SIMULATION MODELS FOR TESTING CONTROL SYSTEMS FOR HVAC APPLICATIONS

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ABSTRACT

CEN TC247 has prepared draft standards for main types of room controllers. These standards include a performance testing procedure that was designed to facilitate the introduction on the market of innovative controllers (adaptive controllers, fuzzy controllers...). The test procedure is based on the connection of the real controller to be tested to a virtual building and technical plants.

The objective of the study which is part of the European SIMTEST project [Simtest 98], [CEN 99] is the development of a testing method by emulation for control systems for heating ventilating and air conditioning applications.

This study was focused on the development of numerical models of building and HVAC systems, which are the core of the test facility.

The models developed are adapted to the needs of HVAC controller design and test. They take into account static and dynamic phenomena, which are necessary to assess, control functions in terms of comfort and energy consumption.

These models are adapted to the test of all controllers, which are in the scope of the three draft standards CEN TC247, in particular to controllers for heating systems, fan coils, variable air volume systems and chilled ceilings

We present in this paper:

1) The testing method developed including the simulated environment with its models, the interfaces and the test procedure,

2) The validation of the testing method by inspection and comparison of the results obtained by emulation to the results obtained by real tests in a cell. Each application is tested with two different controllers: a high performance and low performance controllers. The same controllers are used in the two different testing methods.

INTRODUCTION

The idea of testing control systems by connecting them to a virtual building and HVAC system was first widely developed within the Annex 17 of the International Energy Agency, which involved European as well as American research laboratories. The final report of this annex was published in 1993 and proves that the approach was technically feasible. At least 6 test benches were developed at that time in Finland, Belgium, the Netherlands, United Kingdom, France and the United States of America. Numerous publications [Annex 17 -92], [Annex17 -93], were made and two symposiums on that topics were organised by ASHRAE in 1991 [Ashrae –91] and 1994 [Ashrae -94]. No control manufacturer was involved in this annex. Although they developed their testing facilities in house [Gruber -86]

The aim of this study, which is part of the European SIMTEST project, is to develop a testing method for controllers by emulation that allows to validate the controllers by the manufacturers and testing laboratories with a reasonable effort. The method should not be restricted to a small group of simulation experts within the research community. The main innovation consists in the clarification of the testing procedure and in the development of a test environment that is easy.

THE PRINCIPLE OF TESTING METHOD BY EMULATION

- **Test Principle**

The test principle relies on the testing of a real controller against a set of examined criteria.

A simulator including building zone and HVAC plant models within Matlab/Simulink environment emulates the environment of the real controller.

The link between real and simulated environment is achieved using a data logger and interfaces, mainly a sensor side interface and an actuator side interface.

The sensor side interface converts the indoor temperature calculated within the zone model to a signal that the controller temperature input can process. This is done in the considered cases by a sensor resistance simulator.

The controller determines then the control signal for the valve control. This controller output signal is used for controlling a real valve. So the real drive and actuator are used because many control algorithm are adapted to specific drives. The valve position is then measured by the actuator side interface. Its output signal is fed back into the simulator via the data logger. The data logger might convert other signals of the controller like the fan speed signal.

The acquired data are then finally used in the simulator to calculate the new heating/cooling flux supplied to the building zone model resulting in a new indoor temperature.
The following figure shows the layout for the testing:

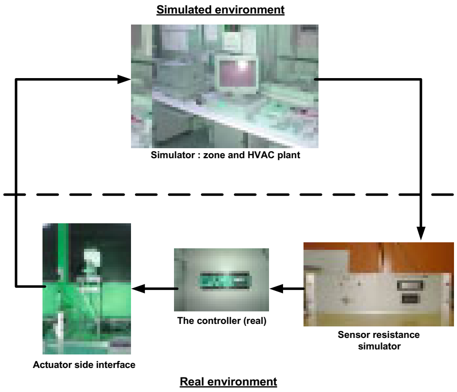

Figure 1: System layout

- **Testing procedures [Simtest WP5 –01]**

- Test parameters

Tests are conducted by simulating three periods of 20%, 50% and 80% load conditions for HVAC emitter during heating and cooling tests.
Tests are performed with the following parameters:

