ON LINE ADAPTATION TO VARIABLE CONDITIONS WITH VARIABLE ENVELOPE STRUCTURE IN FUTURE BUILDINGS

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ABSTRACT

The paper deals with possibilities how to compensate or efficiently use variable outdoor conditions, e.g. solar radiation and outdoor temperature in order to assure the appropriate indoor conditions. This is not studied with conventional approaches, e.g. with heating, cooling, ventilating, humidifying, etc. but with on line dynamical adaptations in the building envelope. Variable wall insulation, movable window insulation, movable shading system and rotating object were proposed and studied. For efficient experimenting a mathematical model was developed. For efficient validation and verification a small physical "chamber" was built.

INTRODUCTION

Modelling and simulation is a very efficient approach when designing new technical solutions (Matko et al. 1992). When talking about smart or intelligent building the studies are more and more oriented into communications, multimedia, internet etc. but not into the main important aspects for pleasant behaviour – temperature, humidity, illumination. There are many possibilities for modelling and simulation and for control system design of such systems with respect to temperature and illumination (Škrjanc et al. 2001, Trobec-Lah et al. 2005, Zupančič et al. 2001, 2004, 2005). In the papers cited above control systems for heating, cooling, ventilating and blind positioning were designed. But what is even more challengeable is to study, how to compensate variable "environmental disturbances" influences with on line adaptations in buildings envelopes. Using appropriate simulation results we propose some solutions: variable wall insulation, variable, movable window insulation, movable shading system and rotating object. We are not dealing with practical implementation of these ideas from which some still do not have possibilities for implementation or the implementation costs are too high. However we are sure that intelligent houses of the future will also offer such solutions.

In this paper a simulator we developed for our investigations, will be briefly described. For verification and validation purposes a real "chamber" was built and will also be briefly described. However the emphasise is laid to the simulation studies which show the possibilities, how to adapt the variable structure envelope to the variable outdoor conditions, e.g. to solar radiation and outdoor temperature "disturbances".

SIMULATOR DESIGN

The mathematical modelling of a "chamber" was dealt in Škrjanc et al. 2001, in Lampret et al. 2002, in Zupančič et al. 2004, 2005. In the modelling the following phenomena were considered: thermal conduction, thermal convection, radiation and long wave radiation. Here only the main simulator properties will be briefly described. The scheme of the modelled system is depicted in Figure 1.

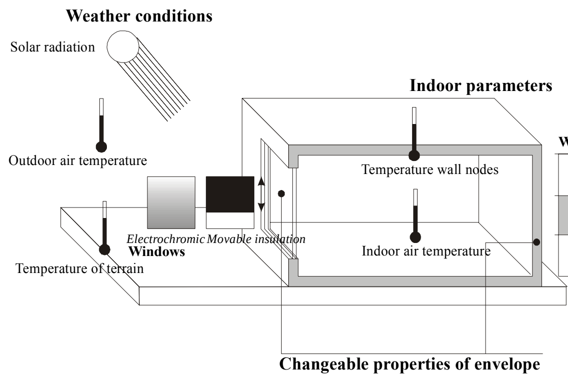

Figure 1: The scheme of modelled system

The inputs to the simulation model are the outside conditions as well as dynamical parameters of envelope:

- **variable outdoors (weather) conditions:** oscillation of the outdoor air temperature, oscillation of the temperature of the terrain, global solar radiation, level of cloudiness, ratio of diffuse/direct radiation
- **changeable properties of the building's envelope:** *the opaque elements* ; thermal capacity and resistance of these elements, the transparent elements (windows); geometry of openings, optical characteristics of glass and resistance of fill between glass panes, *interior properties*: absorption, emission coefficients of walls and thermal capacity

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of furnishing, *some other characteristic*: changeable orientation

- **additional heating and cooling: the power of heater and ventilator**

The outputs of the simulation model are:

- **the indoor air temperature and interior heat flow**
- **the walls, windows and surface temperatures**

It is possible to simulate rectangular building with arbitrary walls, floor and ceiling composition. The opaque elements of the building envelope are floor, ceiling, walls and they can be composed of 5 layers, which enables adequate thermal description of different envelope structures. In each wall one window of rectangular shape could be placed. All windows in the model are supposed to be double-glazed and filled with different gases. The inner space of the building can contain furniture and equipment. The ratio of furnishing/surface of the envelope is flexible, the material properties of furniture are optional. The solar radiation is composed of direct radiation and diffuse solar radiation. The ratio direct/diffuse radiation in the model is flexible. The orientation of the building is optional parameter and it is defined by the declination angle between real (geographic) south and the direction of axes buildings axes.

