International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-3, Issue-9, February 2014

Direct Digital Control of HVAC System and CO_2-Based Demand Controlled Ventilation

Viktor Iliev, Darko Babunski, Igor Seso, Saso Andovski

Abstract ***- In modern world, 'saving' or 'cut down costs' are commonly used expressions. As an answer to the demands, the idea of integrated facility management and building automation, as part of it, has been proposed and recognized. While overall operating costs of a building may represents as much as 75% of all the expenses incurred on the building, they can be reduced 25% by means of integrated facility management comprising all system functions during the life cycle of the building which is one step closer to energy efficient and environmental aware buildings. That is the point that is worth thinking.***

This paper presents simulation model and structure of a SCADA application for Direct Digital Control(DDC) of HVAC (Heating Ventilation and Air-Conditioning) system in cooling/heating mode and design a system that provides suitable air quality in school through the existing air conditioning system using CO2-based demand controlled ventilation. For simulation of this applications, PLC model number Siemens S7-200 is used, extended with an analog module EM235. Program package Micro WIN Step7 is used for control algorithm creation. SCADA application in software package WinCC is used for visualization and monitoring the work of the HVAC system.

Index Terms — HVAC system, PLC, SCADA, DDC, CO2 demand controlled ventilation.

I. INTRODUCTION

HVAC systems are more frequently applied in industrial facilities as well as in living compounds and offices [1]. Full automatic control of these systems is inevitable. As object of full automatic control and regulation these systems represent complex structure comprised of large number of electrical, hydraulic and pneumatic components [2]. Basic task for HVAC systems is conditioning of fresh air for heating, ventilation and cooling of certain room. Basic parameters of air that need monitoring are temperature and humidity. Their value depends on outside air temperature (outside temperature) and values required (given) by the user of HVAC system for purpose of regulation of managed components. For this reason it is necessary to produce system capable of controlling the required parameters. By using the signals given by the sensing elements (sensors), control system is performing full (or partial) automatic control of HVAC system by managing mainstream components.

The basis of using CO_2 for ventilation control is established in well-quantified principles of human physiology.

All humans, given a similar activity level, exhale CO2 at a predictable rate based on occupant age and activity level. This relationship is described in ANSI/ASHRAE standard. As a result, CO_2 can be used as a good indicator of human bio effluent concentration and/or occupancy (i.e. doubling the number of people in a space will approximately double CO_2 production).

II. REAL HVAC SYSTEM CONFIGURATION

As example, real HVAC system comprised of following components will be analyzed:

Air-handling unit (AHU) for distribution of fresh air [3], (Fig.1),

- Air flapper valve
- Air filter
- Heat recuperator (water/air)
- Heat exchanger (water/air)
- Humidifier
- Pressure and suction fans

Fig.1. Air-handling unit

Pumps for heating/cooling medium (water) recirculation,

- Heat recuperator pump
- Heat exchanger pump

Control valves,

- Three way electric valve
- Electromagnetic valve

Sensing elements,

- Internal temperature thermostat
- External temperature thermostat
- Filter differential pressure sensor
- Fan differential pressure sensor
- Heating/cooling medium temperature sensor
- Three way valve electric actuator
- Air-conditioning chamber air pressure sensor
- Freezing protection
- Air humidity sensor

III. DIRECT DIGITAL CONTROL ENVIRONMENT DESCRIPTION

Direct Digital Control (DDC) is intelligent control system [4] that has ability to measure, regulate, control, and monitor operation of HVAC systems. Monitored parameters are: room temperature, heat exchanger outlet temperature,

Manuscript received February, 2014.

Viktor Iliev, University of Ss. Cyril and Methodius, Faculty of Mechanical Engineering, Skopje, Macedonia.

Darko Babunski, University of Ss. Cyril and Methodius, Faculty of Mechanical Engineering, Skopje, Macedonia.

Igor Seso, University of Ss. Cyril and Methodius, Faculty of Mechanical Engineering, Skopje, Macedonia.

Saso Andovski, Mechanical engineer, Pharmaceutical industry, Skopje, Macedonia.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

humidity, room exhaust air temperature, freeze protection, filter differential pressure and pressure/suction fans differential pressure.