Parameter	Heating	Cooling
Temperature set point	20 °C	24 °C
Initial zone temperature	20 °C	24 °C
Outdoor temperature	-4 °C	30 °C
Internal gains	See table 2	See table 2
Test run duration	9 hours	9 hours

Table 1: Test parameters

- Time parameters

The test is split into 6 periods to evaluate the zone controllers performance at three load conditions, when the controller output is in the process of stabilising (following a change in load condition) and when the output is considered stable (following time period T1) as shown in table:

Period	Internal gains	Heating load	Cooling load	Start time	Finish time
1	0% gain transient	80% load ts	20% load ts	180s	T1
2	0% gain steady state	80% load ss	20% load ss	T1	T2
3	30% gain transient	50% load ts	50% load ts	T2	T2 + T1
4	30% gain steady state	50% load ss	50% load ss	T2 + T1	2 x T2
5	60% gain transient	20% load ts	80% load ts	2 x T2	2 x T2+ T1
6	60% gain steady state	20% load ss	80% load ss	2 x T2 + T1	3 x T2

Table 2: Time parameters

With: T1=2700s, T2=10800s

- Temperature Control accuracy classification

Classification of temperature control accuracy is dependant upon Control Accuracy (CA) and Control to Set point Accuracy (CSA).
For the purposes of testing, CA and CSA are calculated at two points in time:
1. Immediately following a load condition change (index ts).
2. When the load condition has stabilised (index ss).
Control Accuracy is the ability to maintain a constant zone temperature at a given set point and load condition. CA is defined as the maximum peak-to-peak amplitude of zone temperature hysteresis.

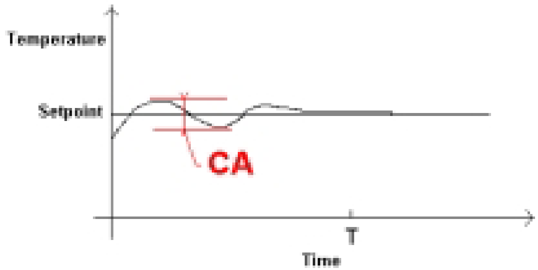

Figure 2: Control accuracy

The two values of CA are given by the following equations:

$$CA_{ts} = \underset{periods\ 1,3,5}{Max} \left| Tin_{\max} - Tin_{\min} \right|$$

$$CA_{ss} = \underset{periods\ 2,4,6}{Max} \left| Tin_{\max} - Tin_{\min} \right|$$

Control to set point Accuracy is defined as the maximum difference between the mean zone temperature and set point

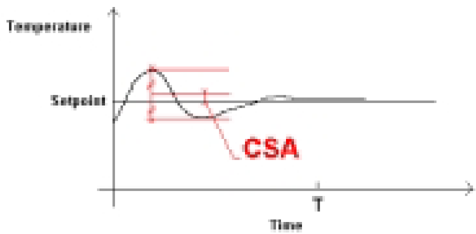

Figure 3: Control to set point accuracy

The two values of CSA are given by the following equations:

$$CSA_{ts} = \underset{periods\,1,3,5}{Max} \left| \frac{Tin_{\max} + Tin_{\min}}{2} - \text{Setpoint} \right|$$

$$CSA_{ss} = \underset{periods\,2,4,6}{Max} \left| \frac{Tin_{\max} + Tin_{\min}}{2} - \text{Setpoint} \right|$$

Classification table

The Temperature Control Accuracy Classification (TCAC) of a zone is defined by a combination of CAts, CAss, CSAts and CSAss as detailed in table below.

Class	CAts	CAss	CSAts	CSAss
1	<=1 K	<=0.5 K	<=1K	<=0.5 K
2	<=2 K	<=1 K	<=2 K	<=1 K
3	<=4 K	<=2 K	<=4 K	<=2 K
4	<=6 K	<=3 K	<=6 K	<=3 K

Table 3: Classification table

The worst result between the four classification parameters gives the class of the controller.

