICS FOR PREDICTING DISTRIBUTION OF AIR INFILTRATION

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SUMMARY

Calculation of air infiltration in a large number of cases can give information of expected variations in yearly air change and energy consumptions. As model is used the equivalent leakage area model written in a spreadsheet computer program. For a typical Norwegian house an analysis of the influence of some parameters is made. The influence of climate is found to be small, if we compare the mean yearly air change for towns in Norway. Prediction of air infiltration is made from known variations in indoor temperature, 50 Pa pressurization air change and leakage and pressure characteristics. 500 simulations with random generated normally distributed numbers are done. The mean yearly air change has been found to be 0,24 in Oslo. But 10% will have values above 0,33. Regression shows a good correlation between 50 Pa pressurization air change and the mean yearly value. A good prediction of the mean yearly air change can therefore be based on the pressurization test without exact knowledge of other parameters. The simulation method can be used on more complicated and correct models to find out how uncertain knowledge of the parameter will influence the final results.

1. INTRODUCTION

Measurements of air infiltration from similar buildings will in most cases not give the same results. This is caused by variations in leakage characteristics and climatic conditions. For measurements of a larger number of houses it is impractical to make detailed measurements and calculations. Instead we can use statistical methods. For each important parameter we can assume variations and use this in a model. If we then make a large number of calculations we will find the typical distribution of air infiltration.

The method was originally made for prediction of moisture condensation and drying in constructions. Later it has been used to predict variations in total energy consumption in occupied buildings, where the occupants' behavior can only be estimated. Variations in energy consumption from 50% above to 50% below the mean value is quite normal. The results are found in reference 1.

In this paper we are only interested in the infiltration given as air change and energy consumption for heating the infiltrated air.

2. EQUIVALENT LEAKAGE AREA (ELA) ALGORITHM

The method was developed at Lawrence Berkeley Laboratory to predict the change in infiltration rate with retrofit and other changes in building envelope. We use this model as it is widely known and gives realistic values without too much calculation time. The model is simplified with few parameters:

1. Leakage of structure - measured with pressurization
2. Ratio of floor/ceiling leakage to wall leakage
3. Internal/external temperature difference
5. Wind speed
6. Terrain class
7. Shielding class

In this paper we will not describe the model in detail. A full description is found i AIVC (ref. 2): Air Infiltration Calculation Techniques - An Applications Guide (1986). The model is written on a spreadsheet computer program (SYMPHONY ref. 3) for personal computer. Using spreadsheet with graphics makes it easy to perform parameter variations and statistical analysis.

3. NORWEGIAN BUILDING

As a standard case we use a building of 120 m^2 with 2 floors and a leakage of 4 air changes per hour at 50 Pa overpressure. This is the maximum allowed leakage in small houses. The leakage in the ceiling is 0,38 of the total. The leakage in the floor is 0,16 of the total. The rest is in the walls. The indoor temperature is 21 ^oC. The flow exponent is 0,7. The terrain is urban. The shielding coefficient is 0,3 as for light local shielding with few obstructions.

A few calculations with parameter variations have been made and the results plotted. Figure 1 shows curves for the calculated air change versus the wind speed. Each curve is for different temperature differences over the envelope. Typical Norwegian houses have infiltration air change between 0,1 and 0,4.

All other parameter analysis are made with climate from Oslo. We use a monthly calculation and need mean wind speed and temperature. The result from the calculation is either the mean yearly air change or the yearly energy consumption. In both cases only for the infiltration air not the

