A conceptual model that simulates the influence of thermal inertia in building structures

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ABSTRACT

Energy consumption in buildings and the required thermal power for maintaining comfortable indoor temperatures are to a certain extent dependent on the thermal storage capacity of materials in contact with the indoor air. This article describes a conceptual model for investigating the effects of increasing the thermal storage capacity of building materials. The aim is to present a simple (minimal) – and thus fully comprehensible – model, but such a model is of course limited with respect to its possibility to quantitatively model real buildings.

1. INTRODUCTION

Optimization of buildings with regard to energy performance and thermal comfort can provide substantial environmental and economical benefits (Öberg, 2005). One aspect of this is the interaction between building materials and heating and ventilating systems, under dynamic indoor and outdoor ambient conditions. An understanding of this requires understanding of the relevant physical mechanisms (Hall and Allinson, 2010). Existing tools for energy balance calculations in buildings are typically engineering programs based on simplified algorithms, but dealing with a large number of parameters. These tools are useful for the design case, where a quantitative result is needed and where there are large variations in the operating conditions like internal loads. The aim of this work was different: to develop a simple generic model for qualitative understanding of the basic mechanisms of thermal inertia in buildings and to simulate its influence on energy use, comfort and power demands in a number of cases.

2. THE MODEL

The building model consists of three parts: an external wall, the indoor air and an internal wall, see Fig.1. The program works with an arbitrarily chosen internal air volume of 1 m^3. The wall surface area and other parameters are then related to this volume as these parameters are related in the type of building of interest. Heat transfer through the external and the internal walls are modelled by forward difference models. In the present case out aim was to investigate if changes in the thermal properties of the inner wall would give advantages concerning heat consumption, maximal power use, and thermal comfort. Heating is modelled as an on-off system with temperature hysteresis. The detailed parameters of the model are not given here (will be published elsewhere). Note that the model is very small and can be described with only about 20 parameters. This makes it a fully comprehensible model.

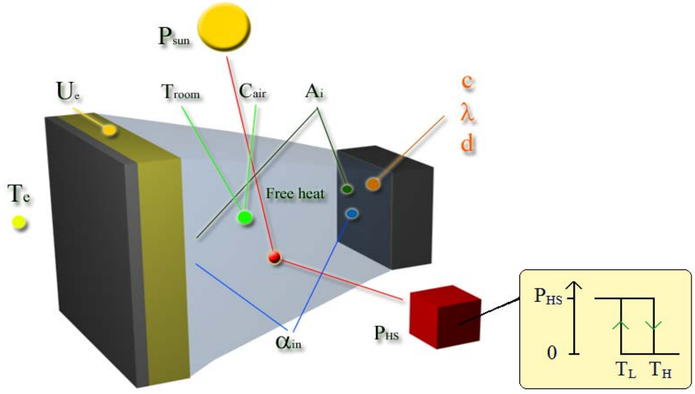

Figure 1. Overview of the variables in the model.

Our interest here has been to study the effect of the thermal inertia of the inner wall on three parameters: 1. Heat consumption; 2. Peak power load and cost of heating; 3. Comfort. For each of these cases a relevant output variable was constructed:

1. Percent lowered heat consumption relative to the standard case.
2. Cost of heating relative to a standard case. Two cost models were used. 2a. Constant cost per heat unit. 2b. Cost of heating was calculated based on a heating tariff in which the energy price increased at low temperatures. The aim of this was to model the increased cost of energy production at low peak temperatures.
3. Comfort (or rather the lack of comfort) was quantified as the percentage of the time when the indoor temperature was above 24 °C.

The standard case was in all cases an internal wall thickness d=0.1 m, a volumetric heat capacity c_v=1.5 MJ/m^{3}K, and a thermal conductivity λ=2 W/mK. These are normal values for a massive concrete wall. The simulations were run for two wall thicknesses (0.1 and 0.3 m) and all combination of seven different thermal conductivities and seven different volumetric heat capacities. For both these parameters a range of values spanning from the values used in the standard case to twice those values were used. These values are typical of what one can achieve with, e.g., iron ore aggregate for increased heat capacity and graphite for increased thermal conductivity. The result parameters are plotted against this 7 x 7 matrix. Six different cases were studied:

A. The energy consumption of a building with intermittent free heating, e.g., from the sun.
B. The same building without intermittent free heat.
C. The energy consumption of an intermittently heated building that is only heated in the weekends.
D. The cost of heating a building during cold-spells when the cost of heat is differentiated so that it is more expensive when it is cold.
E. The cost of heating a building during cold-spells when the cost of heat is constant.
F. The fraction of time with over-temperature when there is a significant free heat from the sun.