- **Test facility description [Simtest WP5 -01]**

The test bench for the controller environment is composed of 4 main elements:

1 - The simulated environment including the building zone and HVAC system models.

2 - The temperature sensor resistance simulator (sensor side interface): The function of this interface is to output a resistance, which is recognised by the controller as a temperature sensor signal.

3 - The actuator interface: The function of this interface is to output a 0-10 Volt signal representing the real drive shaft position. In the case of the fan coil and the VAV application, the actuator interface includes additionally the fan signal of the controller.

4 - The data acquisition system: It could be a data logger, or considering the small number of measurement points, a built-in PC card. Two different types of measurement inputs are needed: digital and analog inputs.

THE SIMULATED ENVIRONMENT: THE MODELS USED [Simtest WP3 -01]

It includes the building zone and HVAC system models: this part depends only on the application used and not on the equipment used. The person who performs the tests doesn't have to change this part of software; it's automatically generated when the application is chosen. :

For each of the four applications, the simulated environment contains six main blocks:

- Building block,
- HVAC system block,
- «Real Test Bench» block which includes the S-function written in C language for communication purposes between the simulator and the interfaces,
- «Bench in» block which connects the model output (air temperature) to the S-function that is needed to control the sensor side interface (variable resistance box),
- «Bench out» block which connects the S-function needed for transmitting the outputs coming from the controller (e.g. fan speed command) and the actuator side interface (e.g. valve position) to the HVAC system model.

A display box showing a display and a scope for each data collected to be recorded in the result file.

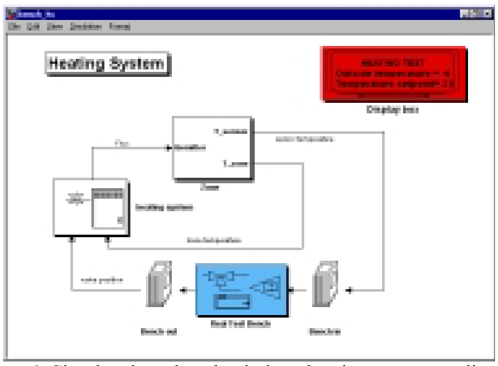

Figure 4: Simulated test bench window: heating system application

- **The building block**

For this block, two models are used: model of zone and model of sensor.

The model of zone is a simplified third order model with three temperature nodes. It represents the static and dynamic behaviour of a building structure facing external and internal excitations.

The model uses the 'thermal – electrical' analogy representation. A reduced number of parameters are needed: 3 capacitors and 5 resistances. It is in the state space form with the air temperature, resultant temperature and temperature of heavy walls as state variables. The radiant and operative temperatures are then deduced as additional output variables. The model is basically a linear model.

Inputs	- Outdoor air temperature - Emitted power vector from the emitter: convective and radiant parts - Integration of internal and solar gains
Outputs	- Zone air temperature - Zone resultant temperature - Zone radiant temperature - Zone operative temperature
Parameters	- The five resistances and 3capacitors calculated from data of zone description

Table 4: Model of zone: inputs-outputs-parameters

The model of the sensor uses the air and the radiant temperature given by the model of the zone to model the temperature measured by the sensor. The parameters of the sensor model are the time constant of the sensor and the weighting factor of air temperature.

- **HVAC system block**

This block depends on the application used:

- Heating application: The block contains the model of radiator and the model of two-way valve.

For the modelling, the radiator is divided into four identical portions connected in series, leading to a fourth order system. Each portion is characterised by it's temperature that is the mean water temperature of the

portion, by the flow rate through the portion and by the heat content of the water and the heat content of the metal of the radiator.
The emission law of each portion is a non-linear function of the difference between the temperature of this portion and the zone resultant temperature that is supposed to be homogenous.
The model of the two-way valve is a non-linear static model that outputs the water flow in the direct circuit following the measured valve position.
The parameters of the valve are it's authority and the coefficient Kvs: nominal flow rate with the valve fully open at pressure drop of 1 bar and the valve characteristic that is the Kv/Kvs as a function of the valve position. Kv is the flow through the valve for the valve positions between 0 and 1 at pressure drop of 1 bar.

