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Distributions of Expected Air Infiltration and Related Energy Use in Buildings Based on Statistical Methods with Independent or Correlated Parameters

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Synopsis

The equivalent leakage area algorithm is used to illustrate the use of statistical simulations to predict distributions of infiltration and energy loss for buildings. The important parameters in the model are: leakage at 50 Pa pressurisation, indoor and outdoor temperature, leakage in the ceiling and the floor, wind speed, building height and shielding class. Most of these parameters are not known accurately. In the statistical method we assumed for each a distribution based on measurement or good guess. To find the resultant distribution of infiltration we make 1000 simulations with random values from the distributions of the parameters. This has been done with normal, uniform and/or Weibull distributions. We find that the infiltration energy loss for a house in Oslo in average is 7025 kWh/year (case 1) and 10% is above 10500 kWh/year and 10% is below 4200 kWh/year. The results are also given as mean air change for infiltration. Results from five other simulations are described.
We normally assume that the parameters are uncorrelated, but it is easy to calculate what happen, if we have a positive or negative correlation. We found, that in this case made correlation between some parameters practically no difference in the distributions. The simulation method can be used on more complicated and correct models to find out how uncertain knowledge of parameters 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 large number of houses is it 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 original made for prediction of moisture condensation and drying in constructions. Later is has been used to predict variations in total energy loss for occupied buildings, where the occupant's behaviour can only be estimated. Variations in energy consumption from 50% above to 50% below the mean value are quite normal. The results are found in Nielsen 1987 [1] and in Dyrstad Pettersen [6].
In this paper we are only interested in the infiltration given as air change and energy loss 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 changes in building envelope. We use this model as it is widely known and gives realistic values without too much calculation time. The model has few parameters:

1. Leakage of structure – measured with 50 Pa pressurisation
2. Ratio of floor/ceiling leakage to wall leakage
3. Height of building
4. Internal/external temperature difference
5. Wind speed
6. Terrain class
7. Shielding class

In this paper will we not describe the model in detail. A full description is found in AIVC: Air Infiltration Calculation Techniques – An Applications Guide (1986)[2].

The model is written in the spreadsheet program EXCEL [3]. This makes it very easy to make parameter studies and statistical analysis and get the results in graphical form.

3. Simulation

3.1 Standard case

The simulation is done by using the ELA model with fixed values or distributions for the parameters. As the standard case we use a building in Oslo of 120 m2 with 2 floors and a leakage of 4.7 air changes per hour measured at 50 Pa over pressure. This is the mean measured leakage in small houses in Norway. The leakage in the ceiling is 0.38 of the total. The leakage in the floor is 0.16 of the total. The rest 0.46 is in the walls. The indoor temperature is 21 C. The flow exponent is 0.7. The terrain is urban. The shielding coefficient is 0.3 as for light local shielding with few obstructions.

We use a monthly calculation of infiltration's and use mean wind speed and temperature from Oslo. The result from the calculation is either the mean yearly air change or the yearly energy loss. The value is in both cases only for the infiltration not the total ventilation.

We use the model in EXCEL model for the cases. To make the simulation of the distributions we use the program Crystal Ball [4], that can generate selected distributions for selected cells in a spreadsheet. In this paper is used normal distributions, uniform distributions and Weibull distributions. The program uses the hyper–cube method that is a special Monte–Carlo method to find the random values in the selected distributions. The number of calculations can be selected. To get good results we need at least 500 calculations with random parameter values. In this and all other cases we used 1000 calculations. We assume that the parameters are independent of each other (no correlation).