Ability of the system to be controlled automatically depends on configuration of regulating components (PLC controller) [5]. System program ensures logic for control and management of mainstream components: fans, pumps, actuators and valves according to required (adjusted) parameters. System schematic is shown on Fig.2. Operation of the HVAC system [2]: Fan F1 (pressure fan) draws outside air that passes through pressure line of the air-handling unit that is through air filter, heat recuperator, heat exchanger, humidifier and enters the air-conditioned room.

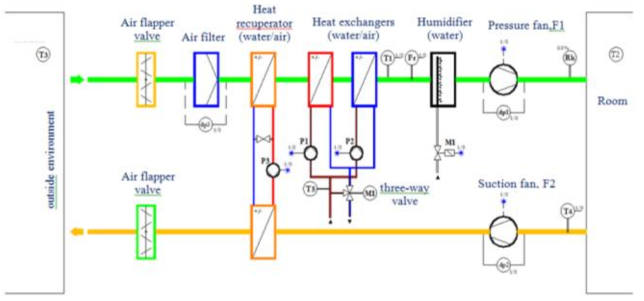

Fig.2. HVAC system schematic

This air has conditioned parameters according to requested from the operator. Air temperature is regulated by turning on and off the heating/cooling pumps and by utilization of three-way electrically actuated valve which enables regulation of heat exchanged through air heat exchangers. Humidity level is achieved by humidity sensor which sends signal to the control system for turning on and off the electromagnetic valve. Heat exchanger freeze protection is achieved by positioning of sensor. If air temperature decreases bellow certain level (for example -15°C) fan shuts down, inflow of air is interrupted and heat exchanger three way electrically actuated valve opens (up to 100%).

Filter clogging is prevented by installing a differential pressure sensor that sends signal for system shut down in case differential pressure reaches certain level. Air flow control and fan operation verification is achieved by utilizing pressure sensors installed at fan positions.

In case when air flow is below predetermined level differential pressure sensors send alarm signal for system shutdown. Recuperator is used to utilize heat (cool) energy of the exhaust air coming from the room. Fan F2 (suction fan) draws inside air that passes through suction line of the air-handling unit.

IV. SIMULATION MODEL

In order to achieve the main goal-building a simulation physical model of Direct Digital Control of HVAC system, Programmable Logic Controller (PLC) type Siemens SIMATIC S7-200 with CPU212 and additional analog module EM235 as extension [6]. All mainstream and sensing system components are connected to the control system. Analog and Digital inputs/outputs are:

Digital Inputs (DI) in S7-200 [7],
1→ START,
2→ T1 – Air-handling unit thermostat, power supply 230 VAC, range 0 ~ 85 [°C],
3→ T2 – Room thermostat, power supply 230 VAC, range 0 ~ 30 [°C],
4→ dp1 – Fan F1 differential pressure transmitter, power supply 230 VAC, range 5 ~ 500 [Pa],
5→dp2 – Fan F2 differential pressure transmitter, power supply 230 VAC, range 5 ~ 500 [Pa],
6→ dp3 – Filter differential pressure transmitter, power supply 230 VAC, range 5 ~ 500 [Pa],
7→ Fr – Freeze protection, power supply 230 VAC, range -10 ~ 12 [°C],
8→ rF% – Humidity sensor, power supply 230 VAC, range 30 ~ 100 [% rF].

Digital Outputs (DO) from S7-200
1→ F1 – Air pressure fan,
2→ F2 – Air suction fan,
3→ P1 – Heat exchanger pump,
4→ P2 – Heat exchanger pump,
5→ P3 – Recuperator pump,
6→ M1– Humidifier electromagnetic valve, power supply 230 VAC, normally closed.

Analog Inputs (AI) in S7-200 (EM235 module) [7],
1→ T3 – Outside Air Temperature sensor, power supply 24 VAC, signal 0~10 [V], range -35~70 [°C],
2→ T4 – Exhaust Air Temperature (in the channel) sensor, power supply 24 VAC, signal 0~10 [V], range 0~50 [°C],
3→ T5 – Cooling/heating medium temperature sensor (installed in the pipe), power supply 24 VAC, signal 0~10 [V], range 0~100 [°C].