Inputs	- Hot water supply vector : Inlet water temperature and flow rate - Zone resultant temperature
Outputs	- Hot water return vector :water return temperature and flow rate - Emitted power vector : convective and radiant emitted power
Parameters	- The radiator characteristics (metal and water) - The emission law exponent

Table 5: Model of hot water radiator: inputs-outputs-parameters

- Fan Coil application: The block contains the model of the fan coil and the model of the diverting three-way valve.

The fan coil model used is a 4 pipes system.
The model is an assembly of two essential models that represent the components of the fan coil: the fan and the coils.
The model of fan assumes that the fan is working in its nominal conditions and that all heat dissipated by the electric motor is transferred to the air.
The model of coil (heating or cooling) is based on detailed geometrical data (the coil description). From these geometrical data, the heat transfer coefficient and the bypass factor are determined. Then the water and the air outlet conditions as well as the heat transferred are calculated. The model takes into account the thermal capacity of the coil in order to give a better expression of the coil performance in transit conditions (first order model). The model assumes that a part of the airflow from the fan coil is directly circulated to the fan and not mixed to the air in the zone.
The model of the diverting three-way valve is a non-linear static model that outputs the water flow in the direct circuit following the measured valve position. The parameters of the valve are it's characteristic (linear/exponential), its coefficient Kvs, its leakage coefficient and it's authority.

Inputs	- Fan speed command - Cold water or hot water supply vector: inlet water temperature and flow rate - Zone air temperature
Outputs	- Return water vector: water return temperature and flow rate - Emitted power vector : convective and radiant emitted power
Parameters	- The coil geometrical data and material, - The nominal fan speeds of the fan and the corresponding electric consumption - The recycled air fraction

Table 6: Model of fan coil: inputs-outputs-parameters

- Chilled ceiling application: The block contains model of chilled ceiling and model of mixing three-way valve.

The model of chilled ceiling is based on first order differential equations representing the heat flow between the water, pipe, panel and air node. A fictitious bulk water temperature is derived from the water inlet and outlet temperatures, and used to determine the heat exchange between the pipe and the water.
The model of the mixing three way valve outputs the water flow in the direct circuit following the measured valve position and the resultant temperature of the mixed flow in the mixed circuit The parameters of this model are the same as for the model of the diverting three way valve.

Inputs	- Cold water supply vector: Inlet water temperature and flow rate - Zone air temperature - Zone surface temperature
Outputs	- Water return vector :water return temperature and flow rate - Emitted power vector : convective and radiant emitted power
Parameters	- The panel characteristics (physical and geometrical data) - The panel radiant coefficient to zone

Table 7: Model of chilled ceiling: inputs-outputs-parameters

THE TESTING METHOD VALIDATION [Simtest WP4 -01]

Validation principle

After the models of the various heating and cooling components and of the zone have been developed and tested with simulated inputs, they have been validated by two types of tests: by open loop tests and the by closed loop tests. Figures 6 and 7 show how the validation was done. Both figures exhibit a similar structure: two paths from left to right and inputs acting on these two paths. The upper path represents the measurements in the real test cell and the lower path the simulation or the emulation. Both the open loop and closed loop tests were done in the following steps:

1) All the initial conditions of the components and the zone and all the input profiles of control input and disturbance inputs are defined.
2) The test cell is initialised with the proper initial conditions.
3) Tests with the test cell are performed and the important variables of the emitter, zone, control input and disturbances are recorded. The list of variables include temperatures, flows, valve control signal, loads, etc. The time interval for recording was a half minute to minute interval. The number of stored variables is high in these experiments. This is indicated with the strong arrow at the output of the real zone.
4) The simulator and emulator environment is initialised in a proper way to the same initial conditions as the test cell before. This can be done by either computing the steady state conditions of the state of the models (and the controller in the closed loop case) or by allowing a certain simulation time in the beginning of the tests for the initialisation.
5) After the initialisation of the model and the controller is accomplished, the simulated/emulated tests are carried out with the same inputs to the models as in the test cell cases. The internal integration time was set to 5 seconds. Fewer time series are recorded in these simulations because the simulated zone has fewer temperature variables than the real zone that was equipped with many temperature sensors.
6) The obtained time series of the important variables are then compared in the comparison block by inspection and analysis of the data. In an iterative way the model structure and the parameters are tuned such that a satisfactory performance is achieved. This means that several simulation and emulation runs were needed.
7) In some cases it was necessary to repeat some of the measurements by the measurement update loop.