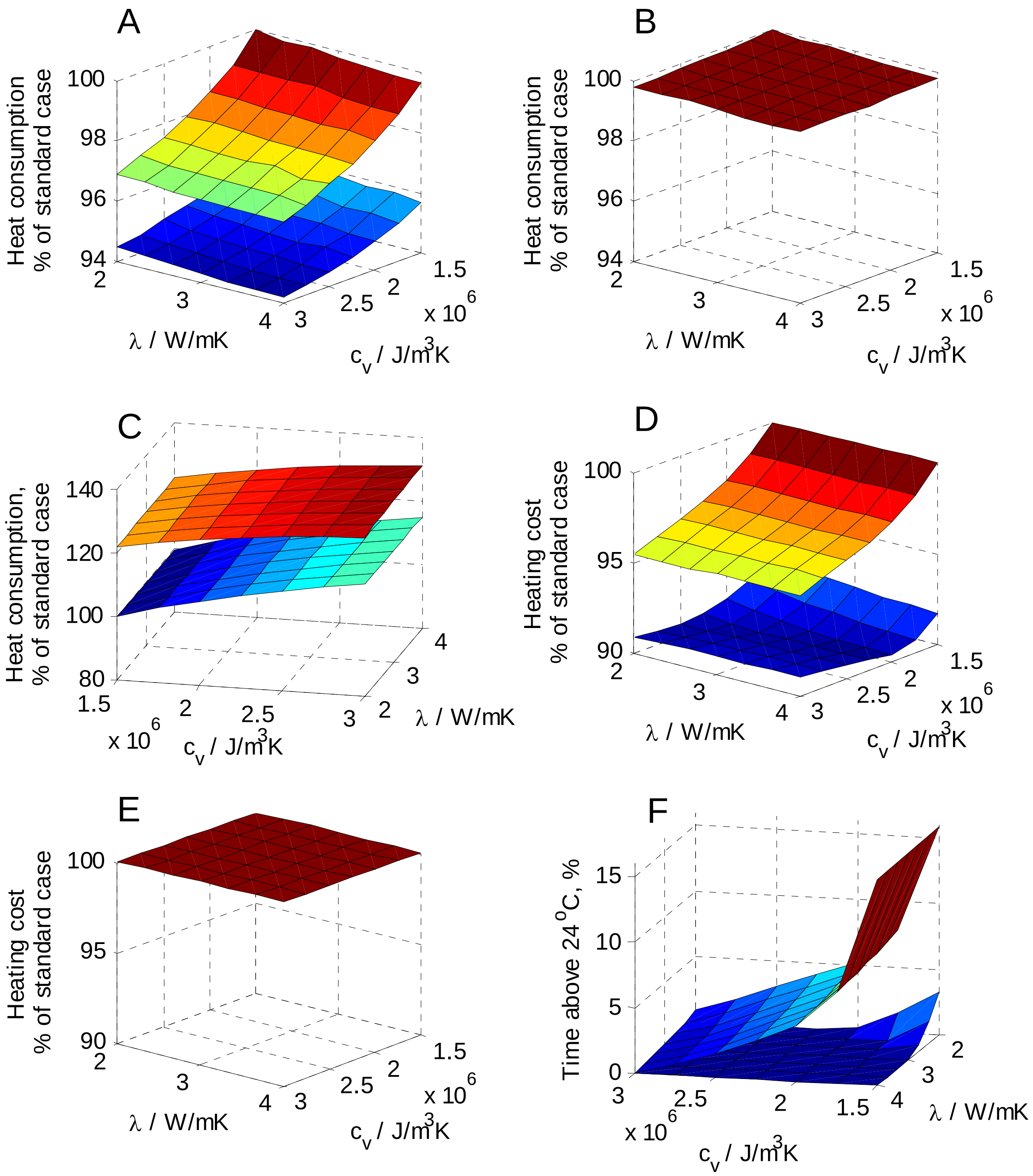

Figure 2. The simulated results in the six cases described in Table 1 and the text. The parameters of interest are plotted against the thermal conductivity (λ) and the volumetric heat capacity (c_v) of the internal wall. The top surface in each diagram is for a wall thickness of 0.1 m and the lower surface is for a wall thickness of 0.3 m (for Fig. B and E only one surface is shown as the two surfaces are almost identical). Note that the plots have been rotated differently in the heat capacity – thermal conductivity plane to more clearly show each result. The colouring differentiates different levels.

3. RESULTS AND DISCUSSION

The results in Fig. 2 show how the energy consumption, cost (related to peak power loads) and comfort are related to the thermal properties of inner wall in the model building for two wall thicknesses *d*. As is seen in the figures the influence of the thermal mass quite different in the tested six cases. In three cases does high thermal inertia (thicker inner wall, higher volumetric heat capacity) give advantages (A, D and F); in two cases it does not much influence the result (B and E); and in one case it is a clear disadvantage to have high thermal inertia. In no case does the thermal conductivity influence the results significantly.

The aim of the present exercise was to show that even simple tools can help us qualitatively understand complex dynamic phenomena. Working with the described model makes it possible to answer questions concerning the importance of high thermal inertia in buildings, for example:

- Will one always save heating energy by including an interior concrete wall in a building? The answer is no; there are cases when high thermal inertia is a clear disadvantage, for example for intermittently heated buildings.
- Does the peak thermal power demand during cold-spells decrease in buildings with high interior thermal inertia? The answer to this question depends on how the heating is organized. In buildings with a tight control of indoor temperature one will not get much temperature changes in interior components and thus it does not make any difference whether, e.g., an inner wall is light of heavy. However, if interior temperature is allowed to decrease significantly during cold-spells, the heating power can also be reduced (during the cold-spell) if the building contains thermally heavy interior structures with stored heat.

We conclude that also rather limited models can be useful for the conceptual understanding of how dynamic building systems work.

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