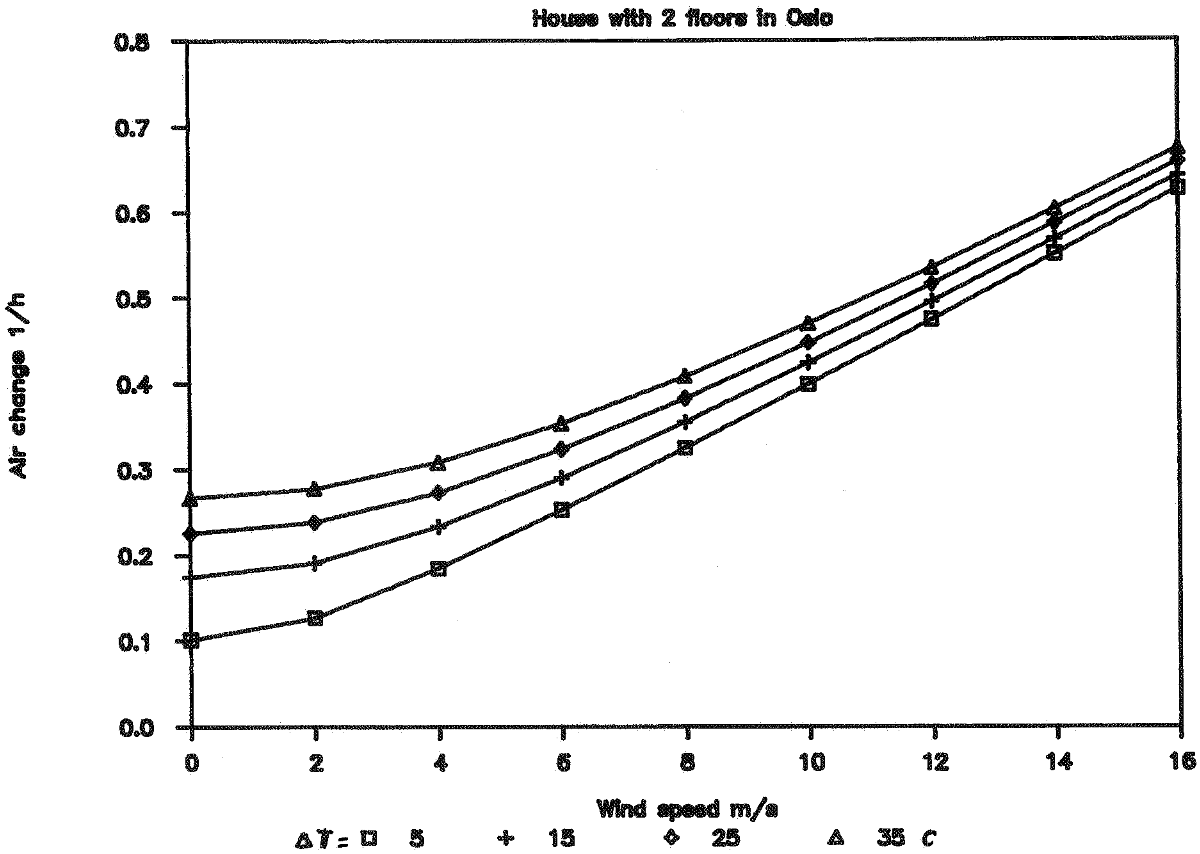

Figure 1. Infiltration air change (1/h) in dependence of wind speed (m/s) and temperature difference (C).

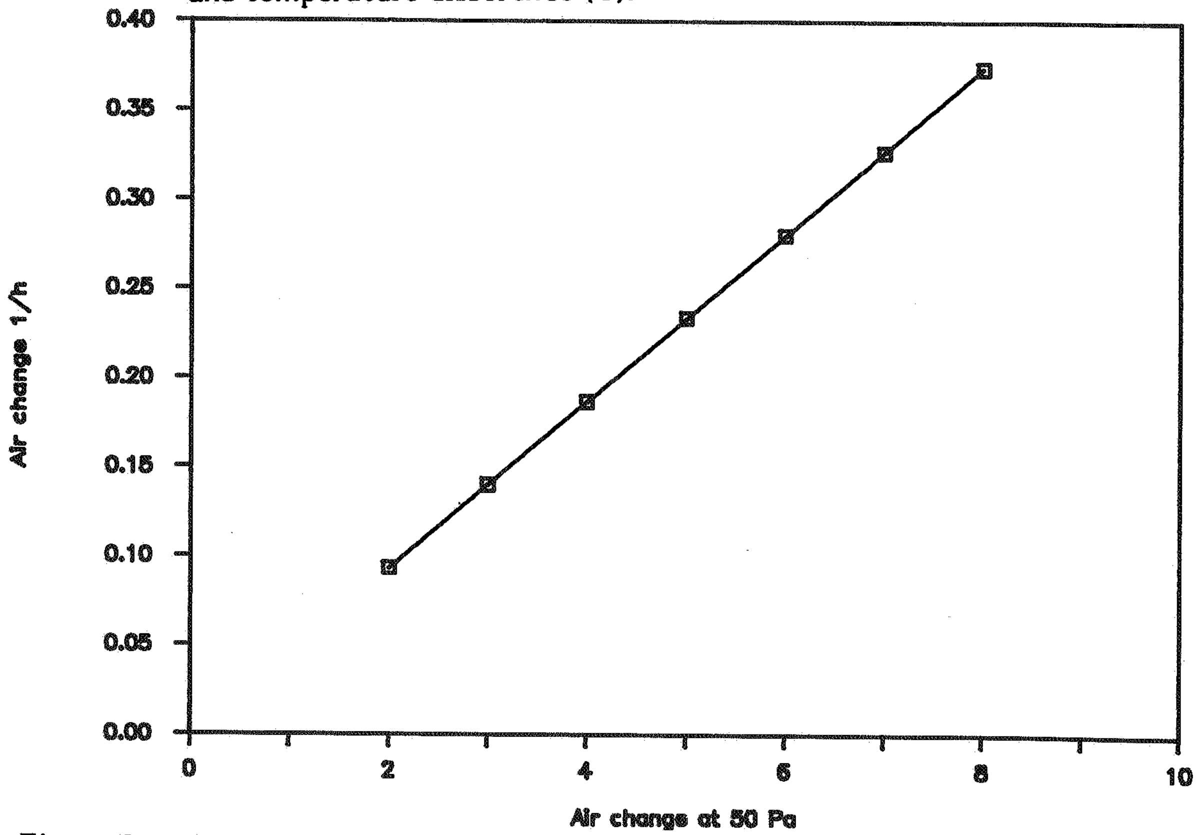

Figure 2. Yearly mean air change (1/h) in dependence of air change (1/h) at 50 Pa pressurization.

total ventilation. The most important parameter in the model is the measured air change at 50 Pa overpressure. Figure 2 shows the variation in the mean yearly air change in dependence of the pressurization air change. For the pressurization air change range from 2 to 8 will infiltration range from 0,1 to 0,4. Parametric analysis are made on other parameters as well but we will only show the dependence of the terrain type (figure 3). The variations are small.