- **Open loop tests**

The open loop tests need simulations and measurements only. No emulation that includes the real controller is needed. The inputs to the models and the real emitter and zone are the control signal and the disturbances acting on the zone. These inputs were defined for each test of each application. For instance six tests were defined for the heating application with the radiator as heating element. In each test one of the inputs (control and disturbance) was varied with a step profile while all the other inputs were held constant.
The tests were also carried out in different test cells depending on the application. As different test cells were used, different set of parameters were needed for the zone model depending on the application. The model of the emitter was also parameterised according to the application.

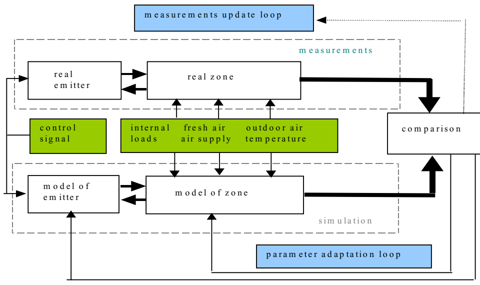

Figure 4: open loop test set up

- **Closed loop tests**

For the closed loop tests several specific features have additionally to be taken into account. First of all the pure simulation has to be replaced by emulation because the controller is real and the models of zone and emitter simulated. Second, the emulation runs in real time in a closed loop which means that all the interfaces between simulator and controller have to be in place. This means all the nonidealities of the components add to the performance of these tests. Third, the inputs to the closed loop set up are chosen differently. Instead of the control signal the constant zone temperature set point is defined as one input. The disturbance input profiles were chosen exactly as they have been defined in the testing procedure. Three different internal loads are defined over the predefined intervals while all the other disturbances are kept constant. The tests have been done for the heating, the fan coil heating and cooling and for the chilled ceiling application.

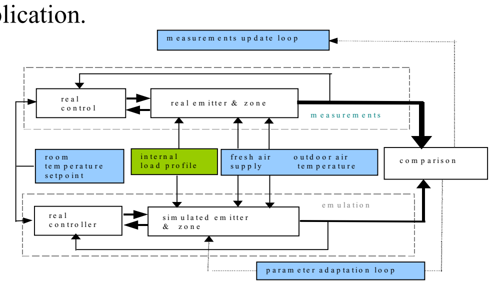

Figure 5: Closed loop test set up

Real test description

In this section we describe only the closed loop test.
The tests were performed for each of the four emitters corresponding to the four applications.
Each test is carried out twice in order to compare the results for two controllers. In the first test, a controller with a good controlling performance is chosen, in the second one a controller with lower performance.
The tests in the heating case (respectively in the cooling case) are carried out for a constant temperature of the cooled wall (respectively heated wall). Two steps are undertaken by changing the internal gain in the zone. It has to be checked that the emitter power is high

enough to achieve the set point temperature in the first period (respectively third period). If the power is not enough, the room temperature set point or the wall temperature has to be changed.
For more clarification, we focus on the heating application test description.

