11.11 #4530

Moisture content of kitchen air in a multi-room residence

Yuguo Li

Dept. of Heating and Ventilation
Royal Institute of Technology
Stockholm, Sweden

Introduction

Moisture problem in residences can lead to the breakdown of building materials and increase the risk of mold growth. It can increase the heat flow through the walls and can also produces odours. Consequently moisture can create sick buildings and indoor air quality problems. For these reasons the moisture content of the air is an important subject to study.

The purposes of this work are two-fold. Firstly, a model has been developed to permit the prediction of moisture content versus time in a multi-room residence. The model is not taking into account absorption of moisture. Secondly, the moisture content versus time relationships for kitchen air during and after cooking time have been analysed as a function of the rate of ventilation and water vapour generation.

Characterisation of the moisture source

The characterisation of indoor pollution sources is one of the most difficult aspects of indoor air quality modelling. Generally, there are two main sources of water vapour in residences, firstly, cooking, laundering, bathing, breathing and perspiring. The second is due to the bare earth in a crawl space or basement and the moisture of the building materials, etc.

One problem is how to take into account condensation and re-evaporation from surfaces. Condensation on a surface occurs when the surface temeprature is below the air dew point. If the outdoor temperature is constant, and assuming steady state conditions, the surface temperature θ_s can be calculated as:

$$\theta_s = \theta_i - k/\alpha \cdot (\theta_i - \theta_o) \qquad (1)$$

where

θ_i = the indoor temperature
θ_o = the outdoor temperature
k = the thermal transmittance
α = the indoor surface convective heat transfer coefficient.

There are some important parameters which are not easy to be taking into account. Firstly, there is a difference between the k-value of the wall and the window. The k-value of the window is much higher than that of the wall, and therefore the window has a higher risk of condensation. Secondly, the heat resistance $(1/\alpha)$ between the air and the surface is influenced by different factors, for example, it is influenced by the air movement caused by the radiator, and the effect of a window curtain. This paper considers a constant k-value and α-value. The simplest representation of the sources and sinks was employed.

$$\text{Sources} + \text{sinks} = \beta \cdot A\,(C_w - C_i) + N_i \qquad (2)$$

Where

β = the mass transfer coefficient
A = the surface area of the solid surfaces
C_w = the effective moisture content on the surface of the wall
C_i = the indoor moisture content in room i
Ni = the water vapour generation rate in room i.

When driving potential $(C_w - C_i)$ is negative, which is the case for the surface temperature being lower than the air dew point, the walls act as sink of moisture, i.e. condensation. After condensation, the liquid water drops are adsorbed on to the wall's surface. When the driving potential becomes positive, re-evaporation may occur and then the wall may act as a net source of moisture.

The value of β is also difficult to define exactly. Here it has been calculated from Lewis's eqation, (when Pr=1, for the air, Pr ≈ 0.8).

$$\beta = \alpha / c_p \cdot \rho \qquad (3)$$

where

c_p = the specific heat J/kg°C
ρ = the density of the air kg/m³.

Multi-room prediction models

It is convenient to represent a building as a series of interconnected zones, each zone being able to exchange air with another zone. This was used in the modelling of air flow and ventilation in multi-room buildings, see Li et al (1990). Many such zones or rooms are characterised by nonuniform mixing. For example, in a room, stagnant parts may occur due to the temperature difference or to the design of the air distribution system. However, approximately, the room can be treated as perfectly mixed.

The fundamental equations of multi-room prediction models have been stated by various authors, see for example, Li et al (1990), where it also possible to examine the solution for an unsteady state case.

Example

To evaluate the influenece of tightness, ventilation and the moisture production rate on the moisture content in kitchen air vs. time, an example house has been used. This is the same as the one used in the indoor radon concentration calculations, see Li (1990), see Fig. 1, Fig. 2.

The interzonal air flow and infiltration were calculated from the multi-room model MIX by Li et al (1990).

A water generation profile for the kitchen was assumed as in Fig. 3. For the other rooms, the water vapour generation profile is constant and equal to that during the no-cooking time in the kitchen, that is 0.03 kg/h. This is the assumed value for a family of four. In the example, the weather for Norrköping, Sweden, 2nd February 1985 (shown in Fig. 4) is used for the calculation. It should be noted that wind directions are relative to the building axis.

The indoor air temperature is considered constant at 20^{o}C, the k-value of the wall is 1.56 $W/m^{2} \cdot {}^{o}C$, and the indoor surface convection heat transfer coefficient is 8.73 $W/m^{2} \cdot {}^{o}C$. The calculation of moist air properties followed the formula given in Peterson (1987). For convenience, the starting value of the moisture content is the same for all calculations.