The simulator was developed in MATLAB-Simulink environment. Figure 2 shows the screen outlook on the highest hierarchical level. In the block Initialisation all the parameters about the materials, geometry of window, orientation, geographic location and starting simulation time are given. So simulation of the behaviour in the case of different materials, orientations, geographic location, position and number of windows and period of the year can be performed. In the block Outdoor temperature and Solar radiation the measured or predefined values of outdoor temperature, temperature of terrain, solar radiation, ratio direct/diffuse radiation and level of cloudiness are given in appropriate data files. Also the power of the heater and the ventilator are defined in block Ventilating&Heating. Position of the roller blind is described or defined in block Geometry of openings. In blocks Opaque elements variable properties can be defined or generated (thermal capacity and resistance), in block Transparent elements properties of openings (optical prop. and thermal resistance), respectively. These blocks represent the input variables of the model. The output variable of the model is vector, where temperatures and heat-flows are gathered. But the simulator can be modified easily in the sense that also other variables of the model can be monitored.

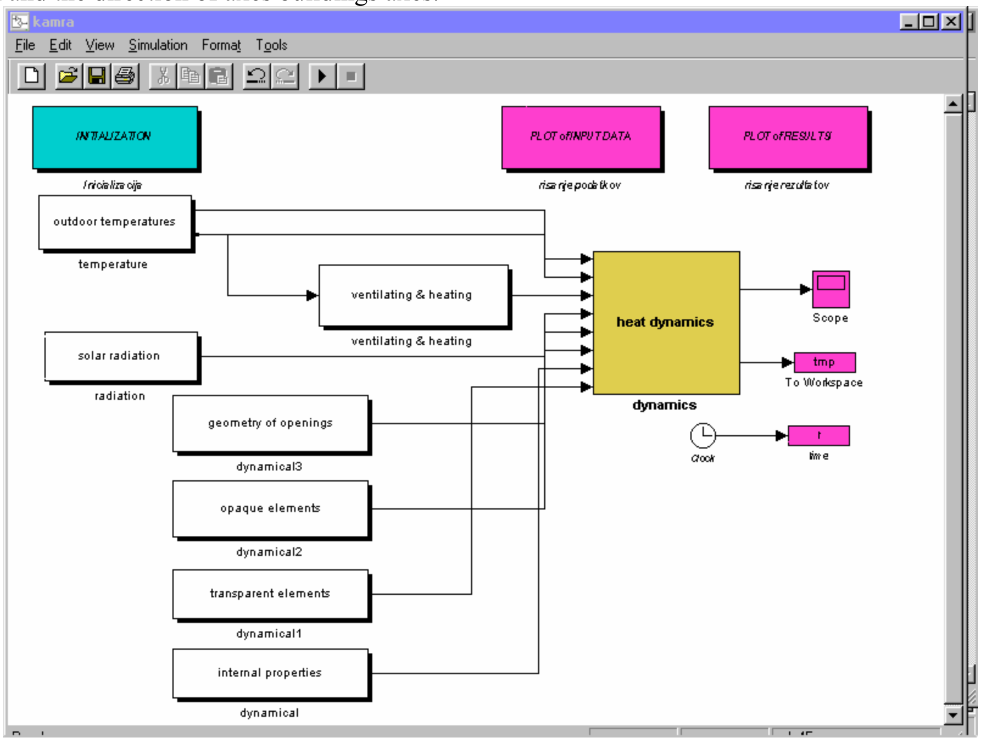

Figure 2: The simulator in MATLAB-Simulink environment

TEST CHAMBER "KAMRA"

For the validation and verification of mathematical model a real system - test chamber "KAMRA" (see Figure 2) was built on the roof platform of the Faculty of Civil and Geodetic Engineering, University of Ljubljana (46.0° latitude, 300m altitude). It has dimensions 1m x 1m x

1m and is designed especially for modelling and control design purposes. The cell is shifted off the ground and the roof is ventilated in order to avoid the overheating caused by direct radiation on the roof. Walls, floor and ceiling are built of lightweight brick blocks but also other materials were examined.