4. CLIMATE VARIATIONS

In a country like Norway there are large variations in climate and it can be expected that it will influence the measured and calculated infiltration.
Figure 4 gives the yearly mean outdoor temperatures in towns in Norway. The towns are ordered from south to north with the most southerly first.
Figure 5 shows the mean yearly wind speeds. Large variations are seen. Typical towns in the inland have low temperature and low wind speed, such as Nesbyen, Røros and Kautokeino. Towns at the coast have high temperature and high wind speed, such as Kristiansand, Bergen, Kristiansund and Vardø.
Figure 6 shows the mean yearly air change for the same building in the various towns. It is a little surprising that the values are so alike. Only Vardø has higher air change. The total infiltration is nearly constant but at the coast is the wind effect dominant and ind the inland the stock effect.
Figure 7 shows the yearly energy consumption for infiltration for the towns. These values are not as constant as the air change, because the energy consumption is more dependent on the outdoor temperature. The inland towns with low temperatures Nesbyen, Røros and Kautokeino have the highest energy consumption. The results of this calculation with different climates show that for a statistical analysis we only need one town to get the correct variations in the air change. If we will get the variations in energy consumption, we can make the calculation for one town and later make a transformation to the other climates.

5. NORWEGIAN MEASUREMENTS

The Norwegian Building Research Institute made in 1979 measurements in single family houses in the southern part of Norway (ref. 4). The leakage was measured at 50 Pa overpressure. The lowest value found was 2,0 and the highest 8,0. The mean leakage was calculated to be 4,7 air changes per

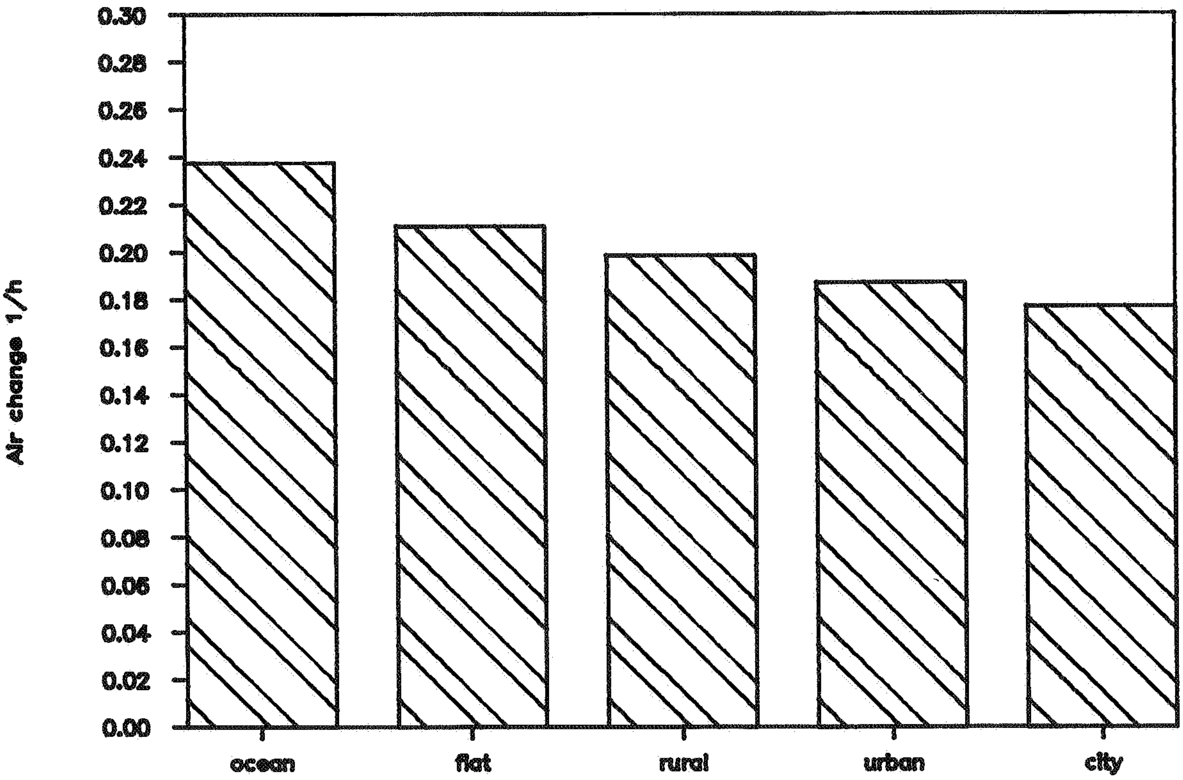

Figure 3. Yearly mean air change (1/h) for different terrain types in the ELA-model.