Results and discussion

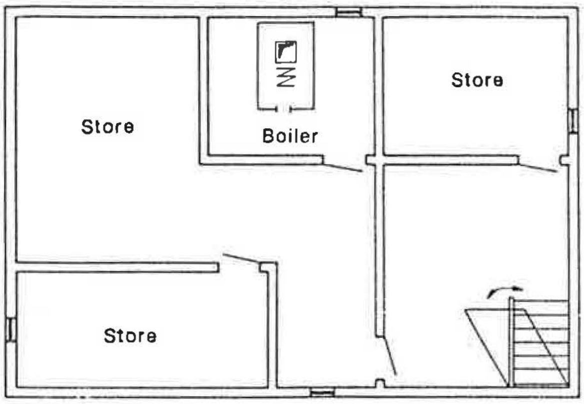

Fig. 1a. The floor plan (basement) of example building.

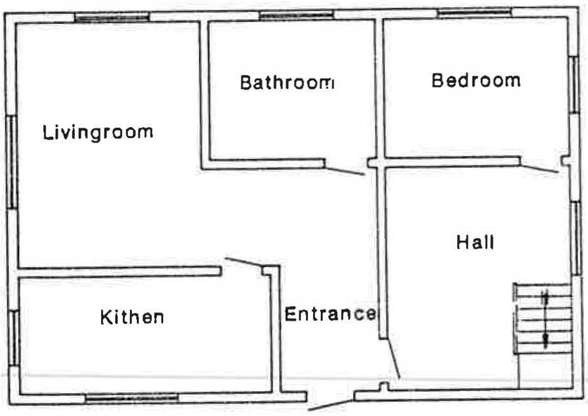

Fig. 1b. The floor plan (first floor) of example building.

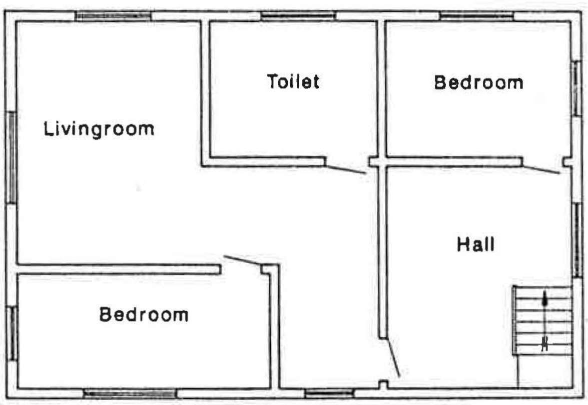

Fig. 1c. The floor plan (second floor) of example building.

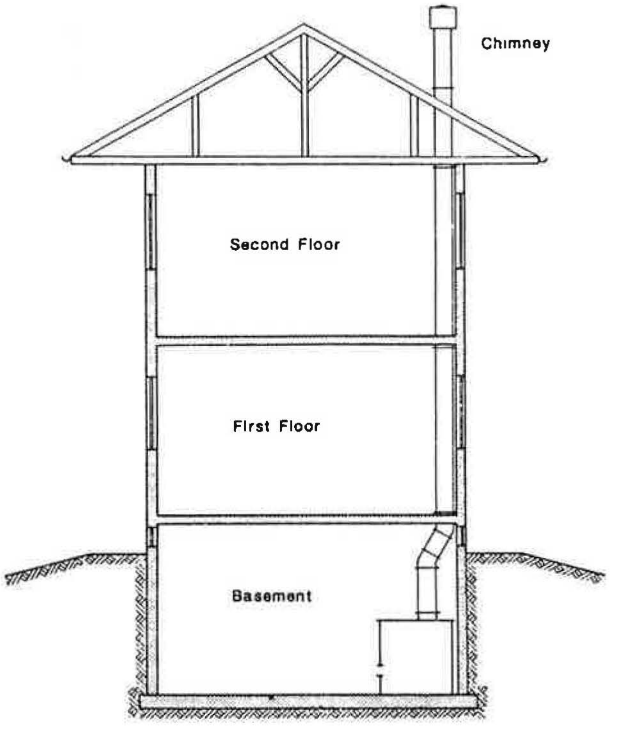

Fig. 2. The vertical section of the example building.