Figure 2: Physical object – test chamber “KAMRA”

The south wall is completely glazed with double-glazing composed of two layers of standard clear glass and air fill, and the thickness of wooden frame is 5 cm. The alternating geometry of the window is made with the automatically moveable roller blind. The roller blind is an external PVC blind and its position can be controlled. The measured values are: inside and outside temperatures, temperature of the ground, direct and reflected solar radiation, indoor illumination and the position of the roller blind.

Our final goal is to achieve the desired indoor temperature and indoor illumination with appropriate heating, ventilation, but also with dynamic changes in the building envelope e.g. with blind positioning. The emphasize was given to the usage of passive energy actions, i.e. to adaptations to external “disturbances” with on line changes in buildings envelopes to achieve pleasant behaviour conditions in the room and to make some energy savings as well.

MODEL VALIDATION

Model validation is the most important phase in each modelling and simulation iterative cyclic procedure. It is based on the comparison of experimental and simulation results, when the real and simulation models are influenced by the same input signals. It is of course important to perform several experiments under different conditions. The experimental data should be different from those used in model development phase. The real experiments were performed in winter, spring, summer and autumn conditions, with heating and ventilating and with roller blind positioning. The real system and the simulation model were influenced with several external temperatures signals, with solar radiations signals and with some variable properties of the envelope of the room. It is desired that input signals contain appropriate dynamics. With these experiments the model was still improved with final parameter tunings.

The validation experiments can be divided into three groups. The first group experiments were performed in May. The roller blind was completely opened (position 0), the walls consisted from dry wall panel (1cm) + mineral wool cavity (8cm) + dry wall panel (1cm). The orientation of the room was south (window), north. The simulation results are presented in Fig. 3. The outdoor temperature varies between 3 ºC -15 ºC. The solar radiation was moderate, up to 500 W/m^2. The observation period was 6 days. The lower diagram shows the indoor measured and simulated temperatures. It can be noticed that the difference is acceptable. The results are worse during the night period.

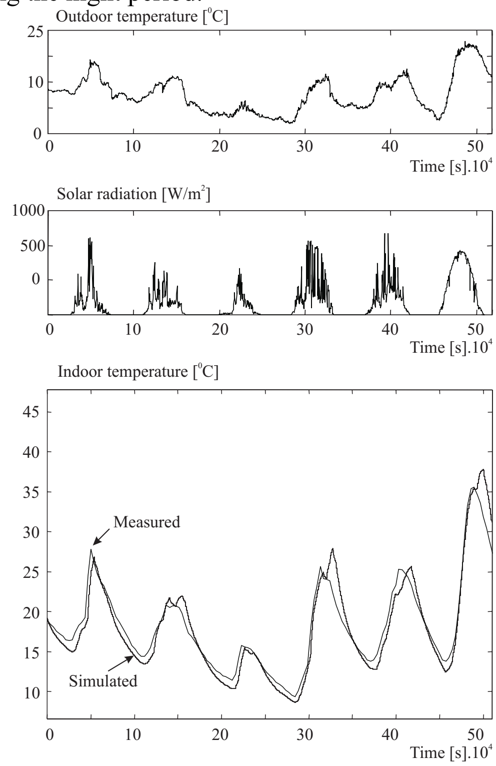

Figure 3: Measured and simulated indoor temperature as a result of variable outdoor temperature and solar radiation.

Figure 4 shows an experiment from the second group (beginning of June). In this experiment the window shading area was also changeable. The observation period is 24 hours, the sampling time is 5 min. The roller blind position (0 – completely opened, 1 – completely shaded), the outdoor temperature (app. 16-31ºC) and the global solar radiation (max. 950 W/m^2 at 2 pm) are shown in the first three diagrams. The lower diagram depicts the measured and simulated indoor temperatures. The error range is acceptable and is probably caused by non modelled phenomena such as unexpected ventilation heat losses through some cracks in the dry wall panels and the influence of wind.

