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A Hidden Markov-switching Building Occupancy Model

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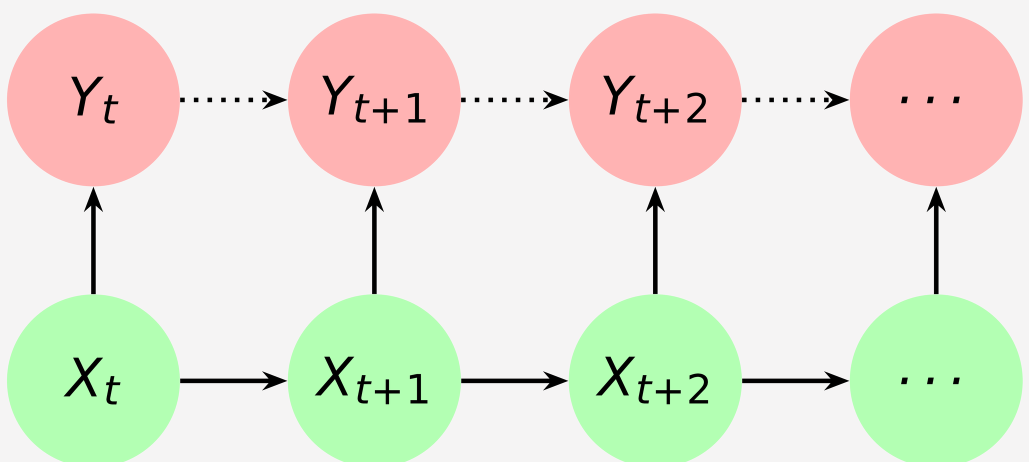
1 Introduction

Heating and ventilation strategies in buildings can be improved significantly if information about the current presence and activity status of the occupants is taken into account. Therefore, there is a high demand for inexpensive sensor-based methods to detect the occupancy status. This study suggests a new occupancy model based on the use of CO_2 trajectories, trained on measurements in class rooms of two schools in Denmark. A Hidden Markov-switching Model with autoregressive observations using a normal state dependent distribution was employed to identify the occupancy states.

2 Methods

The model consists of an underlying inhomogeneous Markov chain of states X_t and a series of observations $Y_t = CO_2$. For each state i that X_t takes at time t, Y_t follows a normal distribution. Furthermore, the observations follow a auto-regeressive process.



The model can be expressed by

$$p\,(X_t = i \mid X_{t-1} = j) \sim (\Gamma_t)_{i,j}$$

$$Y_t = c_i + \phi_i Y_{t-1} + \varepsilon_{i,t}$$

where Γ_t is a transition probability matrix, c_i are the state means, ϕ_i the auto-regressive parameters and $\varepsilon_{i,t} \sim N(0, \sigma_i^2)$. This modelling approach is a generalization both of Hidden Markov Models and Autoregressive models. In contrast to ordinary Hidden Markov Models, the suggested method takes into account that the current CO_2 level is not only dependent on the occupancy status but also heavily dependent on its own past values.

3 Results

Table 1 shows Akaike's information criterion (AIC) and the Bayesian information criterion (BIC) for different numbers of states in the model. One can see that both criteria are lowest for $m = 5$ states. The table also displays the number of parameters which is $m^2 + 6m$.

Table 1: Akaike's information criterion (AIC) and Bayesian information criterion

states	parameters	AIC	BIC
2	16	-19187	-19080
3	27	-20326	-20146
4	40	-20771	-20503
5	55	-21392	-21023

Figure 1 shows a global decoding, i.e. the most likely sequence of states for the given data, for a period of three weeks and one week, respectively. The states are represented by different colours as well as by the grey step function below the CO_2 curve.