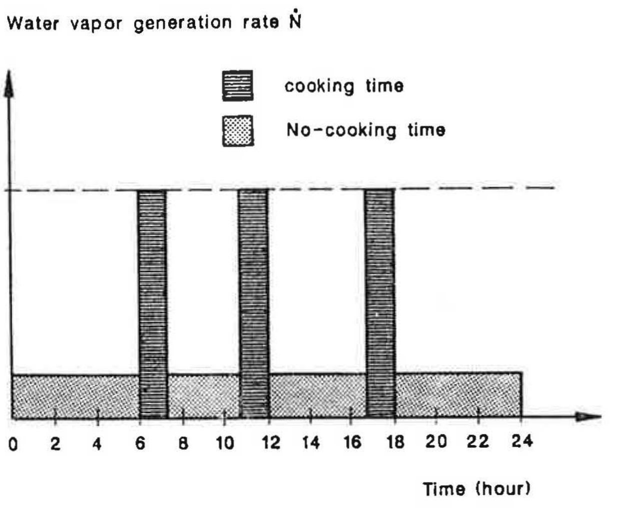

Fig. 3. Water vapour generation profile in the kitchen

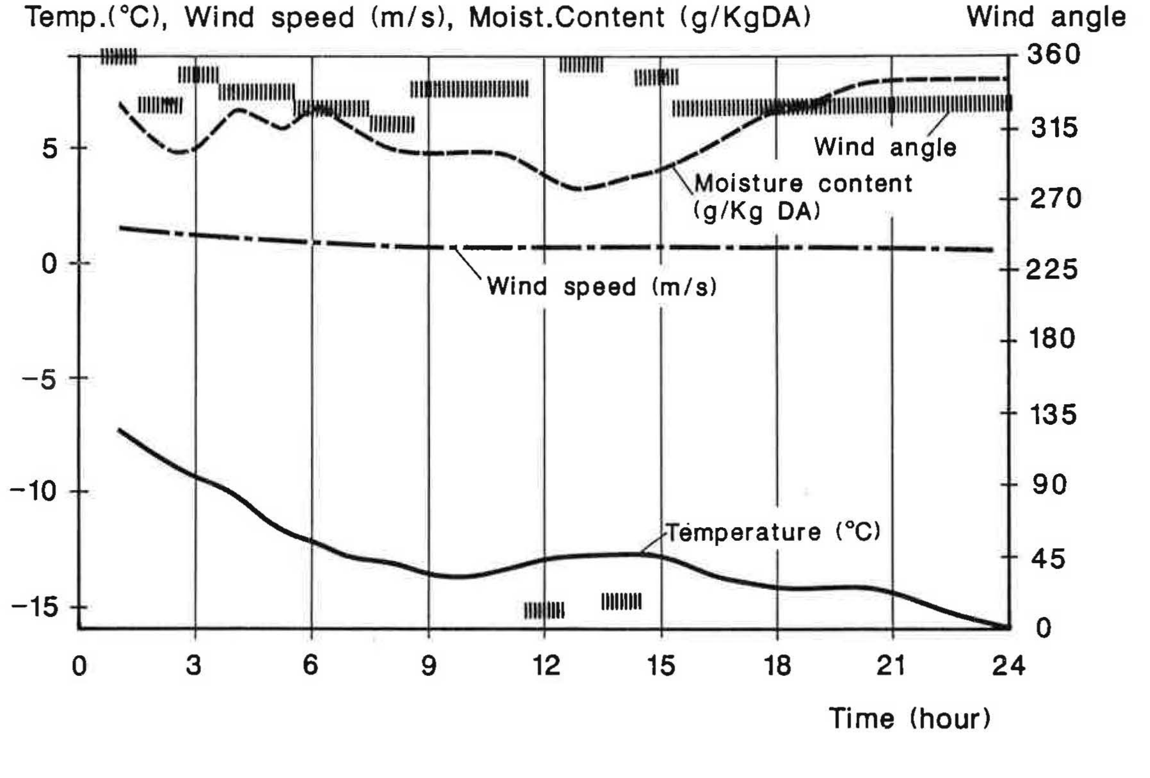

Fig. 4. The weather data for 2nd Feb. 1985 in Norrköping.

From equation (4), the indoor humidity is dependent on:

- o outdoor humidity
- o the ventilation flow rate
- o extra moisture production in the rooms.

The value of this theoretical model, is that is provides a means of predicting a variety of conditions which are otherwise difficult to predict by experiment. With respect to this point, the model provides a means of determining how sensitive the humidity is on each of the influencing parameters.

Figs. 5 to 10 show the relative humidity and the absolute humidity as a fuction of time; for various mechanical ventilation flow rates, k_t values and water production rates in the kitchen. As indicated, the moisture content in the kitchen rises sharply after the start of cooking. It is obvious that the higher the ventilation rate, the easier it is for the moisture to escape from the kitchen. For the case with natural ventilation only, the relative humidity during cooking time will be very high, and can reach a level of 60-70%. Respectively the tighter the building is, the higher the moisture content will be. Also the greater the water vapour production during cooking time, the higher the moisture content in the kitchen. It seems that with normal ventilation, there is no possibility to keep the moisture content constant in the kitchen.