- Tests configuration

The cell is a closed cubic shape room according EN 442 and measuring 4 m x 4 m x 3 m in height. Walls, floor and ceiling consist of water flowed metal plates. One wall rests uncovered in order to simulate an external wall or window. All other surfaces are covered with a joint-sealed thermal insulation of 100mmlayer thickness (thermal conductivity < 0.04W/(K). The emission rate of the inner surfaces is at least 0.9. The test cell is tight enough to prevent any flow from the outside.
The emitter is a flat plate radiator without convection fins. The thermal output (according to DIN 4715) is 791W.
Figure 6 shows the configuration of the test cell. The heating load is introduced into the room by a cooled wall. Load simulators are used to simulate occupants. The values for the heat power of the load simulators and the temperature of the cooled wall depend on the test period. The temperature measuring sensors are placed according to figure 6 and table 7. The fresh air supply is shown in figure 6. The air inlet is placed in the external, cooled wall. The air outlet is placed opposite to the cooled wall on the symmetrical axis of the room. Both, inlet and outlet are placed on the upper level in the zone.

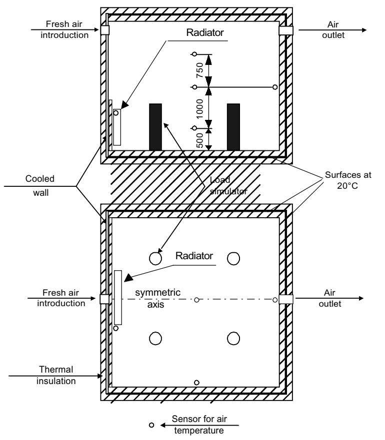

Figure 6: Configuration in the test cell with the radiator

- Load simulators

The load simulators (dummies) are placed symmetrical in the room (see symmetry axis). Their power emission is specified. The radiant and the convective parts are defined since they are used in the simulation. Also the characteristics of the simulators in dynamic conditions are measured.

- Data acquisition

The time step for one cycle of measurements has to be less than 60 seconds. The time step has to be regular, varying steps are not wanted since this would impose problems throughout the simulation.
The measurements are saved at the given time steps in an ASCII file following the specified measurement table.

Test comparison [Simtest WP4 –01], [Simtest WP7 –01]

The evaluation of the closed loop tests has been done in two steps:

1) Comparison of selected variables by inspection of the corresponding graphs.
2) Comparison of the classification criteria and the result of the classification.

The comparison 2) is seen in a relative perspective, which means that a classification ranking obtained by measurements should not be turned upside down by emulation results.

- **Evaluation by inspection**

Generally the following selection of variables are displayed in four different figures:

- measured air temperature at a height of 1.50m and emulated air and sensor temperature,
- measured and emulated water flow rate through the valve,
- measured and emulated water return temperature.

Additionally fan speed and emitted power are displayed for some application. Other variables have also been used for the comparison, are however not displayed here.
The inspection results are given in the table below. The result ‘not comparable’ means that in this case the measurement test was not carried out correctly (stuck valve), the test could however not been repeated and therefore the measurements were not usable.

	Low performance controller	**High performance controller**
Heating	Good	Very good
Fan Coil Cooling	Not comparable	Very good
Fan Coil Heating	Good	Good

Table 8: graph inspection results

Example: Fan coil application – cooling

The stratification of the zone air is here an important issue and was examined by inspection of all the measured room temperatures. Comparing the emulated air and sensor temperatures to the measured 1.5m air temperature show a very good correspondence for the sensor and the air temperature. The cold airflow circulates differently as the hot air flow, so this might

be a reason for the better correspondence in the cooling case. Flow rates and water return temperatures show some differences, which might be caused by some nonmatching boundary conditions (maximal flow rate, inlet temperature). A nice correspondence can also be seen in the switching of the fan stage control signal.
The set point of 25° was only attained in the first disturbance period. The control strategy of the controller seems to be such that first the valve opens fully and then the next fan stage is activated if a certain neutral zone is surpassed. It can be stated that the overall correspondence is very good.

