Object-oriented hygrothermal building physics library as a tool to predict and to ensure a thermal and hygric indoor comfort in building construction by using a Predicted-Mean-Vote (PMV) control ventilation system

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SUMMARY:
The indoor temperature and humidity conditions of the building envelope are important parameters for the evaluation of the thermal and hygric indoor comfort. In the research project GENSIM a new hygrothermal building library, based on the object- and equation-oriented model description language Modelica® has been developed by the Fraunhofer Institutes IBP and FIRST. This library includes many models as for instance a hygrothermal wall model, an air volume model, a zone model, a window model and an environment model. Due to the object-oriented modelling approach, some models of this library can be configured to a complex hygrothermal room model, which can predict the time dependent indoor temperature and humidity conditions in a building construction.

In this paper we will introduce in a first step the object-oriented hygrothermal room model of this library. In a second step, the validation of the room model with some field experiments will be shown. In a third step we will present some simulation results, we obtained by coupling the room model with an implemented Predicted-Mean-Vote (PMV) control ventilation system to predict and to ensure a thermal and hygric indoor comfort in one case study.

In the conclusion, the possible range of future applications of this new hygrothermal building physics library and demands for further research are indicated.

1. Introduction

The heat and moisture behaviour of the building envelope are important parameters for the evaluation of the thermal and hygric indoor comfort. In the research project GENSIM (Nytsch et. al., 2005) a new hygrothermal building library, based on the object- and equation-oriented model description language Modelica® (Modelica, 1997) has been developed by the Fraunhofer Institutes IBP and FIRST. This library includes many models as for instance a hygrothermal wall model, an air volume model, a zone model, a window model and an environment model. Due to the object-oriented modelling approach, some models of this library can be configured to a complex hygrothermal room model, which can predict the time dependent indoor temperature and humidity conditions in a building construction. In this paper the hygrothermal whole building simulation model and its experimental validation will be presented. Furthermore, we will show some simulation results we obtained by coupling the validated building simulation model with a PMV control ventilation system to ensure a thermal and hygric comfort in the building envelope.

1.1 Hygrothermal room Model

The hygrothermal room model of the building library is built by coupling following models of the developed building physics library:

- a wall model, which takes in account vapour diffusion, liquid flow and thermal transport. This model is based on the physical model for the dynamic coupled heat and moisture transport in building components. A detailed model description is given in (Nouidui et. al., 2006).

- an air model, which takes in account the coupled energy and mass balance of the air volume in the building envelope according to following equations:

  Energy Balance

$$\rho \cdot V \cdot c \frac{dT}{dt} + c_{vap}\left(\frac{dT}{dt} m_{vap} + T_a \frac{dm_{vap}}{dt}\right) + r_{H2O}\frac{dm_{vap}}{dt} = \dot{Q}_{cv,surfaces} + \dot{Q}_{cv,\ sources} + \dot{H}_{airchange}\ ; \qquad (1)$$

  ρ: density of the air, [kg/m³]

  T: temperature of the air volume, [K]

  t: time, [s]

  c: heat capacity of the air [J/kgK]

  c_{vap}: heat capacity of the vapour [J/kgK]

  r_{H20}: enthalpy of vaporization for water [J/kg]

  m_{vap}: mass of the vapour [kg]

  $\dot{Q}_{cv,surfaces}$: convective heat fluxes through the building envelope, [W]

  $\dot{Q}_{cv,\ sources}$: internal convective gains such as people, lights and equipment, [W]

  $\dot{H}_{airchange}$: heat fluxes gained or lost due to natural infiltration, [W]

  V: volume, [m³]

  Mass Balance

$$\frac{dm_{vap}}{dt} = \dot{m}_{vap,sources} + \dot{m}_{vap,airchange} + \dot{m}_{vap,airmassflows} + \dot{m}_{vap,surfaces}; \qquad (2)$$

  m_{vap}: mass of the vapour [kg]

  $m_{vap,surfaces}$: moisture fluxes through the building envelope, [kg/s]

  $m_{vap,\ sources}$: internal moisture gains such as people, and equipment, [kg/s]

  $m_{vap,airchange}$: moisture fluxes gained or lost due to natural infiltration, [kg/s]

- a zone model, which calculates the geometry of a zone, the sum of all heat and moisture loads of the zone, the sum of the solar gain through transparent components, the specific long wave and shortwave heat flow of each wall surface of the zone.