Analog Outputs (AQ) from S7-200 (EM235 module [7],
1→ EM1 – Three way electrically operated valve, power supply 24 VDC, signal 0/2~10 [V], (opening 0-100%).

For simulating the automatic regulation of HVAC system, physical model of control system is built. In this model, physical components are represented through models for simulation of A/D inputs/outputs over digital inputs simulator (on/off switches), digital outputs signal displays (indication), analog inputs signal convertors (potentiometers 0-10V) and elements for readout of the analog outputs [8], (eg.voltmeter).

Inputs/Outputs of simulation models are made in following order.

Digital inputs SIMULATOR in PLC controller:

Digital inputs	**Component**
System turn ON - START	On/off switch
Air-handling unit thermostat – T1 Sensor	On/off switch

Room thermostat – T2	On/off switch
Fan F1 differential pressure transmitter - dp1	On/off switch
Fan F2 differential pressure transmitter - dp2	On/off switch
Filter differential pressure transmitter - dp3	On/off switch
Freeze protection - Fr	On/off switch
Humidity sensor - rF%	On/off switch

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

ISSN: 2278-3075, Volume-3, Issue-9, February 2014

Digital outputs simulator:

Digital outputs	Component
Fan F1 turned on/off	Indicator (signalization)
Fan F2 turned on/off	Indicator
Pump P1 turned on/off	Indicator
Pump P2 turned on/off	Indicator
Pump P3 turned on/off	Indicator
Humidifier electromagnetic valve M1 - open/close	Indicator

Analog inputs simulator:

Analog inputs	Component
Outside Air Temperature sensor - T3	Potentiometer 0-5 VDC
Exhaust Air Temperature sensor - T4	Potentiometer 0-10 VDC
Cooling/heating medium temperature sensor - T5	Potentiometer 0-10 VDC

Analog outputs simulator:

Analog outputs	Component
EM1 – Three way electrically operated valve	eg. Voltmeter

After defining of all inputs/outputs, parameters for regulation and electrically connecting the PLC controller with process elements, program algorithm for automatic control of HVAC system is designed. Programming is performed with Ladder logic in Micro Win Step7 software [9]. Physical model and electrical connections are shown on Fig.3 and Fig.4.

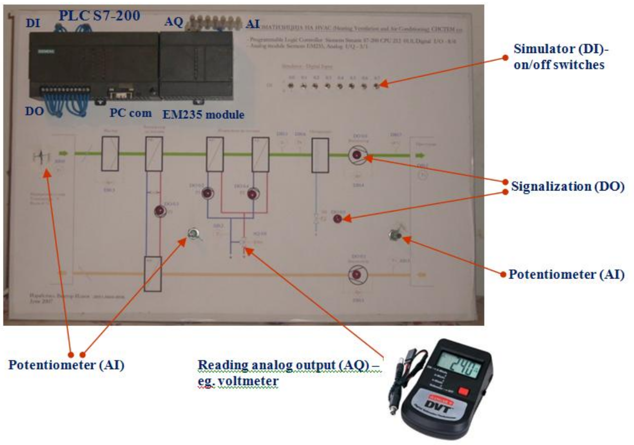

Fig.3. Physical model for Direct Digital Control of HVAC systems

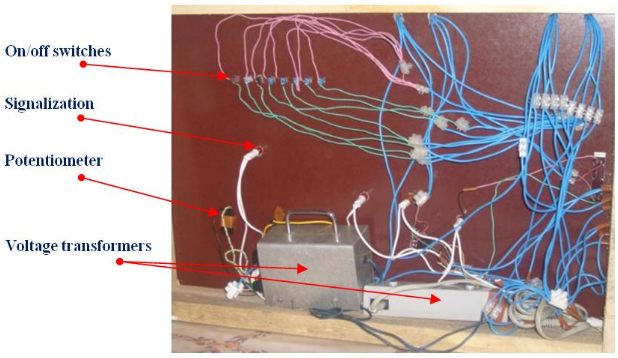

Fig.4. Electrical wiring of the physical model

V. HVAC MONITORING SYSTEM

SCADA application is programmed in WinCC [10] software for monitoring and visualization of HVAC system. This application contains special visual command panels, used for remote control, which allows the operator to perform full process monitoring.