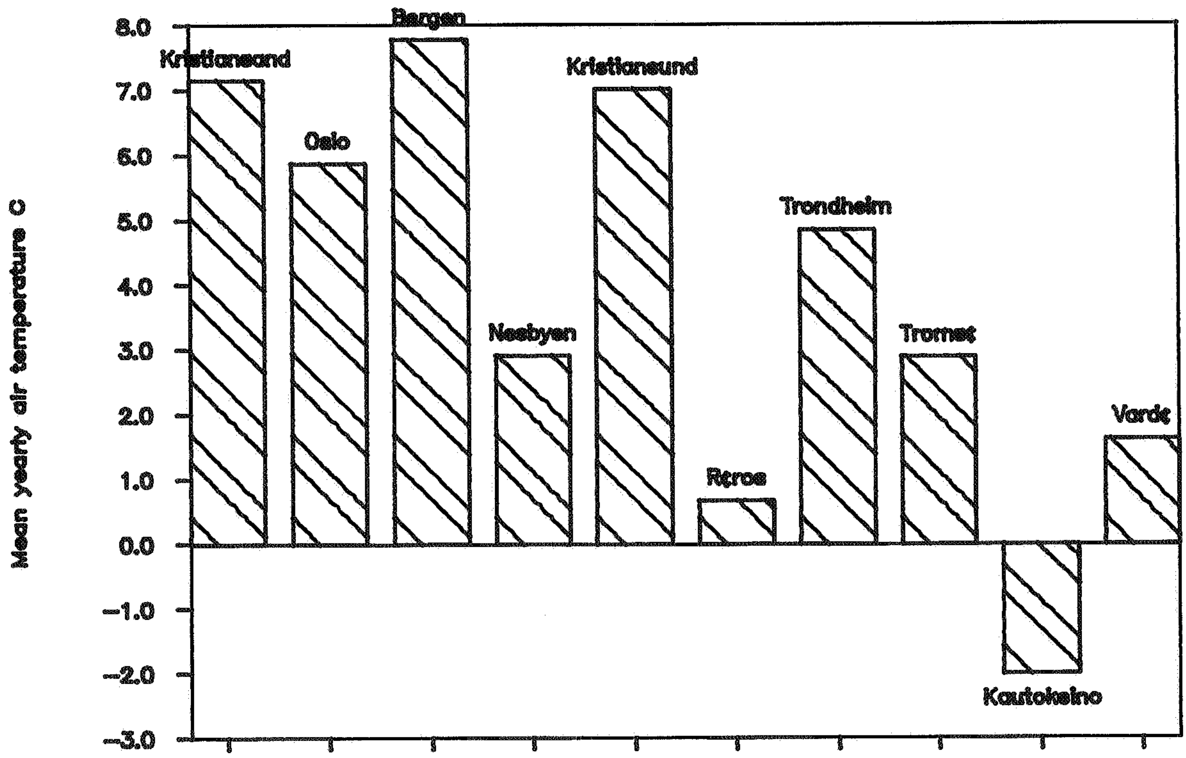

Figure 4. Yearly mean air temperature (C) for towns in Norway

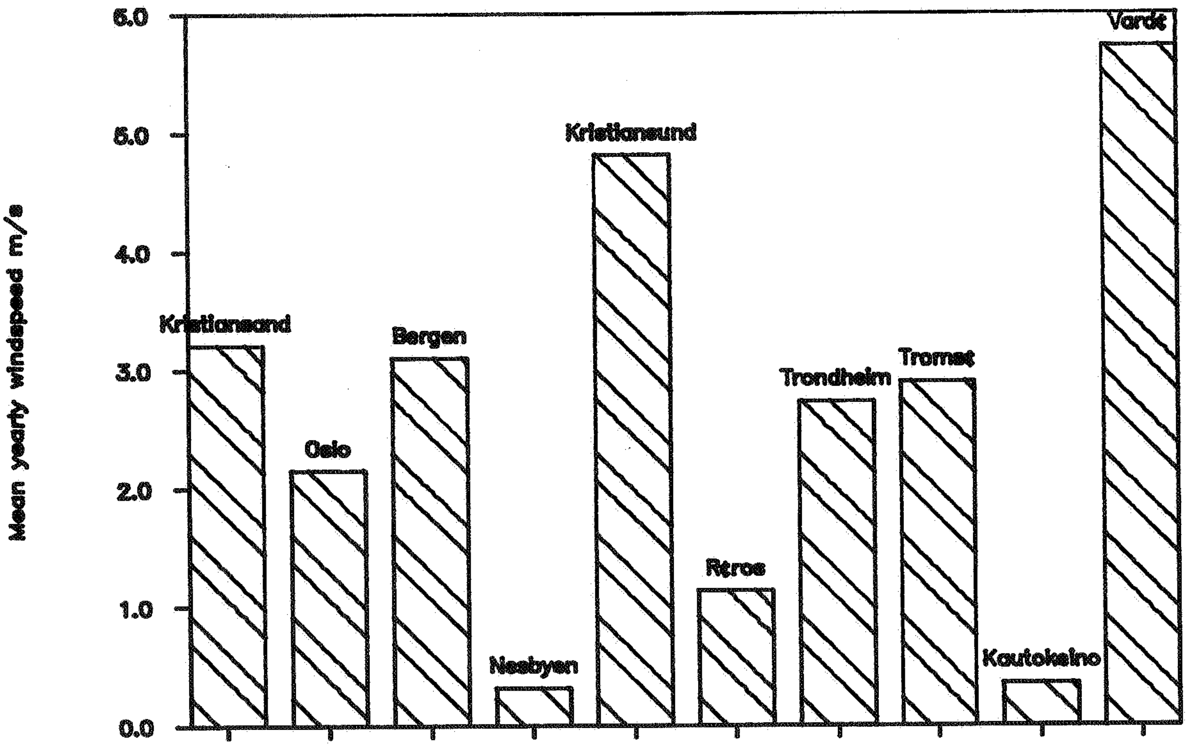

Figure 5. Yearly mean wind speed (m/s) for towns in Norway

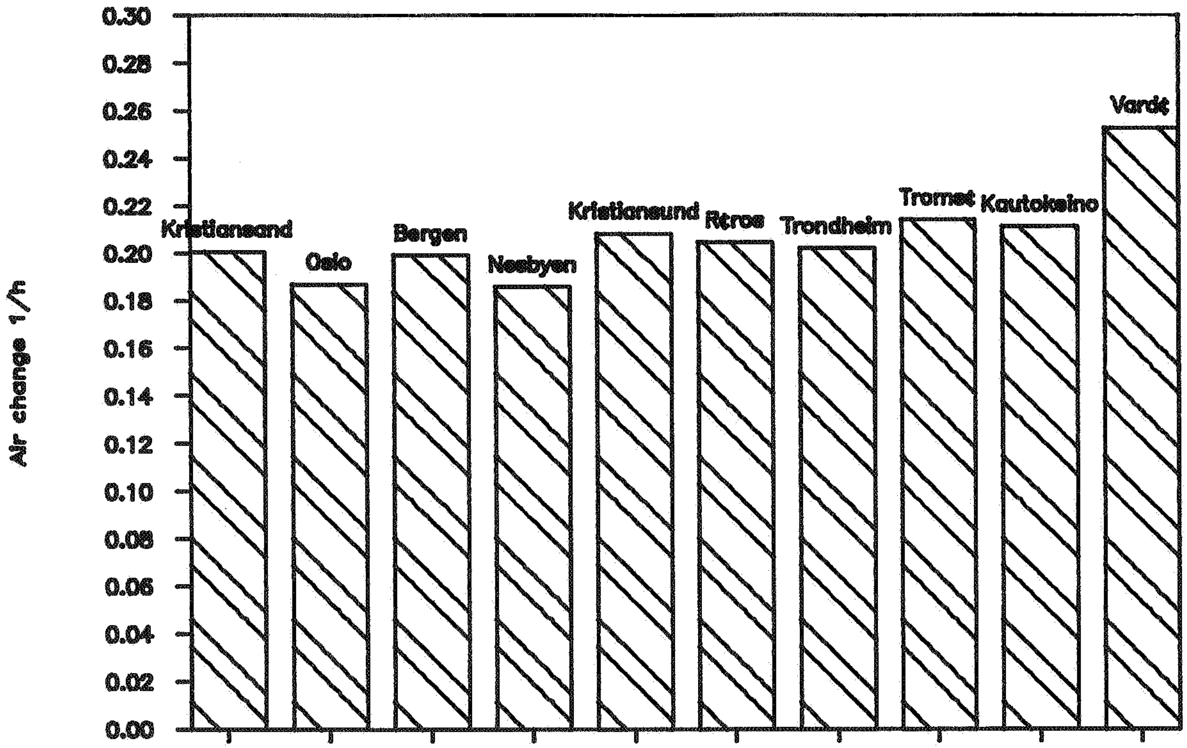

Figure 6. Yearly mean infiltration air change (1/h) for towns in Norway

hour and the standard deviation was 1,5. For the simulation in this paper it was tested if the values were normally distributed. They were. The simulation could then be made with normally distributed values.

6. SIMULATION

The simulation is done by using the ELA model and for some of the parameters used random generated values. The following parameters were each expected to have a normal distribution. The mean values and the standard deviations is given.

1. Indoor temperature
   Mean value 21 C
   Standard deviation 1,5 C
2. Air change at 50 Pa pressurization
   based on measurements
   Mean value 4,7 changes per hour
   Standard deviation 1,5 changes per hour
3. Leakage part in the ceiling
   Mean value 0,38
   Standard deviation 0,05
4. Leakage part in the floor
   Mean value 0,16
   Standard deviation 0,03
5. Shielding factor
   Mean value 0,28
   Standard deviation 0,03
6. Extra building height
   Mean value 1 m
   Standard deviation 0,5 m

Most of the values were selected after discussions with other researchers at the institute. We use the spreadsheet model for the case with the 2 floor building in Oslo and calculations on monthly climate values.
To make one calculation we need 6 random generated numbers between 0 and 1. One random number for each parameter. Note that we have assumed that the 6 parameters are independent of each other. If that is not the