- a window model, which calculates the solar gains and the heat losses through the glasses of the window.
- an environment model, which calculates the necessary climate parameters for the simulation of the room model.

1.2 Validation of the hygrothermal room Model

The hygrothermal wall model has already been validated by comparison with some well-established HAM-simulation tools (Nouidui et. al., 2006). HAM means **H**eat, **A**ir and **M**oisture. For the validation of the hygrothermal room model some fields experiments were carried out in the first two months of the year 2007 at the outdoor testing site of the Fraunhofer-Institute of building physics in Holzkirchen. The aim of these experiments was to compare the measurements with the developed model.

1.2.1 Experimental setup

The experiments were carried out in a building, erected on the IBP test site in the 80s. One of the five rooms of this building is suitable for our purpose, because of the well defined boundary conditions. The ground plan of the testroom is shown in FIG. 1. The rooms have a ground area of 20 m² and a volume of 50 m³. They are well insulated (200 mm of polystyrene) towards the ground. The floor has a vinyl covering to avoid moisture flow through it. The external walls consist of 240 mm thick brick masonry with 100 mm exterior insulation (ETICS). Walls and ceiling of the rooms are coated with 12 mm standard interior plaster. The double-glazed windows are facing south (U-value: 1.1 W/m²K, total solar energy transmittance: 0.57, frame ratio: 30 %). The walls and ceiling are rendered moisture inert by sealing them with aluminium foil. During the tests a wool blanket was situated in front of the window on the outside in order to exclude any solar radiation into the room.

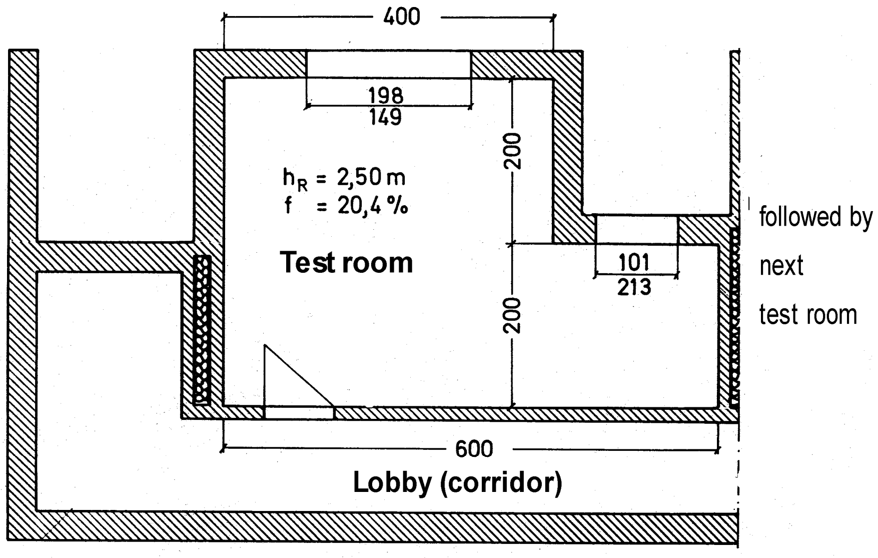

FIG. 1: Ground Plan of the testroom

The temperature in the room is controlled to 20±2°C. A moisture production of 2.4 kg per day has been set in the room. This represents the production of a three persons household (Hartmann et. al., 2001). FIG. 2 shows the diurnal moisture pattern in the testroom. The permanently present basic humidity production of 0.025 kg/h is due to e.g. plants or pets. In the early morning hours between 6 am and 8 am, this value is increased to a peak level of 0.4 kg/h in order to simulate human activities, like having a shower and washing. Subsequently, the moisture production will drop back to the basic rate of production 0.025 kg/h. In the late afternoon the moisture production will increase again to a moderate level (0.2 kg/h) until the evening hours (4 pm until 10 pm), which represents certain activities like cooking, cleaning or doing the laundry.

