Modelling Thermal Transients in Controlled Double Skin Façade Building by using Renowned Energy Simulation Engines

Z. Eškinja*, L. Miljanić** and O. Kuljača***

* Faculty of Electrical Engineering and Computing, Zagreb, Croatia
** University College of Northern Denmark Technology, Aalborg SV, Denmark
*** Zagreb University of Applied Sciences, Croatia
zdravko.eskinja@fer.hr, 1054997@ucn.dk, ognjen.kuljaca@tvz.hr

Abstract - The paper is an analysis and overview of some simulation tools used to model specific thermal dynamics that occurs while controlling double skin façade. Research has been conducted on simplified construction with single zone where one side is glazed. Heat flow and temperature responses are simulated in three different simulation tools: IDA-ICE, EnergyPlus and HAMBASE. The excitation of observed system, used in all simulations, was a temperature step of adjacent zone. Air infiltration, insulation and other disturbances are excluded from this research. Although such isolated behaviour is not possible, experiments are carried out to gain novel information about heat flow transients which are not observable under regular conditions. Results revealed new possibilities for adapting the parameters of the regulator i.e. artificial neural network. Along numerical simulations, the same set-up has been also tested in a real-time experiment with a 1:18 scaled model and thermal chamber. The comparison analysis brings out interesting conclusion about simulation accuracy in this particular case.

Keywords - Double skin façade, experimental tests, heat control, heat flow, simulated tests, simulation tools

I. INTRODUCTION

The energy simulators are being commonly used to examine the building's behaviour in aspect of energy consumptions ([1], [2]). Since these simulators include HVAC system, the idea is to use theirs models in system control, similar as in [3],[4] and [5].

The authors of the paper are interested in special case of building's element called Double Skin Façade (DSF) were cavity air has controllable properties. Thin and transparent envelope of the DSF building brings an un-efficient thermal isolation from external conditions as shown in [5], [8] and [8]. If the clients don’t want to abandon benefits of the DSF, the only way to improve energy efficiency of such system is to equalise the heat loss in total envelope. Also, the user would feel smaller differences between micro zones of the inner space. Usually this is resolved by placing HVAC actuators next to critical part of the envelope like in [9] and [3]. Still, most of the regulators work with one temperature measurement as a control feedback. The improvement of energy efficiency lies in a control that use heat flow as main input. To enable it, the heat should be measured with adequate precise and without extra ordinary expenses. One possibility to overcome the problem is an estimate of the heat flow aided with constant adaption. Such approach has become very often in alternative control systems, as may be seen in [11], [12], [13], [14], [15], [16] and [17]. One further step would be to insert thermally conditioned air directly into the cavity between skins what has sense only if the cavity is closed system and the DSF have function of heat economiser. This paper is analysing workable solutions and possible models that could be used as one of incomes of intelligent control systems for this kind of built. The different models from renowned simulators were tested under same conditions and similar set-up. Tested simulators are listed as follows:

- IDA Indoor Climate and Energy (IDA ICE),
- Heat Air and Moisture model for Building And Systems Evaluation, HAMBASE, and
- Energy Plus.

Figure 1. Temperature in scaled dimension model

Energy Plus were initially meant to be used, but results of initial test had so low quality for given conditions, it could not be even compared.

IDA ICE is commercial software which is used for building modelling, as well as its systems, and controllers with the insurance of the lowest possible energy consumption and the best possible occupant comfort. IDA ICE is a detailed and dynamic multi-zone simulation application for investigation of thermal indoor climate and the energy utilization of the whole building. The physical models of IDA ICE mirror the most recent research and accessible models.
HAMBASE is a simulation model which is made in MATLAB environment. The simulator covers estimations of heat and vapour flows of building [18]. The input is similar to earlier mentioned alternatives: hourly data about exterior temperature and humidity, detailed description, building’s properties etc. As result, the indoor air temperature, humidity and energy usage is calculated, even if heating and cooling of a multi-zone building is involved.

Simulator engines of both: HAMBASE and IDA ICE, are based on same energy equality (1) which is linearized and described with method of thermal networks, what is presented and explained in [19].

\[ \text{LOSS} + \text{STORED} = \text{GAINS} + \text{AUXILIRAY} \]  

Linearization is done around values of interest such as slower transient process and sinusoidal variation of temperature. Hence, using them in control means breaching defined limitations, so this research should answer how much non-recommended input effects the result, and is it possible to gather some useful information from such models.

II. SIMULATIONS

The simulation was performed to analyse thermal response of building’s interior, caused by fast, unnatural change in temperature. Simulated excitation, such as step, cannot be seen in common usage, but this is a best method to compare behaviour of HVAC estimators.