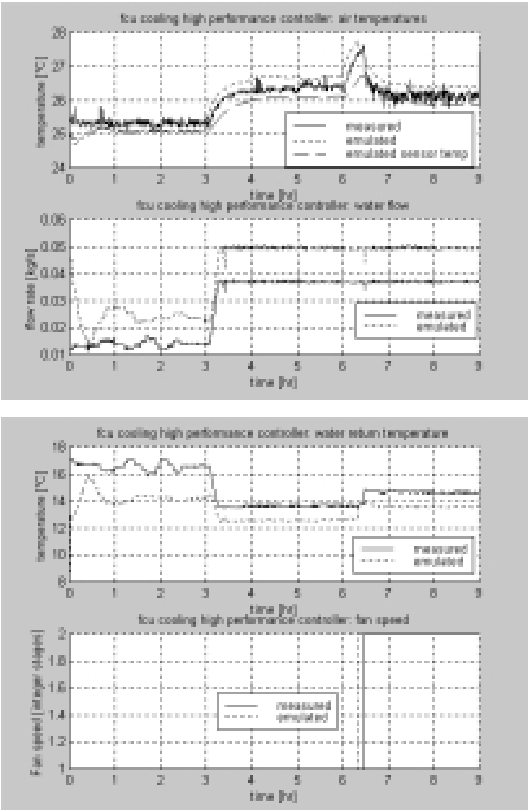

Figure 7: Test results of the fan coil –cooling application

- **Evaluation by classification**

The following table shows the classification results that have been obtained by emulation (E) and measurements (M) for all the tests with the low performance (L.P.) and high performance (H.P.) controllers. In border cases the numerical value of the performance is indicated (e.g. 4/2.02). The numerical values were obtained by applying the equations for CA and CSA. The class numbers are in the last column. For border cases the adjacent class is put in brackets (e.g. 4 (3)).

		CAts	**CAss**	**CSAts**	**CSAss**	**class**
Heating						
H.P.	M	2	4/2.02	2/1.03	3	**4 (3)**
	E	2	4	1/0.94	2	**4**
L.P.	M	3/2.1	4/2.1	2	3	**4 (3)**
	E	2	3	2	3	**3**
Fan Coil	C					
H.P.	M	2		2	3	**3**
	E	2	2	3	3	**3**
L.P.	M	3	2	3	4/4.1	**4 (3)**
	E	2	1	3	3	**3**
Fan Coil	H					
H.P.	M	2	3	2	3	**3**
	E	2	2	2	3	**3**
L.P.	M	2	2(3) /1	2/1.05	2/0.95	**3 (2)**
	E	2	1	1	3	**3**
Ch.Ceil						
H.P.	M	1	1	2	3	**3**
	E	2/1.1	1	2	3	**3**
L.P.	M	1/0.9	2	3	4	**4**
	E	3	4	3	4	**4**

Table 9: Classification results (C: Cooling, H: Heating)

The following remarks can be drawn from these results:
The classes obtained are high, 3 or 4. Additionally no big distinction can be observed between low and high performance controller. These facts might be an indication, that the definition of the classes has to be changed.
The difference in classes between measurement and emulation is good. There are only two cases (Heating low perf. and Fan Coil Cooling low perf.) where the matching is not okay. It is clear however that both cases are border cases (numbers in brackets are borderline cases between two classes).
The ranking is consistent except in the heating application. The emulated low performance case achieves class 3, which is not consistent with the emulated high performance case and the measured low performance case with class 4 each. That application is insofar special that no constant steady state is attained. So the periods where steady state measures are evaluated are periods with limit cycles, which are the same as in the preceding transient periods.
The deciding classes from the table are all results of steady state classes. So the steady state class definition might have to be altered in order to weaken this dominance. Also the definition of the different period lengths for the evaluation have to be reconsidered.

CONCLUSION

It has been shown that simulation models for testing control systems for HVAC applications have been successfully developed and implemented in the MATLAB/SIMULINK environment. The models have been especially developed with towards testing applications, meaning that the important modelled features are selected such that they are sufficient for these applications. The models have been validated in

open loop and closed loop For the closed loop cases, the test bench including all the interfaces between the simulated environment (models) and the real controller was also validated by comparing measurements with real test cells with the emulated tests. The graph inspection and the classification comparison showed a very good correspondence between the measured and emulated controller testing methods for the three applications studied: heating application, fan coil (heating and cooling) and chilled ceiling application.
The emulation method was successfully validated such that it is accurate, is reproducible and is ready for inter laboratory comparisons.