Parameter	Case 1	Case 2	Case 3	Case 4	Case 5
Distri. Indoor Temp.	Normal mean 21 std.dev. 1.5	Normal mean 21 std.dev. 1.5	Normal mean 21 std.dev. 1.5	Normal mean 21 std.dev. 1.5	Normal mean 21 std.dev. 1.5
Distri. Air Ch. 50 Pa	Normal mean 4.7 std.dev.1.5	Normal mean 4.7 std.dev.1.5	Weibull loca. 4.7 scale 4.7 shape 2	Weibull loca. 4.7 scale 4.7 shape 2	Normal mean 4.7 std.dev.0.3
Distri. Leak. ceiling	Normal mean 0.38 std.dev. 0.05	Uniform min. 0.2 max. 0.5	Uniform min. 0.2 max. 0.5	Normal mean 0.38 std.dev. 0.05	Uniform min. 0.2 max. 0.5
Distri. Leak. floor	Normal mean 0.16 std.dev. 0.03	Uniform min. 0.05 max. 0.25	Uniform min. 0.05 max. 0.25	Normal mean 0.16 std.dev. 0.03	Uniform min. 0.05 max. 0.25
Distri. Shielding C	Normal mean 0.28 std.dev. 0.03	Uniform min. 0.20 max. 0.35	Uniform min. 0.20 max. 0.35	Normal mean 0.28 std.dev. 0.03	Uniform min. 0.20 max. 0.35
Distri. Extra height	Normal mean 1.0 std.dev. 0.5	Uniform Min. 0.0 Max 2.5	Uniform Min. 0.0 Max 2.5	Normal mean 1.0 std.dev. 0.5	Uniform Min. 0.0 Max 2.5
Infiltration	kWh/year	kWh/year	kWh/year	kWh/year	kWh/year
10%	4200	4050	3875	3825	5825
30%	5825	5775	5775	5750	6600
50%	7025	7175	7425	7400	7175
70%	8500	8745	9475	9400	7825
90%	10500	11050	12800	12675	8900
Mean Air change	hours-1	hours-1	hours-1	hours-1	hours-1
10%	0.14	0.13	0.13	0.13	0.20
30%	0.20	0.19	0.19	0.19	0.22
50%	0.23	0.24	0.25	0.24	0.24
70%	0.27	0.28	0.31	0.30	0.25
90%	0.34	0.35	0.42	0.41	0.28

Table 1. Selected parameters and their distributions for 5 cases. The results from the ELA–method calculation of infiltration in kWh/year and mean air change is given for some per–centiles.

For case 1 is the mean infiltration energy loss 7025 kWh /year. But 10% will have an energy loss above 10500 kWh/year and 10% will have an energy loss less than 4200 kWh/year. In figure 1 is found a frequency distribution and a cumulative curve for the energy loss by infiltration. The results could also be given as a mean air change in the building. The mean value is 0.23 air changes pr hour. But 10% will have an air change above 0.34 and they could save energy by tightening. For the 10% below 0.14 there is a risk of indoor climate problems if the occupants don't open windows or use a ventilation system. In figure 2 is found a frequency distribution and a cumulative curve for the air change. Case 1 is the same that was calculated in Nielsen 1987 [5] with 500 values. The results are similar.

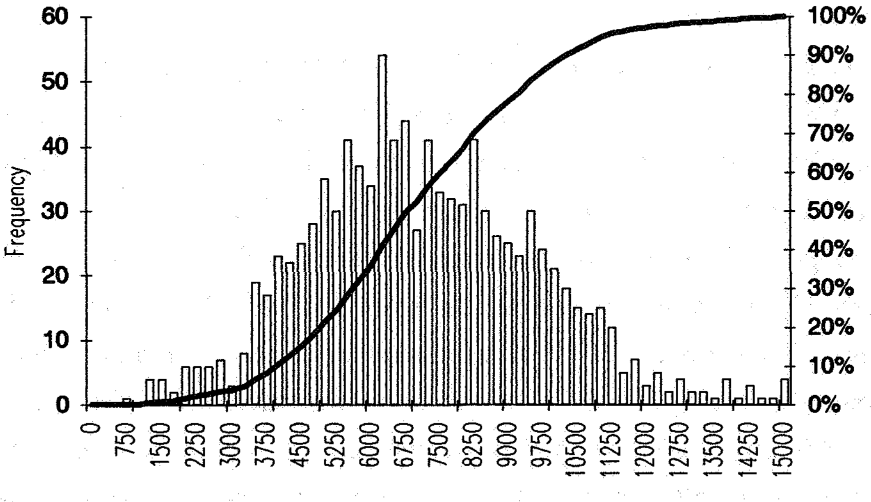

Figure 1. Histogram for energy loss (kWh/year) for a house in Oslo with parameter distributions defined as case 1 in table 1. The histogram gives both the frequency count in bins with bandwidth of 250 and the cumulative curve.