Figure 5 illustrates main command panel in SCADA application. Panel allows adjustments in individual components regulation, for example – the three way electrical valve EM1 (selectable by VALVE - push button). Valve characteristics gives cooling/heating medium temperature in respect to outside air temperature.

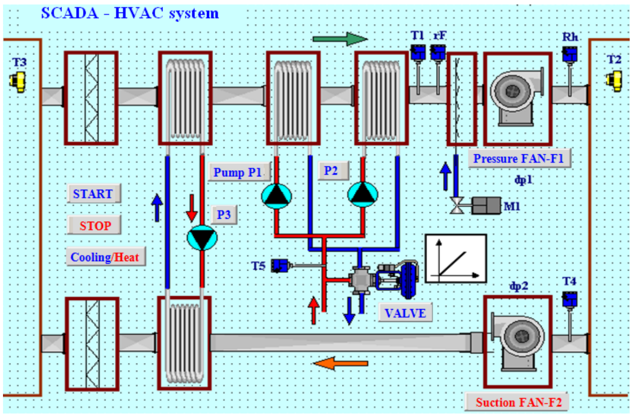

Fig.5. Main panel of the SCADA application for control of HVAC system

VI. CO_2 BASED DEMAND CONTROLLED VENTILATION

One technology for saving energy in HVAC systems is demand controlled ventilation (DCV). DCV impacts overall building sustainability through influence on the total and peak energy consumption of the HVAC system and indoor air quality.

CO_2-based demand controlled ventilation, when properly applied in spaces where occupancies vary below design occupancy, can reduce unnecessary over ventilation while implementing target per-person ventilation rates. A recent interpretation of ANSI/ASHRAE standard [11], has affirmed that carbon dioxide (CO_2)-based demand-controlled ventilation systems can use as an occupancy indicator to modulate ventilation below the maximum total outdoor air intake rate while still maintaining the required ventilation rate per person, provided that certain condition are met.

In this paper the main aim is a design a system that provides suitable air quality in school through the existing air conditioning system (Air Handling Unit). When it comes to air quality, in this case means the content of CO_2 (Carbon Dioxide) in the supply air in the school rooms are air conditioned. Air quality affects health, working ability and comfort of the people and therefore of particular importance to the amount of CO_2 is maintained within the limit. In this case the only source for the generation of CO_2 are the people through the respiration.

Provision of adequate quality is done through the supply of a certain quantity of fresh air that is by regulating the fresh air dampers (FAD-fresh air damper), mixing (MAD-mixing air damper) and exchaust air (EAD-exhaust air damper) which be regulated depending on the CO_2 concentration in air (regulation will be described below). In this case, the CO_2 concentration expressed in ppm (parts per million) which will

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

be control inside the rooms or in supply air is 850 ppm. The outside air CO_2 concentration is 350ppm.

Figure 6 show the existing schematic of Air handling Unit (AHU).

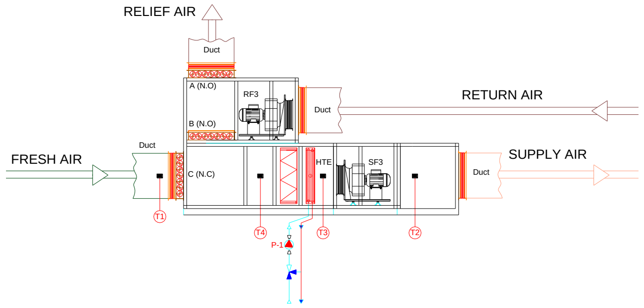

Fig.6. Existing schematic of AHU

VII. Fresh Air-Flow Rate Calculation

The quantity of fresh air needed for a person depends on the CO_2 concentration in outside air and the CO_2 concentration in rooms i.e. in the exhaust air. The quantity of fresh air in this case is. [12]:

$$K+V_{pp}*k_a=V_{pp}*k_i$$

where:

K = CO_2 generation rate per person based for light activity, K = 20 [l/h] CO_2,

k_a = harmful substances concentration in the outside air or in this case that CO_2 concentration is 350 ppm,

k_i = permissible harmful substances concentration in the exhaust air or inside in rooms, in this case CO_2 concentration is 850 ppm,

