to Rh, T and CCD respectively. The errors e_{km} and the control actions u_{km} are computed via simulations of the two-variable and the SISO FLC systems in Fig. 5 in a MATLAB^{TM}- Simulink model [19] using the derived two- variable TSK plant model for Rh and T and the ZN SISO model for CCD instead of the real plant. The fitness functions combine two criteria to ensure good system performance and energy efficiency of the control – one related with the system error reduction, and another linked to the minimization of the control effort used.

The optimal tuning parameters computed are: $\mathbf{q}_{FLC1,2}$=[K_{e1}=0.3, K_{d2}=1.9, K_{p1}=1.8; K_{e2}=0.8, K_{d1}=2.6, K_{p2}=1.3]; $\mathbf{q}_{FLC3}$=[K_y=1/600, K_{d3}=0.02 , K_{p3}=0.2].

4 Real Time Fuzzy Logic Control of Air Humidity, Temperature and Carbon Dioxide Concentration

The designed FLCs are implemented in a Simulink model for real time control of Rh, T and CCD in the laboratory HVAC in Fig. 1. The Simulink model follows the block diagram in Fig. 3 where Simulink blocks for connecting the model to the interface board are added - ‘Analog Input’ (drivers) for reading of the measured values for the variables from the ADC and ‘Digital Output’ (drivers) for passing the PWM pulses to the DO for control of the SSR [22]. The step responses to reference changes of Rh and T from real time control are presented in Fig. 7 together with the process of compensation of the increased CCD by the FLC_3 control of the ventilation. The coupling effect between Rh and T is reduced and observed only in y_2 for t=0÷1000,s when the reference for Rh y_{1r} is stepwise changed by 5%. The changes in y_{2r} are well compensated in y_1 and the changes in CCD (y_3) are compensated both in y_1 and y_2. The main channels reference step responses y_{1r} - y_1, y_{2r} – y_2 and the disturbance rejection in y_3 have short settling times – t_{s1}=400,s, t_{s2}=900,s and t_{s3}=1200,s. The step responses have no overshoot – an evidence for energy efficient economic control.

The control algorithm in Fig. 5 is programmed in a PLC SIEMENS SIMATIC S300 using also SIEMENS SIMATIC WINCC and Fuzzy Control [23]. The analog signals from the transmitters for humidity and temperature in the range [2, 10], V are converted by the PLC ADC to integer numbers in the range [6400, 32767]. So, the conversion of the ADC output to values of the physical variable requires scaling - for the air relative humidity 6400=0%; 32767=100% and for the temperature 6400=-30°C; 32767=70°C. After the scaling an exponential filter filters the measurement noise. Then the algorithm follows the diagram in Fig. 5. The PWM is connected to the digital outputs of the PLC that control the SSRs for the humidifier, the electrical heater and the fans.

A designed operator panel enables switching among different screens for:

- display of various mnemonic diagrams of the control system

- input of the parameters of the controllers, the filters and the PWM, also the references and the schedule for their change, the bounds and the initial values of the signals and the limits for the anti-wind up for the integration, the sample periods for control and for archiving;

- selection of modes of operation among: programming, manual and automatic control; control only of one variable - Rh, T or CCD; control of two selected variables; control of all the three variables; in manual control plant identification is enabled;

- display of the values and the graphs of the output variables, the references and the control actions;

- start and stop of the real time operation and interruption by an operator for new input or mode selection – at ‘start’ the initial values for the variables and the control are set equal to their current values, at ‘stop’ the final values ensure safety closing of the real time operation, e.g. switching off the heater and the humidifier, operation of the fans at high speed for several minutes.

A desired screen can be selected by the help of the functional buttons on each screen.

In Fig. 8 the screenshots of the mnemonic diagram of the two-variable FLC system and the step responses of air humidity and temperature, their references and the control actions are displayed.