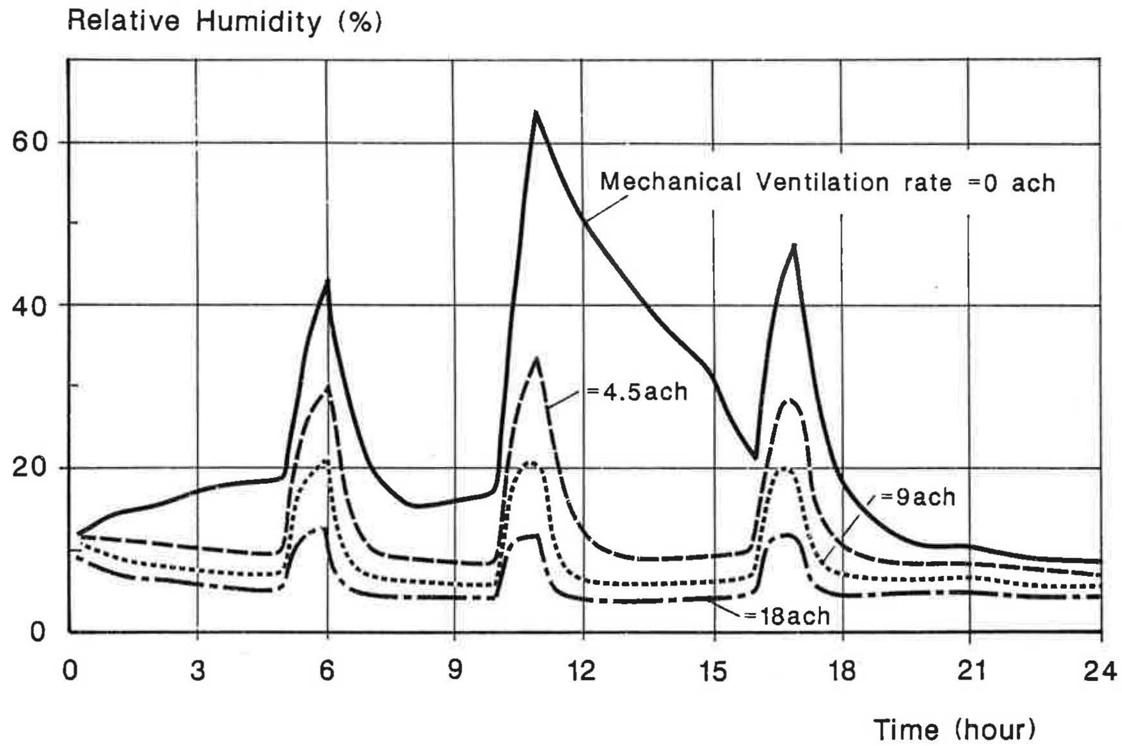

Fig. 5. Relative humidity of kitchen air vs. time for various mechanical ventilation system.

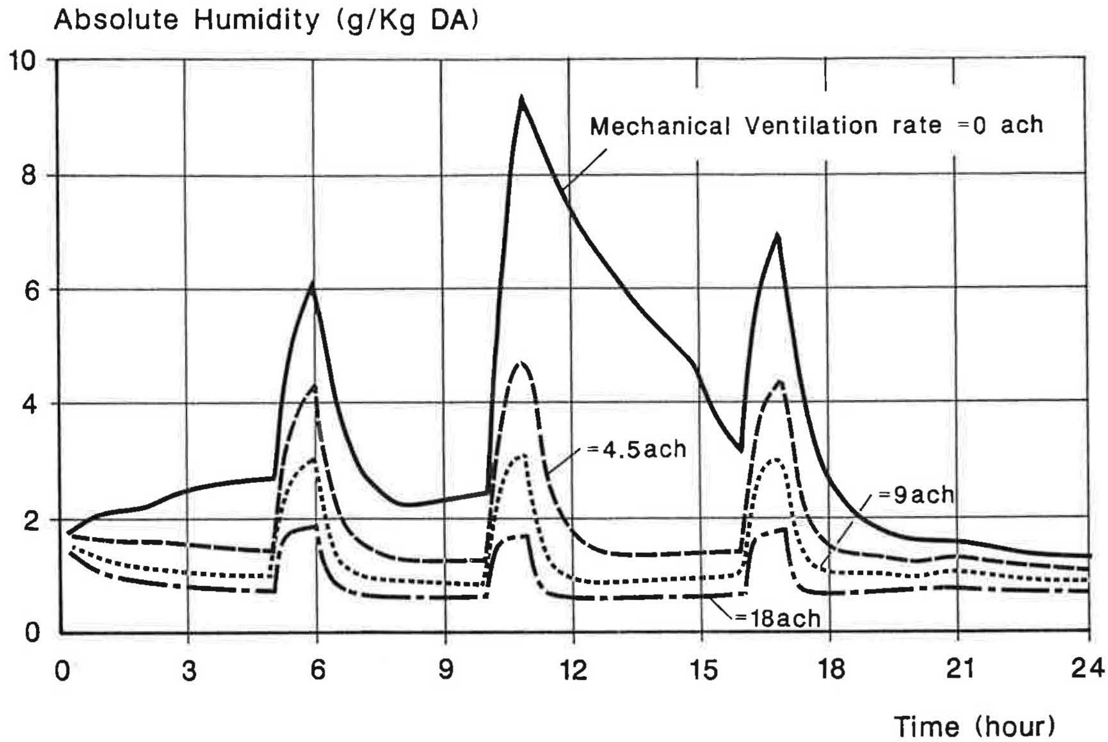

Fig. 6. Absolute humidity of kitchen air vs. time for various mechanical ventilation system.