V_{pp} = fresh (outdoor) airflow rate per person expressed in [m^3/h]

$V_{pp} = K / (k_i - k_a) = 0.02 / (0.00085-0.00035)=40$ [m^3/h]

VIII. DETERMINE TYPE AND LOCATION FOR CO_2 SENSORS

A CO2 sensor [13] for demand-controlled ventilation can be duct mounted or wall mounted. Criteria for selecting sensor location will vary with system type and building specifics. During design, construction, start-up, and continuing operations, the sensor location's role in ventilation control should be evaluated with respect to performance factors, including delivery of design ventilation rate upon controller call for maximum outdoor air intake, and lag time upon call for increased outdoor intake.

Duct-Mounted sensors are typically located in the return airstream of an air-handling system. This approach is best applied where the ventilation system operates continuously and where all the zones served by the air handler have similar levels of activity and occupant densities, occurring at the same time. A duct-mounted sensor is not recommended where the system serves a number of areas with diverse occupancy. A duct-mounted sensor in the return air duct of a system that also incorporates a ceiling return plenum may be subject to error because of building infiltration or supply duct leakage. A CO_2-base DCV system incorporating a duct-mounted sensor should be evaluated and corrected, if required, for ventilation effectiveness in the occupied zone.

Wall Mounted sensors can be installed in a location similarly to a thermostat. The location selected should provide input that provides indication of conditions within the occupied zone. Locations that should be avoided are areas close to doorways or air vents and areas that are within one foot of where people would regularly sit or stand. When using one sensor to represent multiple spaces, the location most critical for ventilation rate delivery should be selected.

In this case CO_2 concentration will be measured through duct-mounted CO_2 infrared gas sensors. Sensors will be located in:

- sensor with tag **3_CO₂T** which measurement the outside air CO_2 concentration, located in the pressure site of the AHU, mounted in the middle line of the duct relative to the height of the duct,
- sensor with tag **2_CO₂T** which measurement the air CO_2 concentration which supply the rooms, located in the main fresh air duct of the AHU, mounted in the middle line of the duct relative to the height of the duct,
- sensor with tag **1_CO₂T** which measurement the air CO_2 concentration which suction from the rooms, located in the main echaust air duct of the AHU, mounted in the middle line of the duct relative to the height of the duct

It is important to note that leakage or suction of air through ducts is not allowed in location where the sensors are mounted because the wrong values of CO_2 concentration and energy losses is a possible. For better regulation and energy saving CO_2 sensors is necessary to check once of year if there is a need to be calibrated.

Selected location of the CO_2 sensors (transmitters) and air damper actuator is shown in Figure 7.

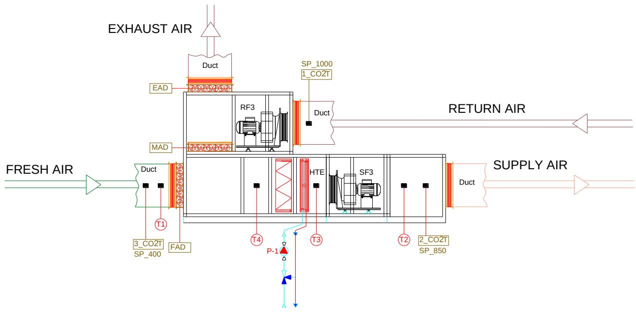

Fig. 7. AHU–Located CO_2 sensors and air dampers (design strategies)

IX. CONTROL SYSTEM FOR CO_2 DEMAND CONTROLLED VENTILATION

The control of a demand controlled ventilation (DCV) system aims at providing quick and correct reactions to changes in the concentration of the selected indicator/contaminant. The reaction should not be influenced by the presence of other substances in the form of gas, vapour or particles (cross-sensitivity). Nor should the reaction be affected by environmental factors such as temperature, vibration electromagnetic fields. Thus, the correct connection of sensors to control system is of the utmost importance, and so is the design and construction of all devices being part of the control system.