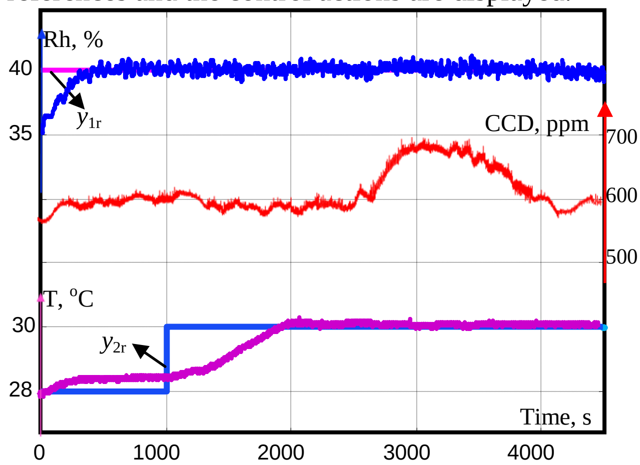

Fig. 7. MATLAB^{TM} real time FL control of Rh, T and CCD of a laboratory HVAC system

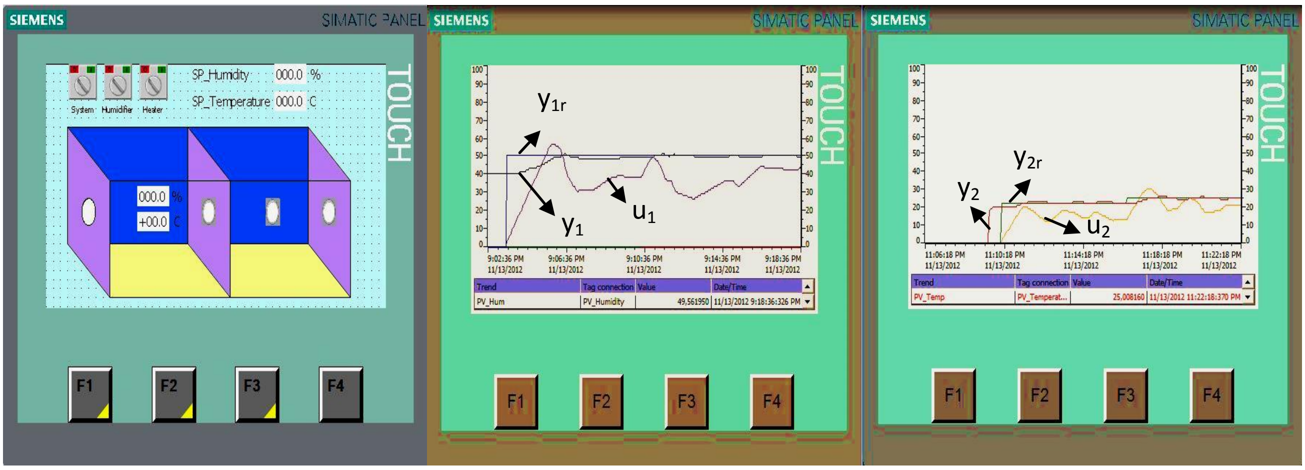

Fig. 8. Screenshots from real time two-variable PLC-FL control of Rh and T of laboratory HVAC

5 Conclusion

The novelty of the research presented in this paper concludes in the following. An approach for the design of FL controllers is developed for the most important variables for the indoor human comfort – the air relative humidity, temperature and CCD, accounting for their coupling. It is based on the application of GAs optimization in both the derivation of a nonlinear two-variable transfer functions based TSK plant model from experimental data and the off-line tuning of the parameters of the FLCs. The tuning criterion is formulated by a suggested fitness function that combines two requirements – for high systems accuracy (minimization of system error), and for minimal energy for control. The FLCs are intended for and used in real time control of the three variables in a laboratory HVAC system. The experimentally recorded transient responses have short settling times and no overshoot – an evidence for good systems performance and economic controls. The FLC algorithms are fast and simple and are easily programmed in a PLC. The PLC-FLC real time control confirms the good systems performances and the economic controls.

The future research will focus on application of the approach to other important with respect to energy savings and difficult to control plants.

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