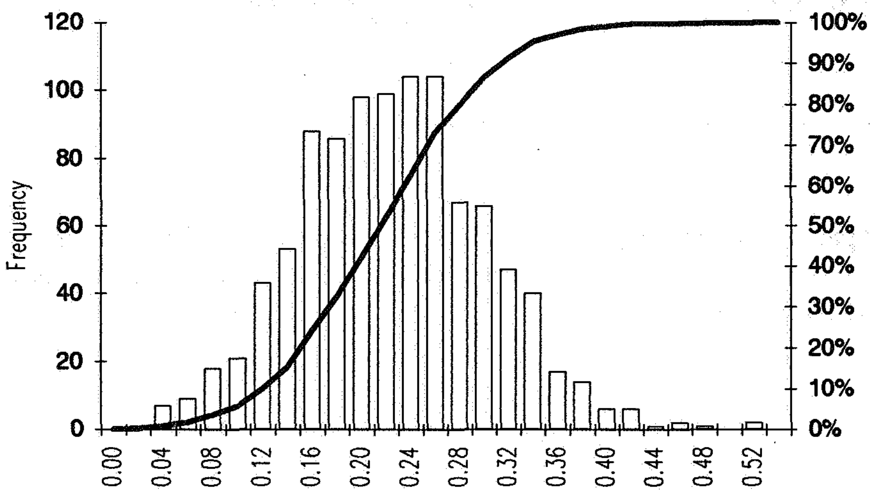

Figure 2. Histogram for mean infiltration air change pr hour for a house in Oslo with parameter distributions defined as case 1 in table 1.

In case 1 we have used normal distributions for all the parameters. In case 2 have we used a uniform distribution (same probability of all values between minimum and maximum) for the leakage in the ceiling and floor, shielding factor C and the extra height. Use of a uniform distribution can be a good guess if we don't know very much of the parameters. The calculated distributions of the infiltration and mean air change is found in table 1 as case 2. Comparing the values between case 1 (normal) and 2 (uniform) shows, that the variations are smaller for normal distribution. That is expected as a normal distribution has most values near the average value.

3.2 Correlated or uncorrelated values

In the simulation in case 1 were all the parameters independent. We expect, that it is a good guess for the indoor temperature and the other parameters. For the measured air change at 50 Pa pressurisation it must be expected that there is a positive correlation with the leakage in the ceiling and the extra height. In both cases higher leakage and extra height will give a higher measured air change. In the model we have stated that the correlation factor between these parameters is 0.75. This is a strong correlation. In figure 3 is the leakage in the ceiling shown versus the measured air change at 50 Pa over pressure for correlated and uncorrelated values. Figure 4 compares the energy loss distributions in the two cases. The difference is very small. In this case is it not important if the parameters are correlated or uncorrelated. This is not very surprising as the influence from the leakage and extra height is small. But in other models can the correlation's be very important. The change in correlation coefficient is done very easy in Crystal ball.

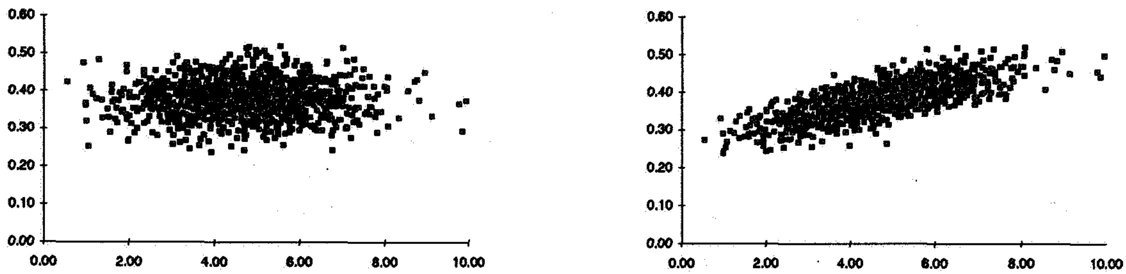

Figure 3. The leakage part in the ceiling (y–axis) against the air change at 50 Pa pressurisation (x–axis). The left plot is for uncorrelated values and the right is for correlated values with a correlation coefficient of 0.75.