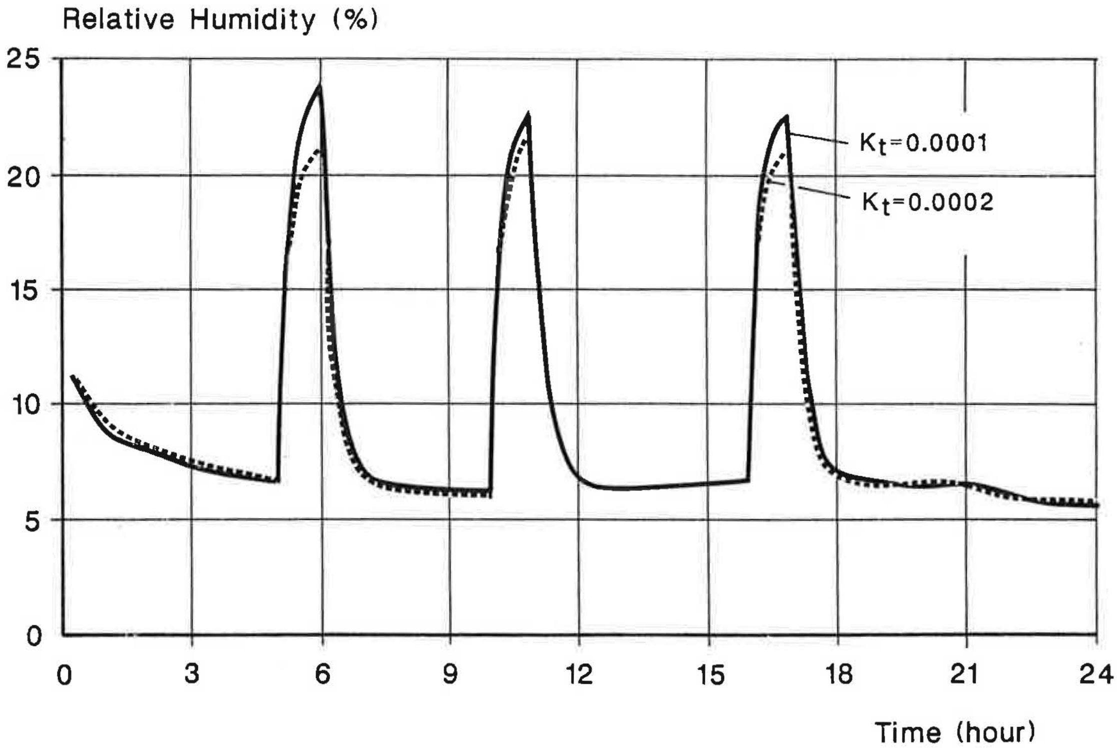

Fig. 7. Relative humidity of kitchen air vs. time for various k_t values.

The reason for the different levels of moisture content during different cooking periods, morning, noon, and evening, is the fluctuation of natural ventilation due to the changing climate conditions, especially the wind speed and direction. The humidity as high as 70% will cause condensation and mold growth in carpets, textiles, etc., especially if there is lee-effect from trees, other houses, and so on. The worst situation can occur in spring and autumn, if the mechanical ventilaiton have failed.

The influence of air leakage can be studied from Fig. 8. This influence could be small, if the kitchen ventilation is very high, such as 9 ach, i.e., this is impossible. Of course, the moisture content will depend a lot on the vapour generation rate, as can be seen from Fig. 9. The result indicates that it's better to prevent the production of steam then to ventilate the kitchen, (if it is possible). Of course, if one wants to keep down the moisture content in the kitchen, with a very high ventilation rate see Fig. 6., one will have a very dry period of around 10% in relative humidity. This is too low and can create a risk for comfort problems.