STUDIES WITH VARIABLE ENVELOPE PROPERTIES

The model was above all developed for the studying of control strategies where we had in mind heating, cooling and blind positioning. However some experiments, which show how variable envelope properties influence living conditions, will be presented in the sequel. The simulation studies were performed with a “bigger object”- 4x3x2.5m and with the south window 3.8x2m. Figure 5 shows the influence of the wall structure to the indoor temperature in a spring period. Three possibilities were studied: inner insulation (brick 9cm + polystyrene 4cm), outer insulation (polystyrene 4cm + brick 9cm) and the situation without insulation (only brick 9cm.)

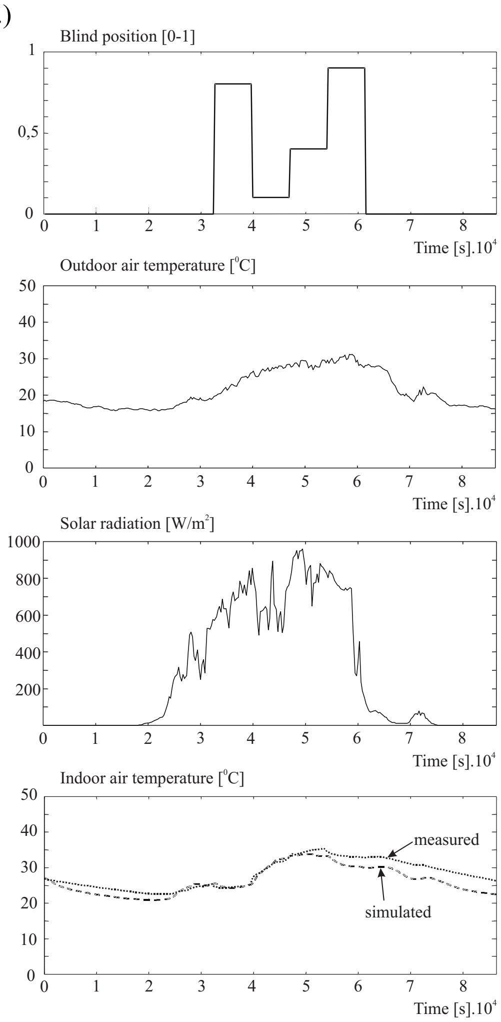

Figure 4: Measured and simulated indoor temperatures as a result of variable outdoor temperature, solar radiation and window shading area.

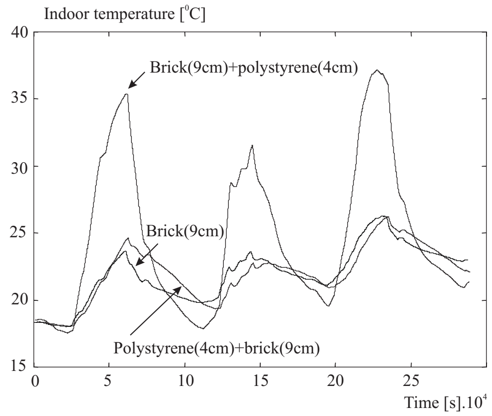

Figure 5: The influence of the wall structure to the indoor temperature.

It is evident that temperature oscillations are much lower (app. 5 ºC) when outer insulation is used. It is also very surprising that the wall without insulation gives similar results. But this happened because the object was in a suitable working regime. The brick wall is cooled by external air during the night and later during the day it cools the room air. Of course the role of outer insulation is much more important during the winter period.

So we came to an idea of a "moving insulation wall". The simulation was performed in a spring period. The total thickness of the insulation layer was 5cm. However the inner and outer thickness were periodically changing from max. 4 cm to min. 1 cm. Two periodical control signals were selected for changing implementation: sinusoidal and pulse. They are shown in Figure 6.

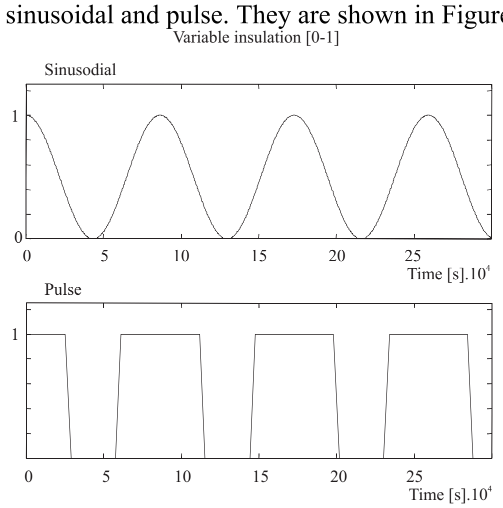

Figure 6: Variable insulation signals

The simulation results are shown in Figure 7.