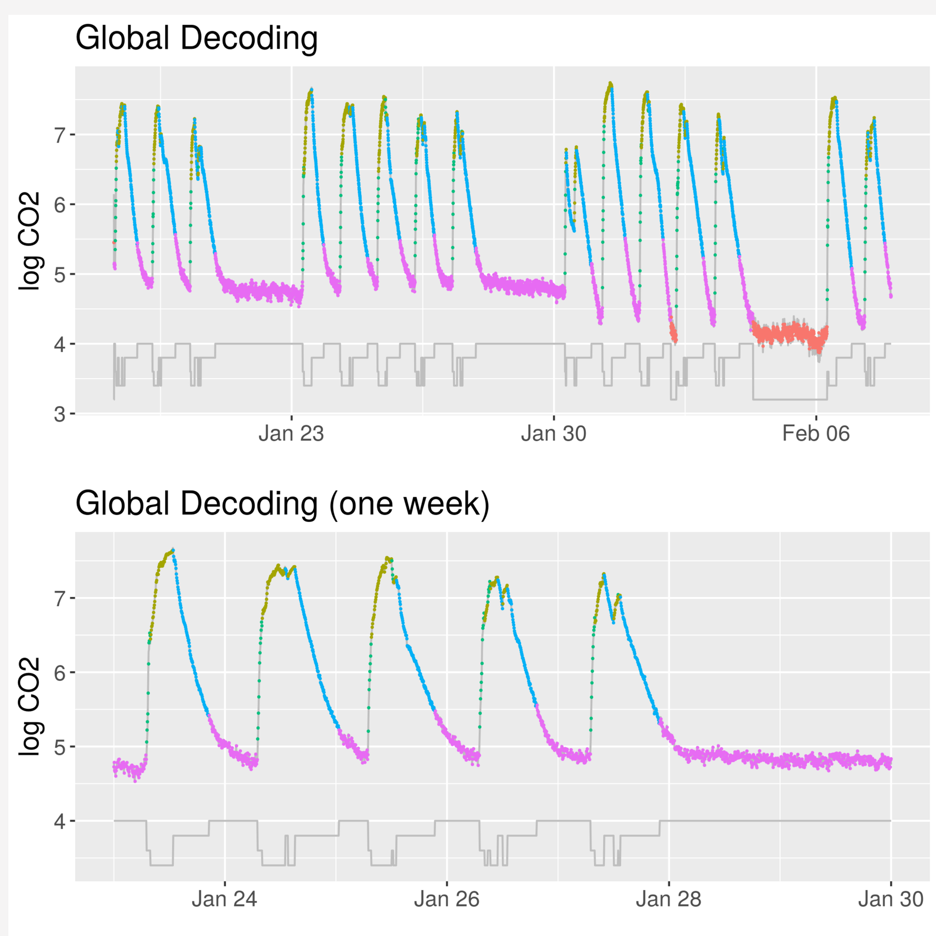


Figure 1: Global decoding for m=5 states

The analysis of residuals shows that the suggested method inherits the dynamics of the CO_2 curves much better than an ordinary Hidden Markov Model. Figure 2 shows that the residuals are fairly mutually independent and normally distributed. This indicates that the model describes sufficiently the variation in the data.

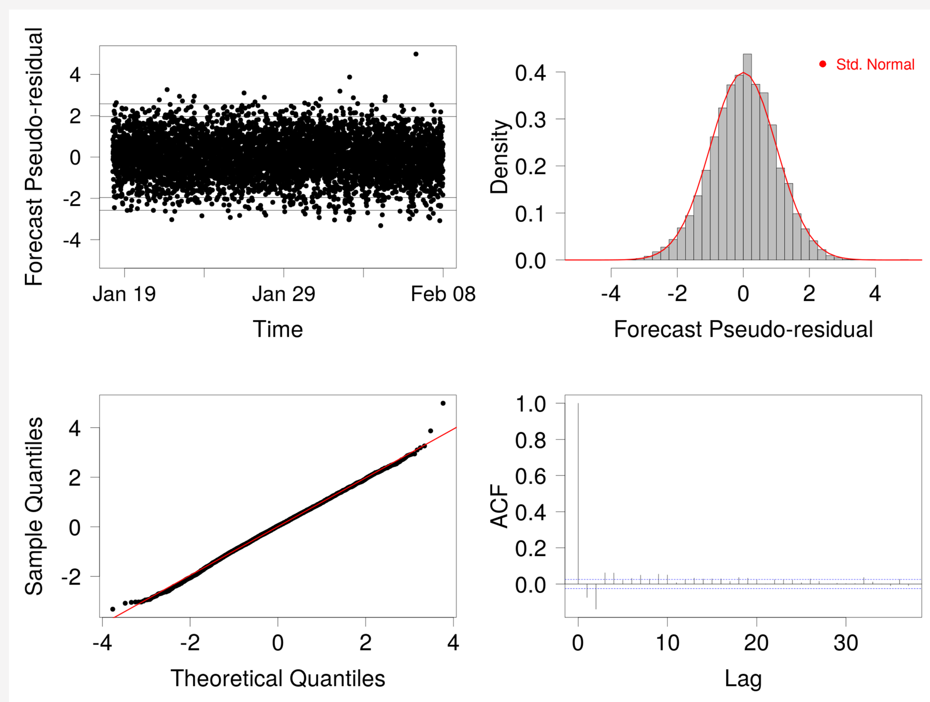


Figure 2: Residual analysis

Figure 3 displays the histogram of the data along with the five state densities of a 5-state (ordinary) Hidden Markov Model. The black line corresponds to the sum of the densities.

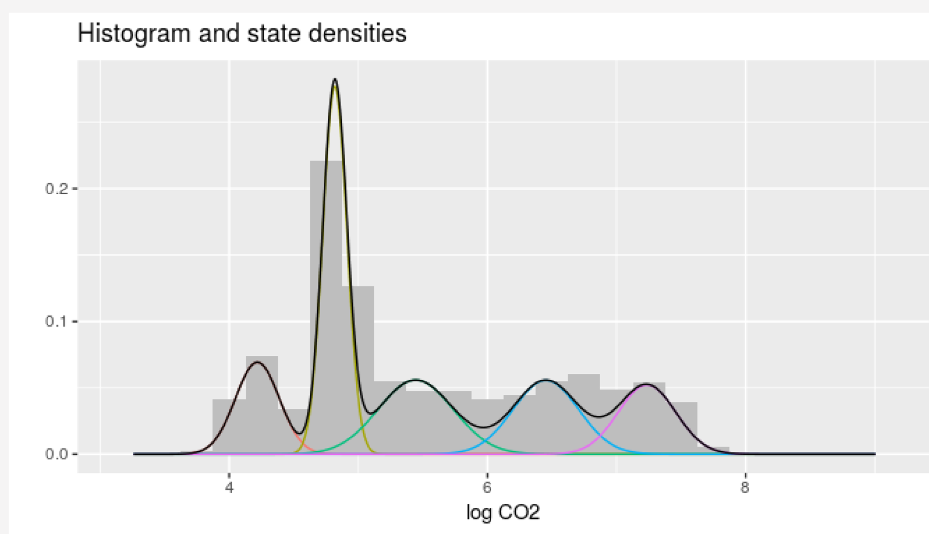


Figure 3: Histogram and the normal densities of the five states

4 Discussion

The auto-regressive part of the model accounts well for the high temporal dependency in a CO_2 curve. Therefore, the suggested model can be considered as a promising candidate for extracting information about the different states of building occupants' activity.