BIBLIOGRAPHY

Simtest -98] SIMulation models for TESTing control systems for heating ventilating and air conditioning application, CEC DGXII C-O, contract N° SMT4-CT.

[CEN 99] Electronic Individual Zone Control Equipment for Heating Applications, Electronic Individual Zone Control Equipment for Fan coil and Induction Unit Applications, Electronic Individual Zone Control Equipment for VAV, CAV and chilled ceiling applications, Draft European Standards prepared by CEN TC247 WG2.

[Annex17 -93] Development of emulation methods, VTT research notes, ISBN 951-38-448-X.

[Annex 17 -92] Simulation and emulation of HVAC systems – meeting in Liège, CSTB research notes, CSTB reference: GEC/DGE 930.9R, CSTB, France, September 1992.

[Ashrae –91]:

- Haves P., Dexter AL., Jorgensen DR. et al. Use of a building emulator to evaluate techniques for improved commissioning and control of HVAC systems, ASHRAE trans.1991, vol.97, paper number NY-91-9-3, 684-688, 7 figs,refs.
- Kelly GE. Park C., Barnett JP. Using emulators/testers for commissioning EMCS software, operator training, algorithm development and tuning local control loops. ASHRAE trans.1991, vol.97, Part 1, paper number NY-91-9-1, 669-678, 14 figs., 1 tab.,refs.
- Laitila PK., Kohonen RO., Katajisto KI. Et al. An emulator for testing HVAC systems and their control and energy management systems, ASHRAE trans.1991, vol.97, paper number NY-91-9-2, 679-683, 8 figs., 1 tab., 3refs.
- Liebecq GA., Nusgens PJ., Wang S., Technical aspects of the design of an emulator for building energy management systems. ASHRAE trans. 1991, vol.97, Part 1, paper number NY-91-9-4, 689-693, 10 figs., 2 tabs.,refs.

[Ashrae –94]:

- Karki SH., Lappalainen VE., A new emulator and a method for using it to evaluate BEMS, ASHRAE trans.1994, vol.100, Part 1, paper number NO-94-23-5, 1494-1503, 10 figs, 9 tabs., 14 refs.
- Kelly GE., May WB., Kao JY. et al, Using an emulator to evaluate the performance of building energy management systems, ASHRAE trans. 1994, vol.100, Part 1, paper number NO-94-23-4, 1482-1493,1 fig, 3 tabs.,refs.
- Peitsman HC., Wang S., Karki SH., Park C., Haves P., The reproductibility of tests on energy management and control systems using building emulators, ASHRAE trans.1994, vol.100, Part 1, paper number NO-94-23-1, 1455-1464, 13 figs, 2 tabs., 9 refs.
- Visier JC., Vaezi-Nejad H., Jandon M., Henry C., Methodology for assessing the quality of building energy management systems, ASHRAE trans. 1994, vol.100, Part 1, paper number NO-94-23-3, 1474-1482, 7 figs, 2 tabs., 9 refs.
- Wang S., Haves P., Nusgens P., Design, constructon and commisionning of building emulators for EMCS applications, ASHRAE trans.1994, vol.100, Part 1, paper number NO-94-23-2, 1465-1473, 6 figs, 17 refs.

[Gruber -86] P.Gruber, A.Duppenthaler: PVHS – Ein Simulator von polyvalenten Heizsystemen, 4.Schweitzerisches Status-Seminar Energieforschung im Hochbau, 2./3. Oktober 1986, ETH Zürich.

[Simtest WP3 –01] Lahrech R. Simtest project, Models description –level 2. Reference: ENEA/AGE – 00.066R.

[Simtest WP4 –01] Gruber P.,Lahrech R., Riederer P. Simtest project, Model validation Reference: ENEA/AGE –00.071R.

[Simtest WP5 –01] Bruyat F., Lahrech R., Tessier Ph. Simtest project, Quality assurance procedure. Reference: ENEA/AGE-99.132R.

[Simtest WP7 –01] Lahrech R., Shumacher M. Simtest project, Intercomparison of tests results.