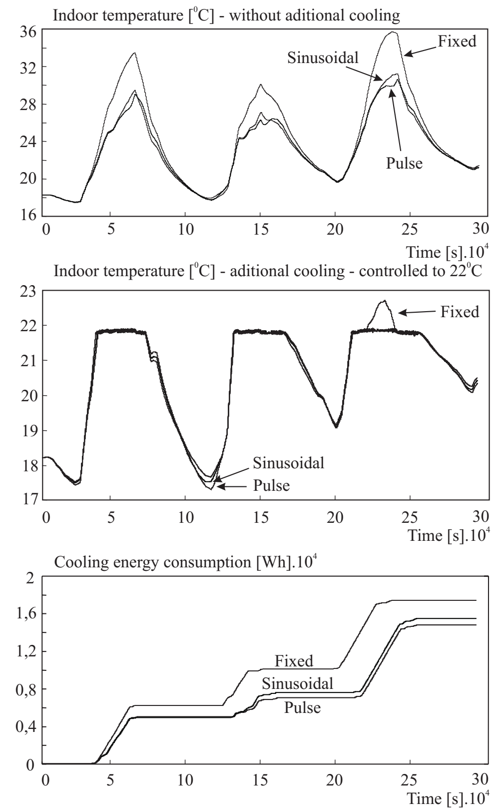

Figure 7: The effects of a variable wall insulation

The upper diagram shows indoor temperatures in three situations when no additional cooling was implemented. Fixed insulation means that initial thickness 2.5 cm on both sides of the wall does not change during simulation. We can notice that maximal temperatures during a three day observation period are much lower (for 5 ºC). The second diagram shows the situation when temperature was controlled to 22 ºC with additional cooling. During the third day the maximal cooling power in the case of fixed insulation was not enough and the temperature significantly exceeded 22 ºC. However in the case of movable insulation the temperature was satisfactory controlled all three days. The lower diagram depicts the cooling energy consumption. We can notice the significant difference between the fixed and variable insulation. App. 3kWh (15%) of energy can be saved with movable insulation. However there is no significant difference between sinusoidal and pulse implementations for movable insulation (pulse regime is slightly better).

The variable insulation is effective only in particular periods, e.g. during the summer. During the day the outer insulation lowers the heat flow from the outdoor to the indoor. During the night the inner insulation prevents the cooling of the room, but on the other hand the heat energy which was accumulated in walls, can be transferred to the environment and the temperature of the wall decreases.

Figure 8 shows the results of an experiment in autumn period when the heating is already needed.

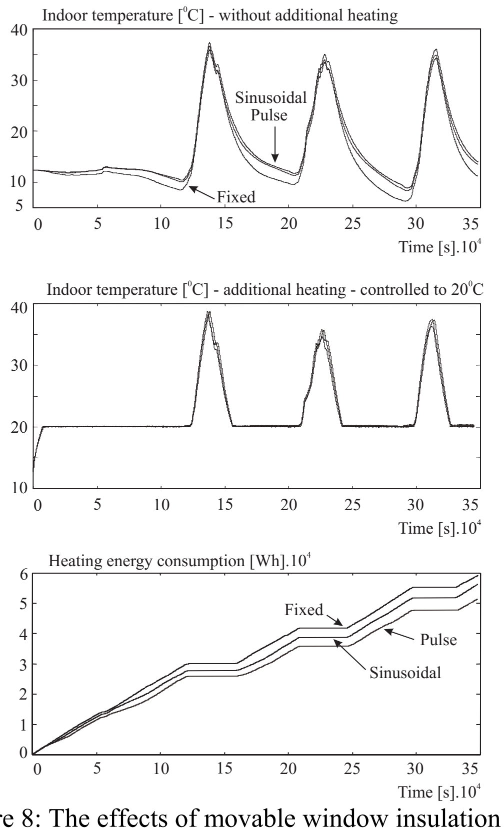

Figure 8: The effects of movable window insulation

In this experiment movable window insulation was implemented. The controlled signal was the same as in the case of variable wall insulation (see Figure 6). The upper diagram shows the indoor temperatures when no additional heating was implemented. We can notice that in cases of movable insulation the night temperatures are app. 3 ºC higher. The second diagram shows the temperatures when the system is controlled to 20 ºC with additional heating. This is the reason why all three curves overlap. However the heating energy can be significantly reduced with movable insulation what shows the lower diagram. The saving is more that 10 KWh in the case of pulse control signal in four days.