The air-tightness of the rooms was measured with blower-door method. After conversion to the air change by infiltration under normal pressure conditions, a value of $n = 0.07\ h^{-1}$ was obtained for the testroom. The additional air change rate of the ventilation system is $n = 0.5\ h^{-1}$, which means a constant air flow of about 25 m³/h.

1.2.2 Simulation setup

For the simulation of the hygrothermal room model, we used material parameters taken from the WUFI® database (Künzel, 1994). The moisture production and ventilation rate are the same as in the experiment. The outdoor climate data, which are continuously recorded at the meteorological station of the IBP are introduced as hourly averages.

1.2.3 Results

The measured and calculated evolutions of the absolute humidity in the test room during two days in January 2007 are plotted in FIG. 3. The figure shows a very good agreement between experiment and simulation.

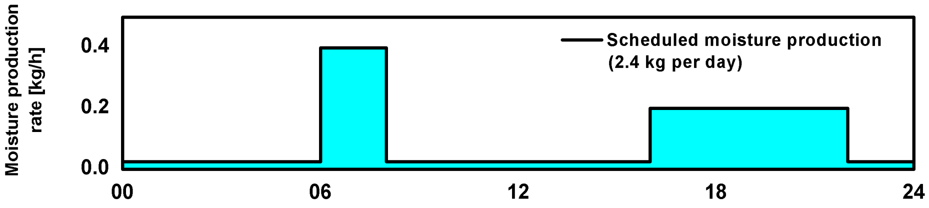

FIG. 2: Diurnal moisture production pattern in the experimental room

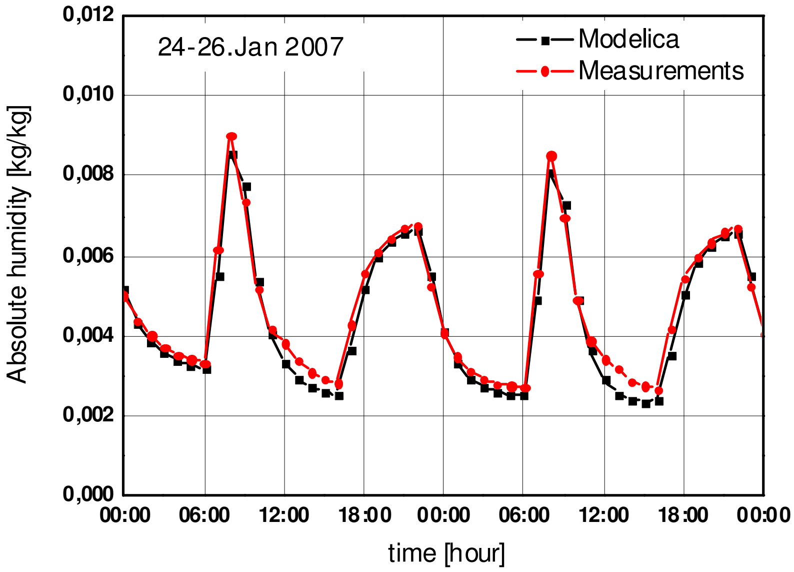

FIG. 3: Calculated (black) and measured (red) absolute humidity of the test room

1.3 Coupling of the hygrothermal room Model and a PMV control ventilation system to ensure a thermal and hygric comfort.

A PMV control ventilation system has been implemented. PMV represents the '**p**redicted **m**ean **v**ote' (on the thermal sensation scale) of a large population of people exposed to a certain environment (DIN, 2005). The inputs of the ventilation system are the time dependent calculated PMV (see equation (3)) and PPD. The PPD is the **p**redicted **p**ercent of **d**issatisfied people at each PMV. It can be derived from the PMV according to the equation (4):