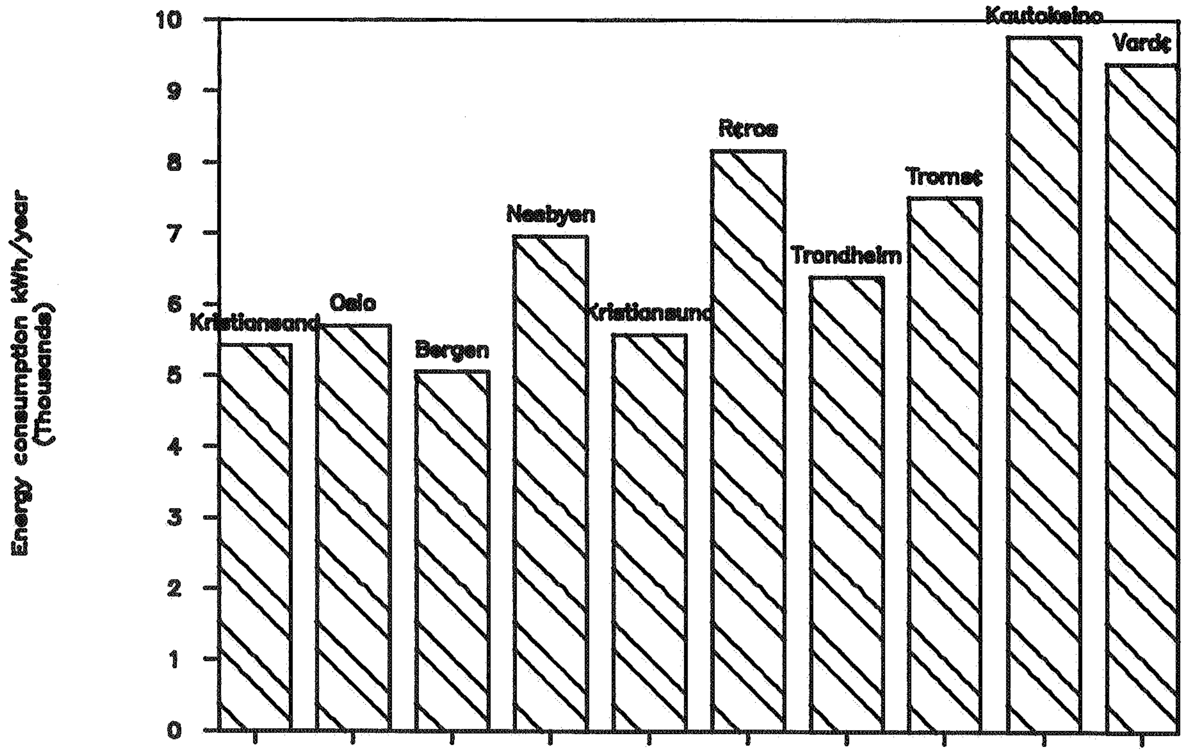

Figure 7. Yearly energy consumption (kWh) for infiltration air for towns in Norway

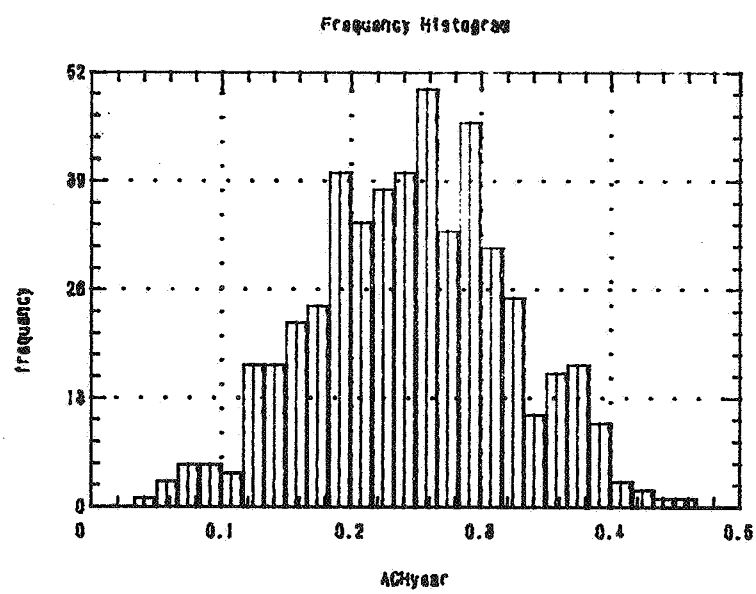

Figure 8. Histogram for 500 simulations of yearly mean air infiltration (l/h)

case, the dependence must be given. Each random number is then transformed to generate normal distribution with the given mean value and standard deviations. If we make many calculations then we will be sure to get parametric values that will follow a normal distribution. In this case we have made 500 simulations. Figure 8 gives a frequency histogram for the mean yearly air change. The mean value is 0,24 and 10% is below 0,13 and 10% is above 0,33. Figure 9 is a normal probability plot of the values from figure 8. As the values follow a straight line, they are normally distributed. A small deviation in the lower part is probably caused by a few cases being taken away. The results can also be given as a cumulative distribution curve, where it easyer to find the number of cases above or below a certain value.

Figure 10 gives the frequency histogram for the energy consumption. The mean value is 7530 kWh/year and 10% is below 3600 kWh and 10% is above 10000kWh. The results show that measurements of energy consumptions typically will give from 3600 to 10000 kWh/year.