The next experiment describes the influence of the movable shading system in the window in spring-summer period. It is reasonable to prevent the overheating due to strong solar radiation. Again the control signal for shading system was the same as presented in Figure 6. The results for three day observation period are presented in Figure 9.

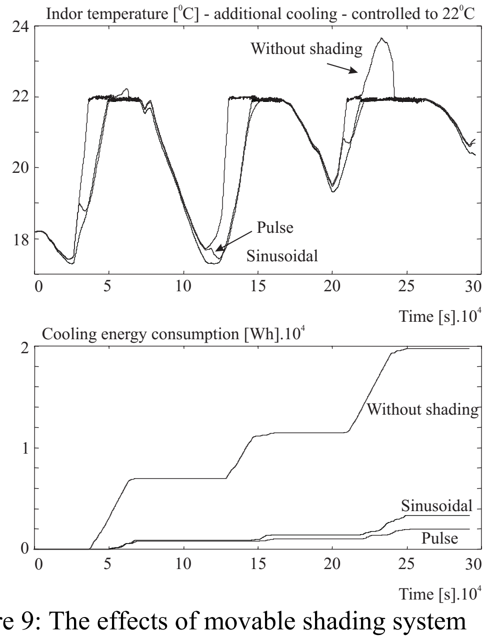

Figure 9: The effects of movable shading system

The 1 kW cooling system controlled the temperature to 22 ºC. If the shade was not used the temperature exceeded the reference temperature for app. 2 ºC during the third day. This did not happen when movable shading system was used. The energy saving for cooling was significant - app. 14 KWh in three days.

The last experiment was devoted to a very sophisticated idea of rotating object which is interesting in autumn-winter period. The object rotates so that the south window position is coordinated with the position of sun. The angle of rotation is 360º per day. Simulation results show that the maximal indoor temperature is app. 5 ºC higher in comparison with the fixed object. The indoor temperatures are shown in Figure 10.

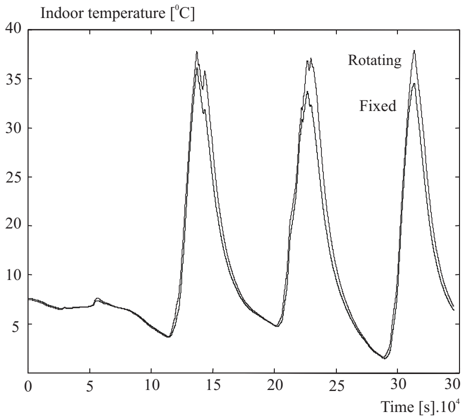

Figure 10: An experiment with rotating object

CONCLUSIONS

The developed "chamber simulator" was efficiently used for studying of radiation and thermal dynamics flows. It was mainly intended for control system design. The control systems for heating, cooling and roller blind positioning were developed in the past. However this paper describes, how dynamic on line adaptations of envelope structure properties can be efficiently used. We studied the effects of the position of the insulation in the wall structure, the effects of variable wall insulation, movable window insulation, movable shading system and the effects of rotating object. Currently there are perhaps no practical solutions for some proposed implementations but future will probably give also answers to some proposals. Although only so called feed-forward studies were shown in this paper, when the control signal was chosen in advance, it is also possible to improve our solutions with feedback control, when dynamic changes in the envelope would be implemented on the basis of temperatures, radiations and other environmental changes.

Although this paper deals only with the effects to the inside temperature our investigations have already been focused to the indoor illumination features caused by solar radiant flows. Up to now many real experiments have been performed and they give us a good basis to include also the illumination part in the described simulator. The problem is that solar radiation influences simultaneously the indoor temperature and illumination – two processes with very different (slow and fast) system dynamics, so the controller design procedures can also be very different. It is questionable weather it is reasonable to include both phenomena into simulator as it leads also to numerical problems with stiff systems.

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