$$PMV = [0.303 \cdot \exp(-0.036M) + 0.028] \left\{ \begin{matrix} (M-W) - 3.05 \cdot 10^{-3}[5733 - 6.99(M-W) - P_a] - 0.42(M-W) - 58.15 \\ -1.7 \cdot 10^{-5} M(5867 - P_a) - 0.0014M(34 - t_a) \\ -3.96 \cdot 10^{-8} f_{cl}[(t_{cl} + 273)^4 - (\overline{t}_r + 273)^4] - f_{cl} h_c (t_{cl} - t_a) \end{matrix} \right\} \tag{3}$$

$$PPD = 100 - 95 \cdot \exp(-0.03353 \cdot PMV^4 - 0.2179 \cdot PMV^2) \tag{4}$$

M : metabolic rate, [W/m^2]
W : external work [W/m^2]
t_{cl}: surface temperatur of the cloth [°C]
$\overline{t}_r$: mean radian temperatur [°C]
t_a: air temperatur [°C]
f_{cl}: clothing area factor [-]
h_c: convective surface coefficient [W/m^{2}K]
P_a: water vapour pressure [Pa]

The maximum possible air change rate of the system, the relative humidity and the temperature of the air volume, where the PMV control system will be integrated, are necessary inputs for the ventilation system. The air change rate of the system is regulated in a way that a critical PPD-value set by the user could not be reached. For testing the implemented ventilation system, we integrated it in a model room. The boundary conditions of the room, used for the simulation are described in the next paragraph. We compared for our purpose three ventilation systems: a traditional shock ventilation, a constant ventilation system and a PMV-control ventilation system. As the worst case, we consider the model room without ventilation system.

1.3.1 Model room and Simulation parameters for the ventilation systems

The geometry and the material parameters of the model room are identical to the testroom used in paragraph 1.2. The temperature in the room is controlled to 20°C. A new moisture profile for a typical living room of a four persons household has been assumed (see FIG. 4 (left)). This production is derived from the activities of the occupants (Kainz, 2004). The metabolic equivalent of task profile used for the simulations is plotted in FIG. 4 (right). We assumed a constant clo-value of 1.0. For the shock ventilation, we assumed that the occupants open the windows for 10 minutes anytime they entry in the room. We assumed for the constant ventilation system an air change rate of 0.6 h^{-1}. For the PMV-ventilation system, we assumed a maximal air change rate of 0.6 h^{-1}. A critical PPD of 10% has been set for the simulation. This corresponds to the interval, which will be felt as acceptable for the most of people (DIN, 2005). We make the simulation over the last three months of the year 2006 with the weather data recording at the Fraunhofer Institute IBP in Holzkirchen.

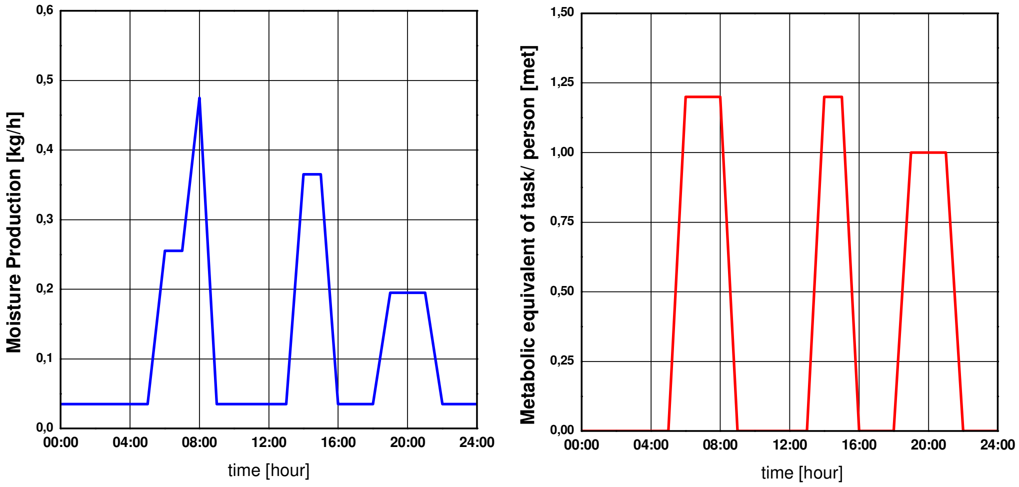

FIG. 4: Daily moisture production and metabolic equivalent of task used for the simulation