Determine type of control approach is one of the most important elements of a system of air conditioning to provide the required air quality, comfort air conditioning though the energy saving. If only considering the air quality control or regulation of CO_2 concentration that will give satisfactory results with P (proportional) regulation. But recognizing the

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

need for regulation of heating and cooling of an air conditioning system in order better i.e. fine regulation without temperature leaps during sudden changes of heat and ventilation load, PID (proportional-integral-derivate) regulation gives the best results.

The existing control system for HVAC system in school is the type Honeywell XL80 that is not possible to provide PID regulation of CO_2 and also no possibility for connecting CO_2 sensors and air damper actuators.

Because of this need to provide a new system that allows PID regulation with the DDC controller. It must be noted that this controller except CO_2 regulation may provide complete regulation of the air handling unit (AHU) of the HVAC system.

X. SEQUENCE OF OPERATION DESCRIPTION

DDC controller through integrated PID module is looking at determine the error between the desired value in this case CO_2 concentration of air suction from the rooms and reading its value from DDC sensor 1_ CO_2T and the real time CO_2 concentration of supply air in rooms through the sensor 2_ CO_2T. Figure 8 show ventilation system control.

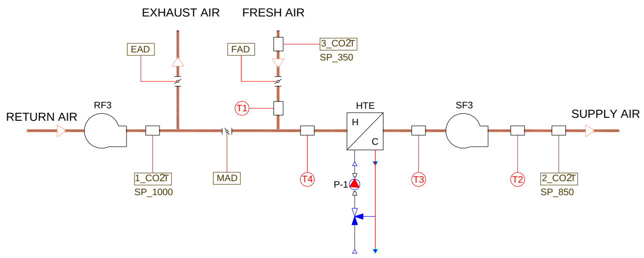

Fig.8. Flow schematic and ventilation system control

PID controller also checks whether there is a great difference between set point and actual CO_2 value and whether over time the difference decreases. Having these functions inside the controller provides constant level of air quality in rooms without suddenly changes in the opening dampers and thus saving energy and keeping in mind that a winter with very low temperatures.

When the sensor 1_ CO_2T (located in the duct airflow in the rooms) detects that the CO_2 concentration is increased up to 1000ppm or suddenly increased the number of people in the rooms, the DDC controller perform the data processed and through a digital signal gives command to opened fresh air damper (FAD) but simultaneously closed mixed air damper (MAD) and opened exhaust air damper (EAD).

All air dampers in conjunction with the degree of opening of the fresh air damper (FAD), or when opened this air damper then closed mixed air damper (MAD) and opened exhaust air damper (EAD). Fresh air damper will be opened up to that position when the sensor 1_ CO_2T will detected CO_2 concentration from 850ppm in the air suction from from the rooms. If no change in the number of people in the rooms that no change of CO_2 concentration (in the rooms) the air dampers will remain in this position until the next disturbance in the CO_2 concentration.

If CO_2 concentration decrease under the set point value i.e. under 800ppm, then DDC controller closes the fresh air damper (FAD), opens the mixed air damper (MAD) and closes the exhaust air damper (EAD). This operation takes place until get a set point CO_2 concentration.

Compared with ON/OFF regulation this type of regulation not only controls the CO_2 concentration at the same time enables a great energy saving. Also, this regulation to avoid sudden and rapid changes in the fresh air quantity and thus decrease the need for heating/cooling energy.

It is the control logarithm (control system) needs to set up alarm limit for CO_2 concentration in the suction air from rooms whose value should not exceed the limit of 1000ppm for a period longer than 5 minutes. Otherwise occur if CO_2 concentrations greater than limit means that something is wrong with the system. Also, need to set up and boundary alarm for CO_2 concentration for the fresh air, which at a concentration higher than 900ppm stops AHU because no longer able to maintain the set point CO_2 concentration.

Also need to activate timer function for start up and shut down the AHU. In extremely condition (very cold and warm days) when school is not working there must be define an ECO MODE. In this mode the AHU will operate at half capacity of the air that only 10% will be fresh and maintain room temperature of 22^{o}C. When AHU is not working all air dampers are closed.

In working days AHU will start up an hour earlier to create a good climate condition. First open fire protection damper (If the system has existing) and then other air damper. First dampers occupy a position in which the quantity of fresh air is 20% of the total quantity. After this run air suction fan (RF3-return air fan) and air pressure fan (SF3-supply air fan).