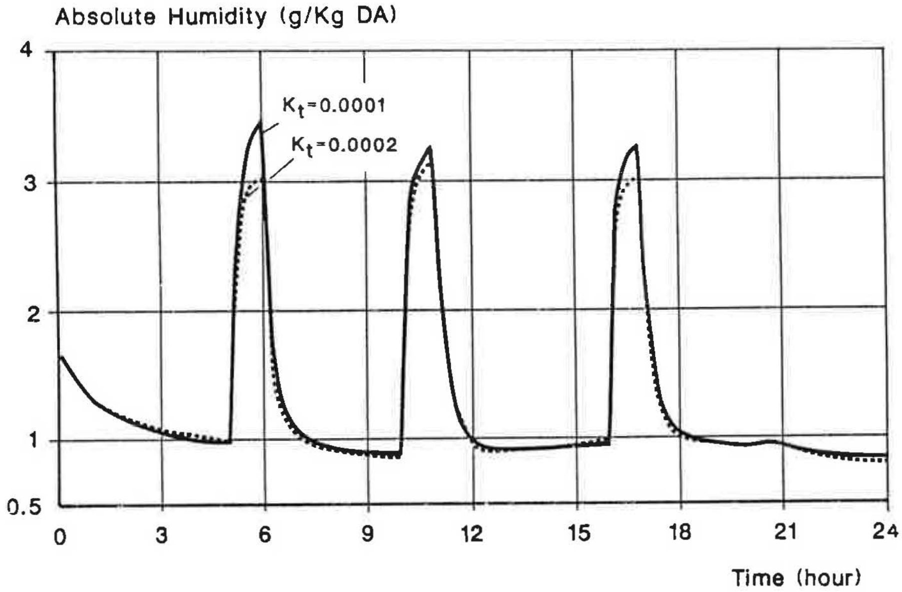

Fig. 8. Absolute humidity of kitchen air vs. time for various k_t values.

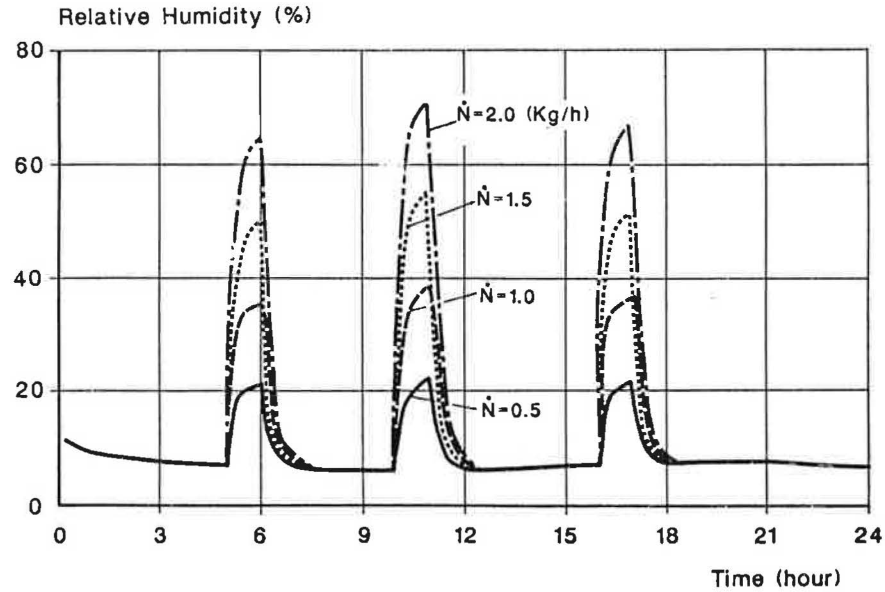

Fig. 9. Relative humidity of kitchen air vs. time for various water vapor production rates.

Condensation is a serious moisture problem in the kitchen environment, particularly on indoor solid surfaces. It is well known that condensation will occur in old houses during the winter time, where there are some places which have a higher k-value, for example, the windows. Fig. 11 shows the different indoor surface temperatures in the house, i.e. on a general brick wall, a layer of triple glazing, a layer of double glazing, and also a single layer of glazing. The single glazing gives the highest risk of condensation. Fig. 12 to 14 show the dew points of kitcken air vs. time for differen conditions, together with the surface temperature vs. time of the double glazing. It can be seen in some cases, that the surface temperature is lower than the dew point, which means that condensation will occur.

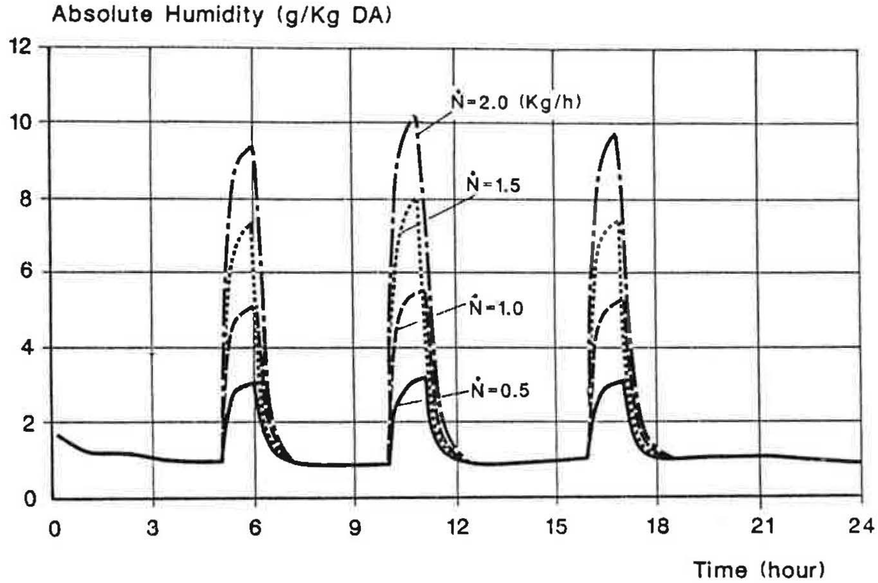

Fig. 10. Absolute humidity of kitchen air vs. time for various water vapor production rates.