1.3.2 Results

FIG. 5 shows the air change rates of the three ventilation systems used in the simulation. The first four figures in FIG. 6 show the simulated relative humidity of the air volume without and with the use of the three ventilation systems for the last two months in the year 2006. The maximum (blue) and minimum (red) values of the comfort interval are plotted in the four figures. The violation frequency ratio of the comfort criterion has been calculated for all the cases and is plotted in the same figure. The simulation results for the case without ventilation system show that it is not possible to be at anytime in the month in the comfort interval. The use of the constant ventilation system allows being about 90 percent of the time in the comfort interval. With the shock ventilation, it is only possible to be about 40 percent of the time in the comfort interval. The use of the PMV-ventilation system gives the best results. With this system and a maximal air change of 0.6 h^{-1}, it is possible to be in the comfort interval for more than 99 percent of the time in the two months interval.

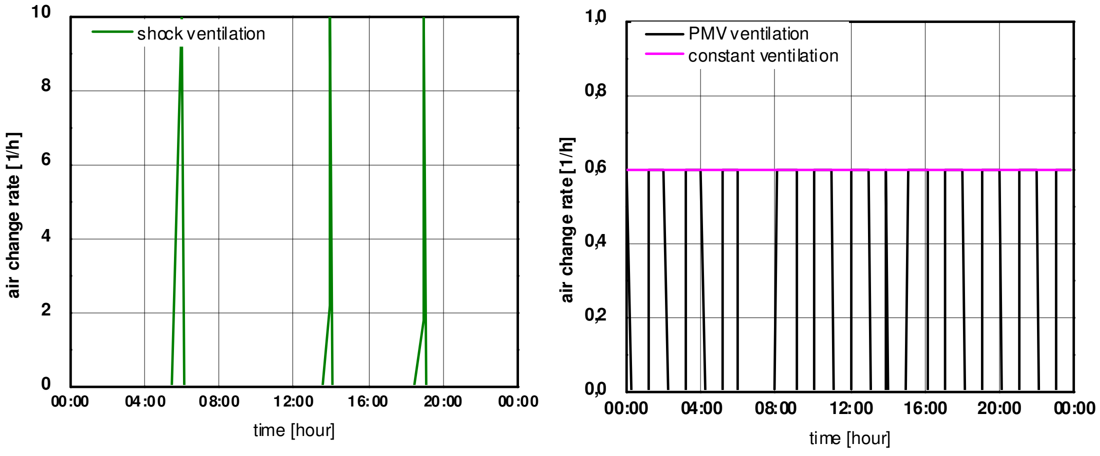

FIG. 5: Air change rate (one day) of the three ventilation systems (schock-, constant-, PMV-ventilation)