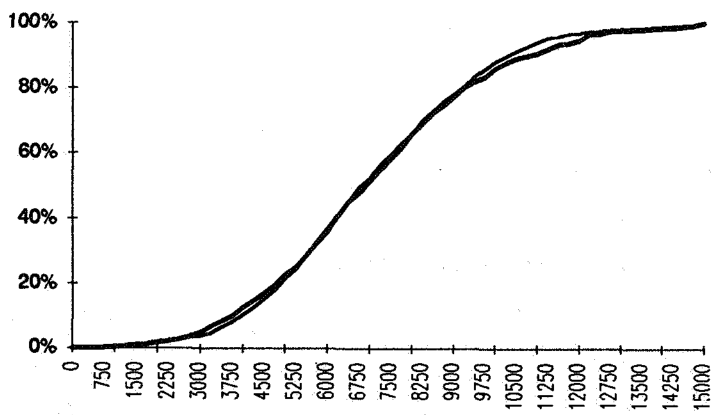

Figure 4. Cumulative distributions of energy loss for infiltration for a case with uncorrelated parameters (thin line) and for some parameters correlated (thick line).

3.3 Weibull distribution

In case 3 and 4 we have used a Weibull distribution for the air change at 50 Pa over pressure. The Weibull distribution is used for values that is always positive and has screwed distribution of the values, see figure 5. This distribution is for instance used for extreme values of river water flow, where high values come more often than in a normal distribution. This could also be the case for air change measurements. Case 3 is with most other parameter's uniform distributed and case 4 with these normal distributed as seen in table 1.

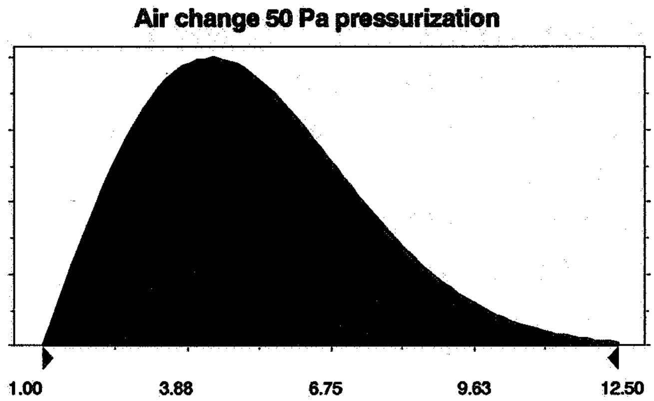

Figure 5. Weibull distribution for air change at 50 Pa pressurisation used in case 3 and 4.

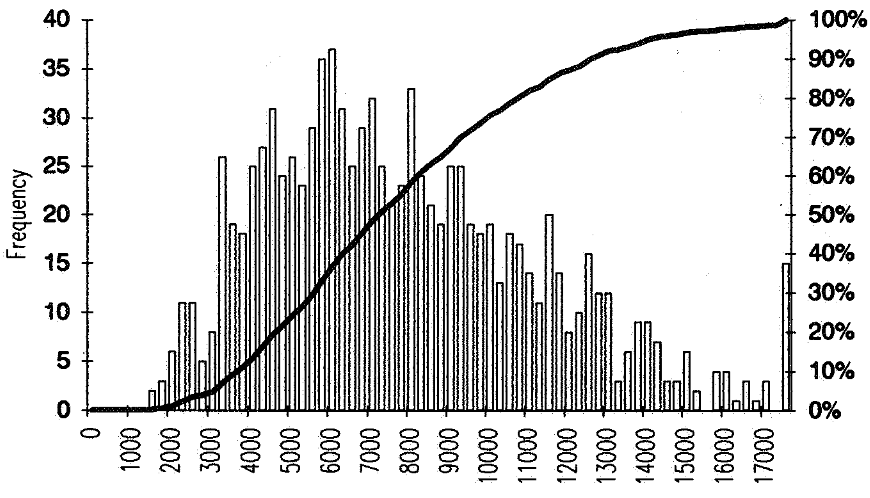

Figure 6. Histogram for energy loss (kWh/year) for a house in Oslo with parameter distributions defined in case 3 in table 1.