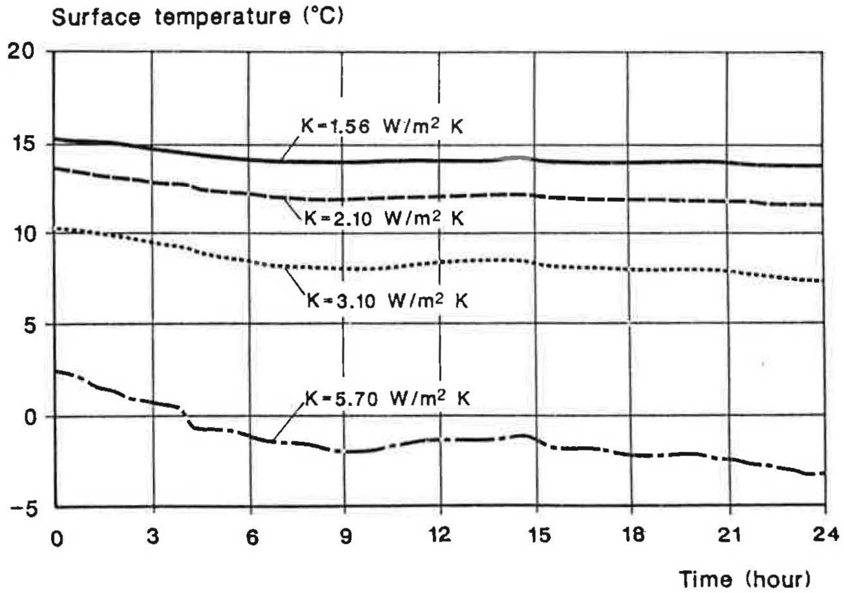

Fig. 11. Surface temperature for different k-values.

Conclusions

The program can be used for calculations in several different situations; for different mechanical ventilation flow rates, different tightness of the building envelope, and different indoor water vapour production. It has been shown that the moisture content in the kitchen rises sharply after the start of cooking. It is obvious that the higher the ventilation rate, the easier it is for the moisture to escape from the kitchen; the tighter the building, the higher the moisture content will be; the greater the water vapour production during cooking time, the higher the moisture content will be in the kitchen. The high humidity during the cooking period increases the risk of condensation and mold growth, especially for the indoor surface with lower temperature. Increasing the ventilation and decreasing the water vapour production together are necessary for decreasing the humidity in the kitchen during cooking period.

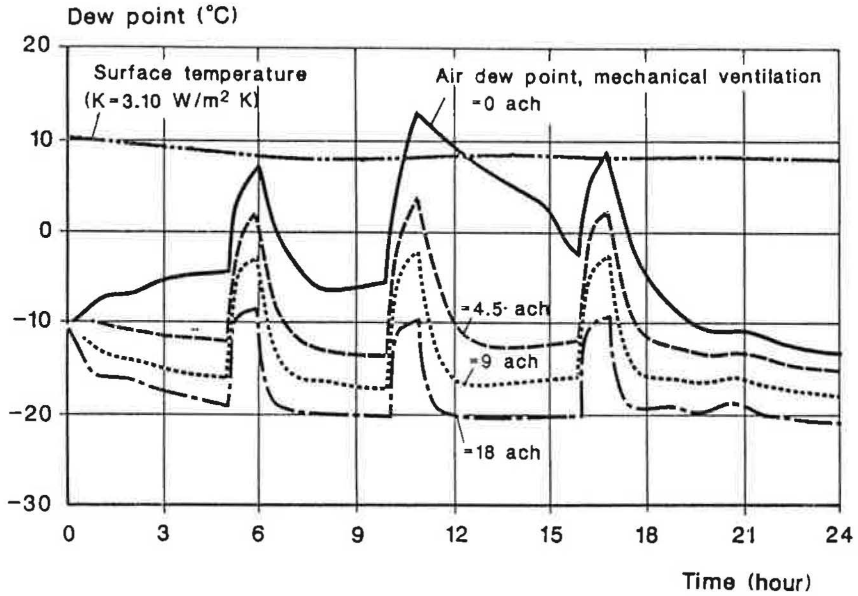

Fig. 12. Dew points of kitchen air vs. time for various mechanical ventilation rates.