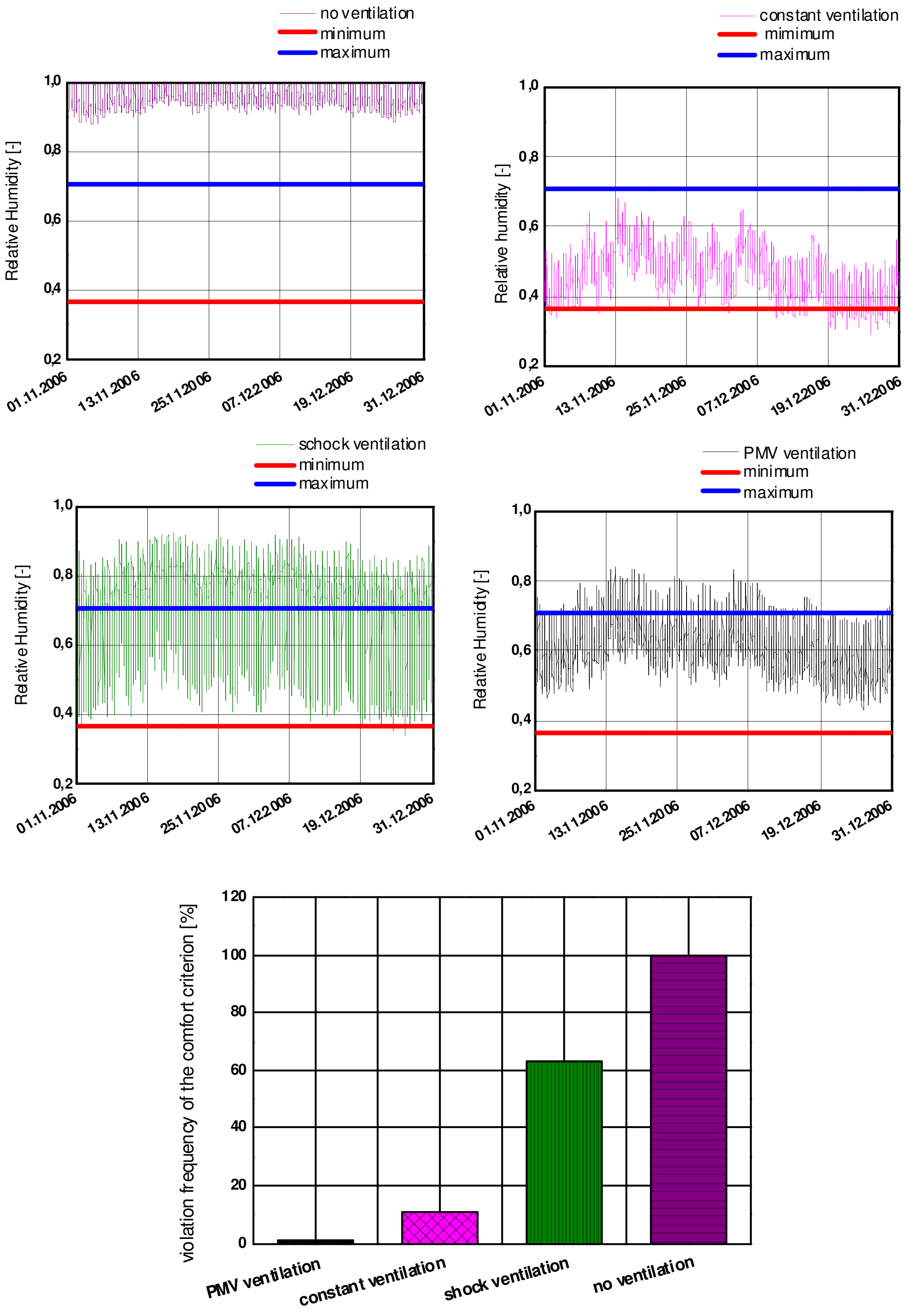

FIG. 6: Relative humidity in the room without (no ventilation) and with ventilation systems (constant-, schock-, PMV ventilation), violation frequency of the comfort criterion with and without ventilation systems

2. Conclusion

In this paper we present the object-oriented hygrothermal room model of the new building physics library developed in the research project GENSIM. We show the first validation results of the room model we obtained by comparing the room model with measurements of field experiments. The results are promising, but many more validation examples are necessary in order to gain confidence in the new model. In a last step we introduce the PMV control ventilation system. We implemented it to ensure a thermal and hygric comfort in building constructions. This system has been integrated in the room model. The simulation results show that the coupling of the room model with the PMV control ventilation system can ensure a thermal and hygric comfort over a long time compared to a shock or constant ventilation.

The developed models open the possibility in the future to improve the energy efficiency of buildings. At the same time it will be possible to design and to test new ventilation systems, which could be used for instance to minimize the risk of mould growth or to guarantee a thermal, hygric and hygienic comfort in building constructions.

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