A. Set Up

Tested object is representing modern energy efficient building structure, where model is made as a part of building with double-skin façade. Dimensions are listed in Table 1 and parameters in Table 2. Even though, the structure has only one interior “room”, it is configured with two separate zones, because specific closed type of DSF building is not supported by any simulator. Zone 1 is the zone which is representing modern energy efficient building structure and Zone 2 is representing double-skin façade. More detailed descriptions may be found in paper [20] and [21]. In all performed tests, simulations were made with artificial weather conditions. Weather file was made in the way that temperature was constant for some period and then there appears huge temperature step from 0 to 35°C. The test was performed without solar radiation or any other disturbance with intention to isolate only one single event. Authors realise that solar influence is the main actuator in daily cycles, but still, in terms of HVAC control, it is just disturbance.

First serial of simulations will involve IDA-ICE software and mentioned response with few different representations and variations. One of variation is dimension, where extreme reduction with scale of 1:18 is applied. Comparison analysis is performed on obtained results described in following subsections.

B. Temperature Simulation – IDA-ICE

Simulated response of the model with scaled dimensions, presented in Figure 2, shows that temperatures are equalizing after approximately 5 days. The difference between mean temperatures of zones is in signal gain, as well as the time required to reach steady states.

In the scaled model, Zone 2 was rising in temperature much slower than Zone 1, which can’t be correct. Zone 2 is smaller and basically made of glass, so we must take in consideration that it needs less time to heat up. The temperature in full dimension model had smaller differences in equalization, as shown in Figure 2 b. Zone 2 has risen in temperature faster than Zone 1, which was
expected. Weather simulation, building set-up and all other crucial factors were the same in both cases. As per comparison of both full dimension and scale models, some differences were noticed.

In graphs of Figure 3, there will be shown mean air temperature differences in scaled and full dimension models. From the results for the Zone 1, it’s visible that in scaled model the necessary time for heating up the Zone is much faster than in the full dimension model. As for the Zone 2, the results seem unrealistic. Heating up of the Zone 2 in the scaled model is much longer than in full dimensional model, which can’t be possible, because of much smaller dimensions.

C. Heat simulation – IDA-ICE

Further analysis was focused on surface heat of various parts of external construction. The simulation results were taken from previous case. In Figure 4, we can find heat losses and gains through all external parts of both zones. The envelope’s element noted as Wall 3 is in fact the interior glazed surface that divides two zones. Only this signal is identical in both graphs. The peak of heat gain of external wall elements in Zone 1 are higher than one of external glazed element with similar surface in Zone 2. This behaviour can’t be possible due to same initial conditions and lower thermal resistance of the thin glazed surfaces. To resolve the cause, the same experiment is analysed also on model with full dimensions. Figure 5 presents heat flow through external parts in the full dimension model. Here, Zone 1 has much smaller heat losses than Zone 2, which was expected and is acceptable by the means of physics. The misbehaviour of the simulator in case of reduced size is caused by breaking the assumptions of model. The models are expecting the sinusoidal shape of temperature variation, and not a steady state, so that is why signals had trouble to reach it (See [20]). Additional negative post effect of violation in parametrisation is in incorrect values of settling times which is present in all experiments.

D. Temperature Simulation – HAMBASE

HAMBASE simulator was tested with same method as shown earlier with IDA-ICE. Figure 6 represents interior temperatures resulted after positive step. In a given display, both responses have comparable values. Beside simulation results, here is also given one experimental result made on scaled version. In the experimental test, one segment of DSF building was used as experimental model, and thermal chamber was used to change thermal conditions outside of the model. The model was built with same material and dimensional characteristic as one in simulation. One of the results, that are described in [20] with more details, is used in this research as a reference. Experimental and simulated results differ in almost all aspects: overshoot, gain, settling time and deviations in steady state. Neither HAMBASE or IDA ICE satisfies the requirement for direct usage in system control.
Because of negative conclusion, there was no sense to show all simulated variations of HAMBASE model. Thanks to the free access of HAMBASE source code, the mathematical model of the software is extracted and analysed. The analysis determined that heat transfer process in HAMBASE engine is described with second order function and its parameters are defined through Matlab optimisation function *fminsearch*. Optimisation function is highly depended on basic element properties such as wall resistance, capacities, inductivities etc. Authors decided to test if direct identification of such parameters would get better results even same second order function is used. Parameters are also identified by *fminsearch*, but now with directly measured data. Input was thermal response on a step as in Figure 6. Figure 7 shows six different curves as a response of differently parametrised model to the same step. Deviations increases if the values of identification step are more different. This behaviour points out to non-linear characteristics in wide range, but liner in small. By knowing this, authors say that control system may use simple model, but must be capable to adapt.

### III. CONCLUSION

This paper has given a specific analysis of two energy simulators for buildings but applied to a special case of fast thermal transient. The aim was to investigate a possibility of using the simulator’s model as an aid to a control system. Experiments have shown that both models are very sensitive to reduction of dimensions value and to a time constant of the thermal process. However, shape of simulated curves remains equal under different model parameters, what indicates that system response is linear only for certain input range. In such range, second order transfer function is sufficient to estimate observed behaviour. Hence, simple model may be used for system estimation and control, but only in limited area. Everything else is too high over the model’s limitations and would end up with demeaning results. Other solution is control method with ability to adapt and compensate non-linearities.

### REFERENCES