The results of the simulation can be used to find the most important parameters. In this case it is the air change at 50 Pa pressurization.

Figure 11 shows the regression line and the points for yearly air change in dependence of the 50 Pa value. The correlation described by the R^2 is 0,98 or very good. A prediction of the mean yearly air change based on the measured 50 Pa air change will therefore be very good. In figure 12 is given the residuals in the regression. The residuals is seen to increase at higher air change but not alarming.

Figure 13 gives the regression between the the yearly energy consumption and at 50 Pa air change. The variations is a little higher than the previous case but still a good prediction

Figure 14 gives a case with a very poor regression. In this case it is between the indoor air temperature and the mean yearly air change.

7. CONCLUSIONS

The statistical method with using random generated numbers is used for calculations of typical distributions in yearly infiltration air change and energy consumptions. The result is that from a knowledge of the 50 Pa leakage air change can we make good predictions of the yearly infiltration as most of the other parameters do not have high influence. These results are based on the simplified equivalent leakage model and will of course not take into account complicated cases with different wind distributions and

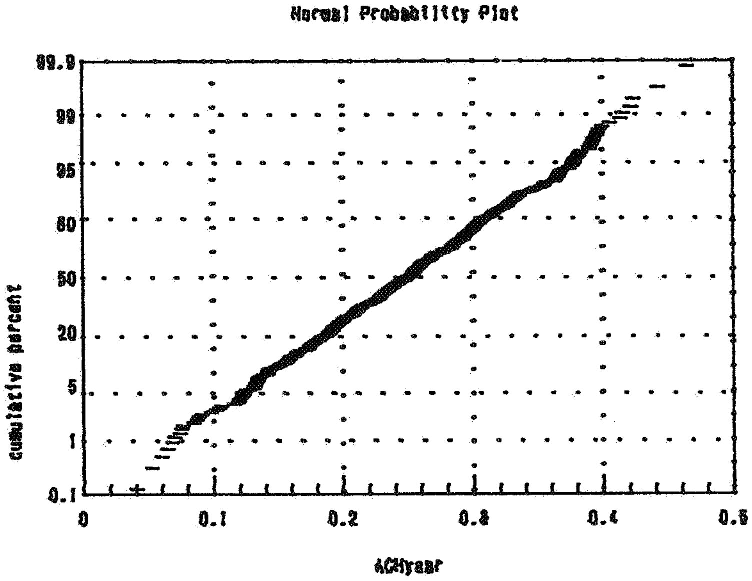

Figure 9. Probability plot for 500 simulations of yearly mean air infiltration (1/h)

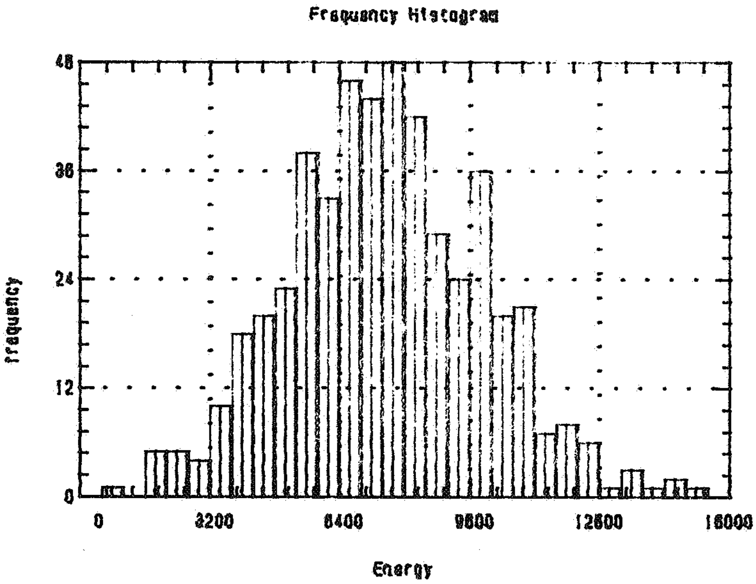

Figure 10. Histogram for 500 simulations of yearly energy consumption (kWh) for infiltration

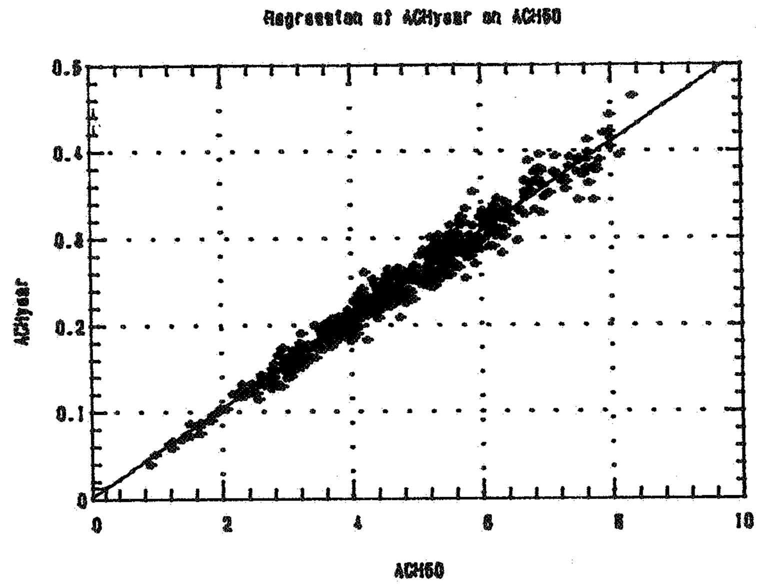

Figure 11. Regression for 500 simulations of air infiltration. Mean yearly air change versus 50 Pa pressurization air change. Regression line is plotted

