Modeling of ventilation rates in bedrooms based on building characteristics and occupant behavior

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1 Introduction

Ventilation is a key parameter in an attempt to predict concentrations of pollutants when assessing exposure or health effects indoors. Measurements of air change rates (ACR) can be time-consuming and costly. Estimation of ACR from information obtained from questionnaires or interviews would be desirable. The number and quality of earlier multivariate regression models predicting ACR in residential buildings is surprisingly limited. Øie et al. (1998) described a model based on three significant variables collected for 344 homes in Norway (R^2=0.06). Wilson et al. (1996) based a model on measurements in ~900 homes in California (model R^2=0.3). In both studies home volume was the strongest predictor of ventilation. This paper reports the associations between ACR in 500 Danish homes and the corresponding building characteristics and occupant habits.

2 Materials/Methods

The concentration of carbon dioxide in the bedrooms of 500 children in Denmark was continuously measured over an average of 2.5 days (Carbocap® CO_2 monitors connected to HOBO loggers). The total ventilation rates in the rooms during the nights when the children were sleeping in the room were calculated using a single-zone mass balance for CO_2 (ASTM, 2002). A thorough description of the measurements, ACR calculations and uncertainty is given in Bekö et al. (2010).

From the data available from the home inspection, interview and a questionnaire distributed to all families, we selected all variables that we believed might influence the ACR or serve as indicator of the ACR in the dwellings (variables related to the building and occupants, observations of parents/inspectors, parameters which impact the IEQ and thus may affect behavior leading indirectly to altered ACR). Multiple linear, stepwise forward and backward regression analyses were conducted to identify predictor variables with inclusion criteria of $p<0.2$. To identify the degree of effect each selected independent variable has on the total ACR, several linear regression models were constructed.

3 Results

The most significant variables influencing ventilation rates in the bedrooms were room volume (higher ACR in smaller rooms), number of people sleeping in the bedroom (higher ACR with more people), average window and door opening habits (higher ACR with more opening), sharing the bedroom with other family members (higher ACR in shared rooms), location of the measured bedroom (higher ACR above ground floor), year of construction (lowest ACR in buildings from early 1970s) and observed condensation on the bedroom window (less condensation at higher ACR).

The final best-fitting model (1: Main-Model) was based on all selected significant variables. In order to determine how well the variability in the air change rates could be explained by variables exclusively related to building characteristics, we constructed a partial model (2: Model-Building) from the building related variables used in the Main-Model. A similar partial model (3: Model-Behavior) was built from the Main-Model with variables related to occupant behavior. Table 1 lists the significant variables that were used for the generation of the three models. Our Main-Model (1, n=426) was significantly stronger than the earlier models predicting ACR in residential buildings. It

explained 46% of the variability in the ACR. Models built only from variables related to building characteristics (2, n=464) or occupant behavior (3, n=466) explained 9% and 30% of the variation, respectively.

Table 1. Summary of variables included in the various regression models

Model No.	**1**	**2**	**3**
Building-related parameters:			
Volume of the measured room	X	X	
Size of dwelling	X	X	
Location of measured room	X	X	
Ventilation in the home	X	X	
Vicinity to road	X	X	
Constr. year of the dwelling	X	X	
Behavior-related parameters:			
No. of people sleeping in the bedroom	X		X
Sharing the bedroom	X		X
Average door opening during night	X		X
Average window opening during night	X		X
Other parameters:			
Condensation on the window (winter)	X		
Outdoor temperature	X		

Figure 1 shows the relationship between the measured values and values predicted with the Main-Model. The y = x reference line (dashed) reveals that our models tend to overestimate the lower air change rates, while they underestimate the air change rate when it is high in reality.

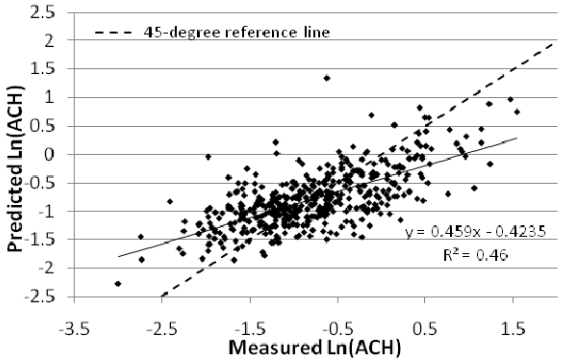

Figure 1. Natural logarithm of the measured air change rates plotted against their predicted counterparts for the Main-Model.

Another limitation of the model is driven by the possible imperfections in our measurements of ACR. The ACR was estimated to be between 0% and 51% lower than the true *total* ACR (airflows both from outdoors and from adjacent spaces). It was, however, less than 25% higher than the true *outside* ACR. The relative error depends on the position of the room in relation to the adjacent rooms, occupancy in the adjacent room, air change rate and room-to-room airflows (Bekö et al. 2010).

The presented models are far from perfect. However, the models can provide an estimate of the magnitude of the average air change rate in a larger group of homes without the need for time-consuming measurements (Table 2).

Table 2. Measured and predicted ACR (h^{-1}).

	Measured ACR in all homes (n=500)	**Measured ACR in homes in Model 1 (n=426)**	**Predicted ACR from Model 1 (n=426)**
Mean (SD)	0.62(0.58)	0.62(0.59)	0.53(0.37)
Median	0.43	0.43	0.43
Geom. mean	0.46	0.46	0.46
Min.	0.05	0.05	0.10
Max.	4.72	4.72	3.87

4 Conclusions

This study demonstrates that it is feasible to build a model, which may be useful when an estimate of the ACR in a dwelling is required. While our best-fitting model provides a good indication of the average ACR in a large study population, its coefficient of determination (R^2=0.46) indicates that the model might not be as successful in estimating the ACR in individual rooms or residences. The results support earlier findings that occupant behavior, especially window opening habits, may influence the total ACR of spaces more considerably than building characteristics.

5 References

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