The calculated infiltration in kWh/year is found in figure 6. It is seen that the distribution has the same form as the Weibull distribution. This is a clear sign, that the measured air change at 50 Pa over pressure is the most important parameter in the model. Comparing case 3 and 4 with 2 and 1 it is seen, that the 10% with the highest energy loss has increased 2000 kWh/year. Figure 6 is histogram for the energy loss with case 3. Note that there is a column of 15 cases, where the energy consumption is above 17500 kWh. These are the extremes – the highest value is 25600 kWh.

3.4 Measured air change at 50 Pa over pressure

The statistical method can also be used to show the influence on measuring errors on a result. In case 5 we have measured the air change at 50 Pa for a house to 4.7 changes pr hour with a standard deviation of 0.3 changes pr hour. If the uncertainty for the rest of the parameters is as in case 2, we find an expected distribution of the energy loss for infiltration in figure 7. From the figure we can find the mean value of 7175 kWh, but we must expect variation from 5000 to 10000 kWh/year.

Regression shows a good correlation among 50 Pa pressurisation air change and the mean yearly value. A good prediction of the mean yearly air change can therefore be based on the pressurisation test without exact knowledge of other parameters.

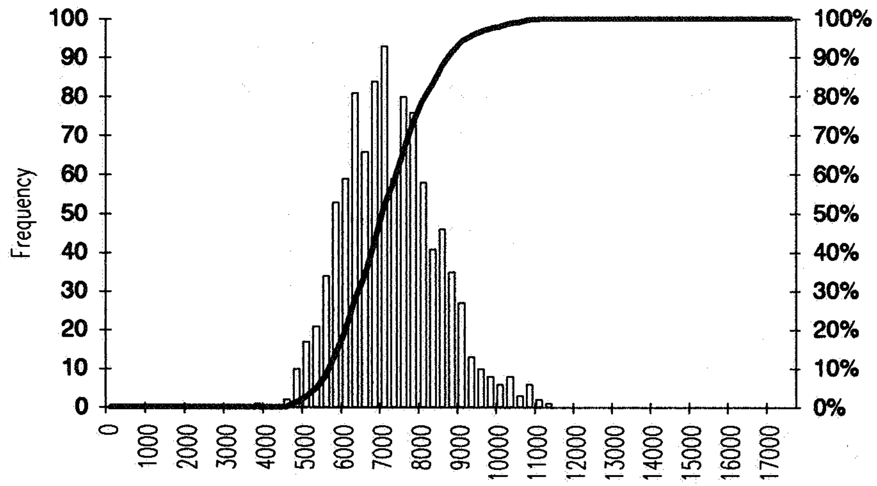

Figure 7. Histogram for energy loss (kWh/year) for a house in Oslo with parameter distributions defined in case 5 in table 1.

4. Conclusions

The statistical method with using random generated numbers has been used for calculations of typical distributions in yearly infiltration air change and energy losses. To find the resulting distribution we must know the distribution for the parameters in the model either from measurements or from good guesses. The resulting infiltration distribution depends mostly on the air change at 50 Pa over pressure. A good knowledge of the 50 Pa leakage air change can give good predictions. The knowledge of the distribution of energy losses for infiltration can be important to see the possibility to save energy (high infiltration) or the risk of indoor climate problems (low infiltration). In this case was it not very important if some of the parameters were correlated. This results is based on the equivalent leakage model and will of cause not take into account complicated cases with different wind distributions and more rooms in the building.

The simulation method is useful for other types of models either simplified or very complicated. It is possible to find expected distribution for measuring a large number of cases and it can be used for estimation of resulting errors in complicated measurements.

5. References

1. NIELSEN, A. F.
   Estimate of energy consumption in single family houses by using statistics. (In Norwegian) Norwegian Building Research Institute project report 20, 1987

2. LIDDAMENT, W.L.
   Air Infiltration. Calculation Techniques – An Applications Guide
   Air Infiltration and Ventilation Centre, 1986

3. EXCEL, version 4.0, Microsoft, US. 1992

4. Crystal Ball, version 2.0, Decisioneering, Denver, US., 1991

5. NIELSEN, A. F.
Use of statistics for predicting distributions of air infiltration,
8th AIVC conference: Ventilation technology research and applications,
Proceedings paper 9, page 9.0–9.13, 1987

6. DYRSTAD PETTERSEN, T.
Analysis of statistical variations in energy consumption in dwellings
Paper for 3rd. Nordic symposium in building Physics,
Copenhagen September 1993