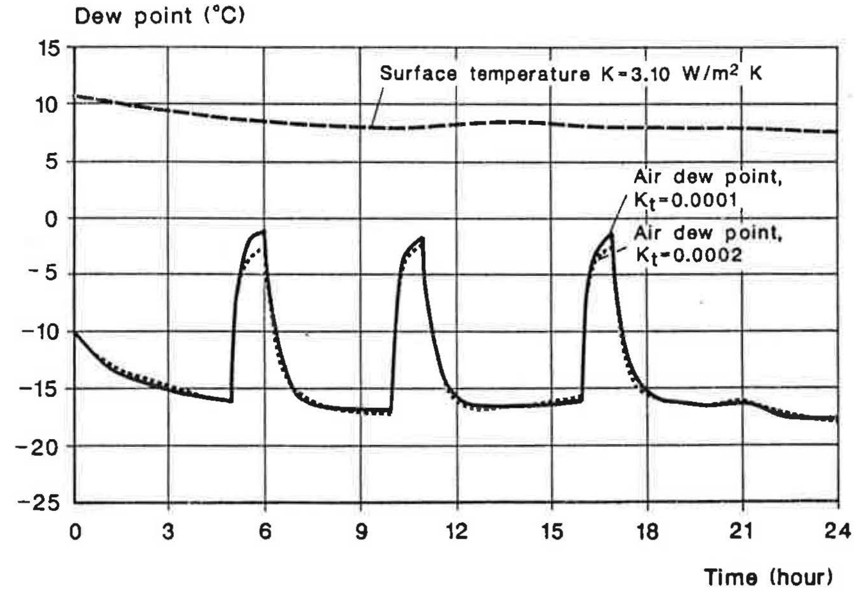

Fig. 13. Dew points of kitchen air vs. time for various k_t values.

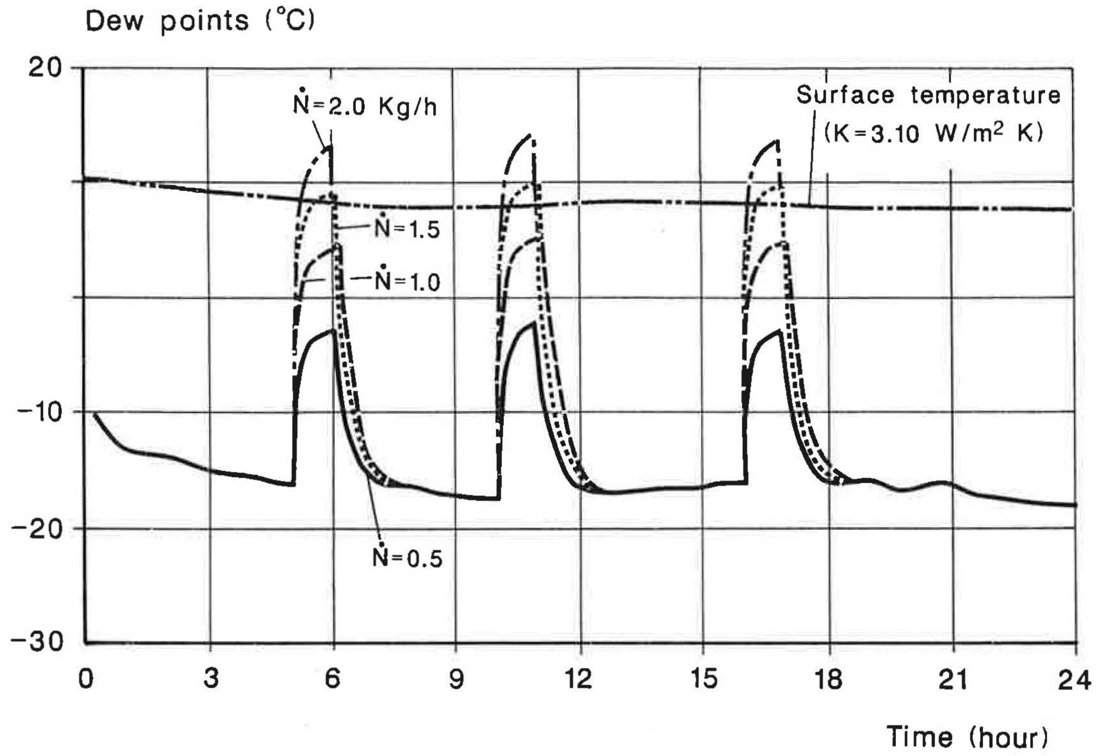

Fig. 14. Dew points of kitchen air vs. time for various water vapor production rates.

References

ASHRAE: ASHRAE Handbook and product directory, 1977 Fundamentals. American Society of Heating, Referigerating and Air-conditioning engineers, INC, New York, 1977.

Li, Y.: The spreading of tobacco smoke on an office floor. Climate and Building, No. 2, Dept. of Heating and Ventilation, the Royal Institute of Technology, Stockholm, 1990.

Li, Y., Peterson, F.: The modelling of multi-room air flow and its application to exhaust ventilation analysis. Climate and Building, NO. 2, Dept. of Heating and Ventilation, the Royal Institute of Technology, Stockholm, 1990.