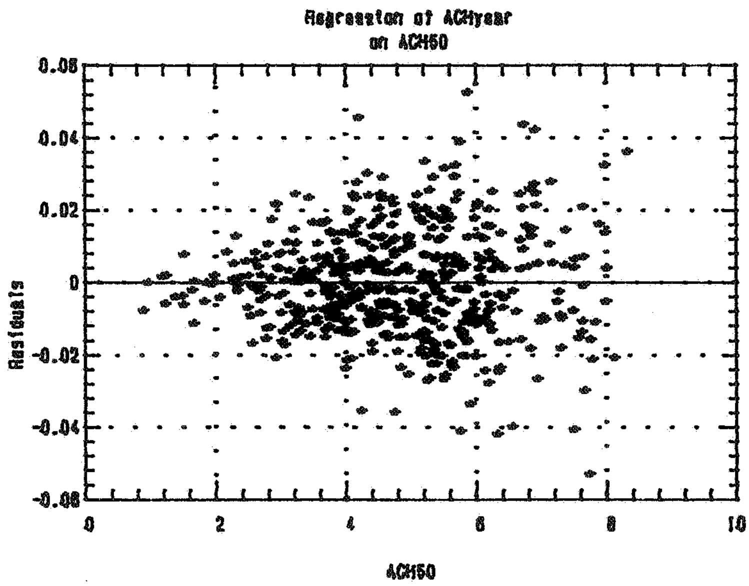

Figure 12. Residuals from the model in figure 11

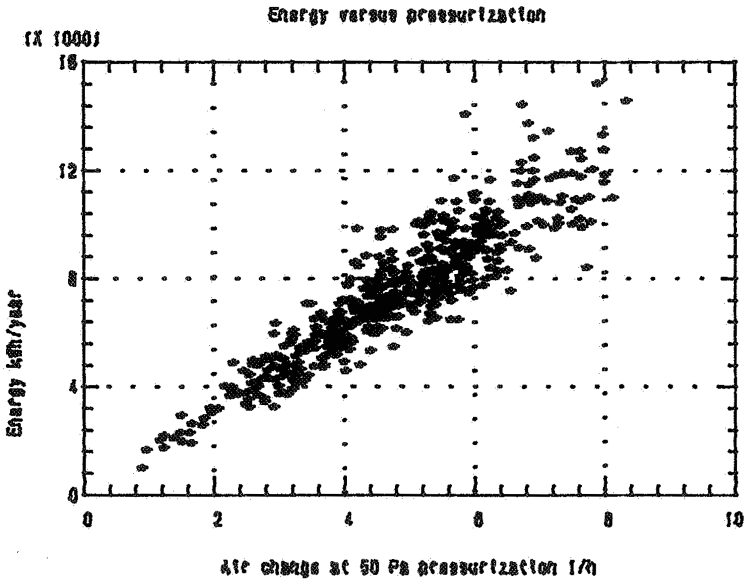

Figure 13. Regression for 500 simulations of air infiltration. Yearly energy consumption versus 50 Pa pressurization air change

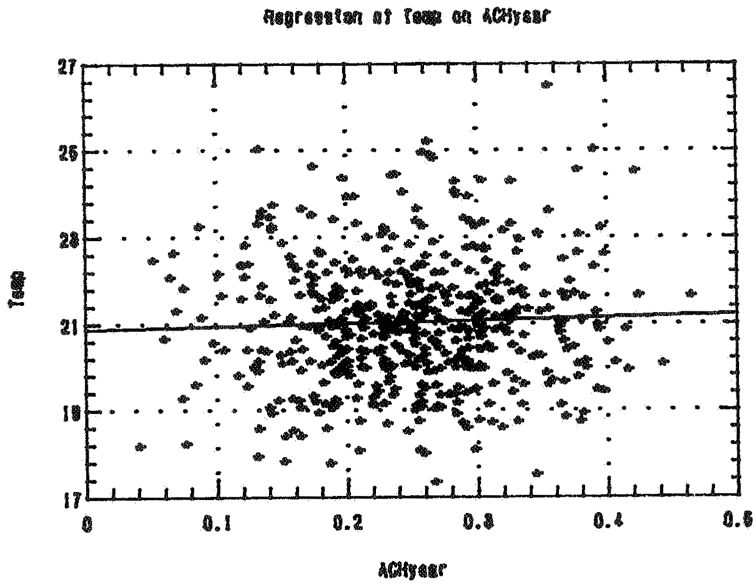

Figure 14. Regression for 500 simulations of air infiltration. Indoor temperature versus yearly mean air change

more rooms in the building. But the simulation method can be used on very complicated models to find out which parameters are important as it is highly unlikely that all values are in the extreme at the same time.

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