AHU start up before entry of students in the rooms quantity of fresh air that the openness of damper FAD control with CO_2 sensor 1_ CO2T. When starting to enter students in classrooms i.e. increase the CO_2 concentration then air damper will begin to regulated with DDC controller in order to achieve the set point CO2 concentration. All air damper must be control with modulating mode (no ON/OFF control).

In the heating mode when the temperature transmitter T2 (located after supply air fan) signaling a value lower than set point then tree-way mixing valve opens until to achieve the set point. In the cooling mode it goes above defined regulation. Also for heating / cooling modes is good to have PID regulation.

System must have freeze protection thermostats. If freeze protection thermostat T3 (must be located after water heaters) will detect a temperature lower than 5^{0}C then shut-down AHU i.e. shut-down the fans SF3 and RF3. All air dampers are in closed position and three-way valve will be opens to 100% position until to achieve temperature over 5^{0}C. This alarm must appear to controller and can be reset to again start up the AHU.

The system must provides and FREE COOLING mode. This mode of operation is activate when the outside temperature will be equal to the inside room temperature or the same temperature which is measured in suction duct. In this mode of operation air damper FAD and EAD are 100% open and the air damper MAD is 100% closed.

The program must define a condition when the system operation with free cooling mode and the CO_2 concentration in suction duct measurement through 1_ CO_2T sensor is within the limits of 350-800ppm then air damper do not regulated for CO_2 concentration of 800ppm until not exceed this value. CO2 alarms are operational.

Building model that will be apply for Demand Controlled Ventilation using CO_2 composed of the following components (Fig.9):

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

DDC – DDC controller
FAD – Fresh air damper actuator
MAD – Mixing air damper actuator
EAD – Exhaust air damper actuator
1_CO_2T – Return air CO_2 sensor (CO_2 transmitter) set point 1000 ppm
2_CO_2T – Supply air CO_2 sensor (CO_2 transmitter) set point 850 ppm
3_CO_2T – Fresh air CO_2 sensor (CO_2 transmitter) set point 400 ppm

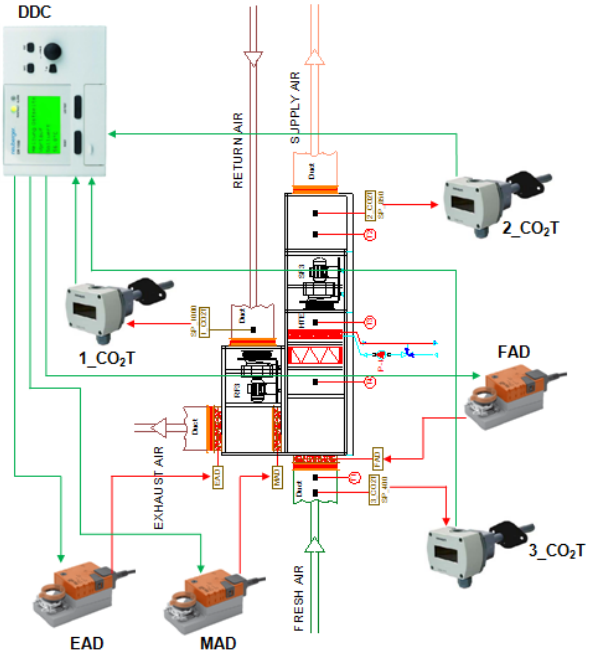

Fig.9. Building model for DCV using CO_2

XI. CONCLUSIONS

Building automation and integrated building management recently experiencing a boom. The reason for this are increasing maintenance costs that could in 25 year lifecycle of the building, which is not automated and optimal maintenance, account for up to 75% of the total. These costs can be reduced 25% by means of integrated facility management comprising all system functions during the life cycle of the building which is one step closer to energy efficient and environmental aware buildings.

In the building automation domain are HVAC systems, as well as automatic control systems for presence, lighting, security systems, elevators, escalators, automatic doors and all communications infrastructure. The guidelines show the development towards integration of telecommunication systems on the level (LonWork, BACNet, Profibus), so that systems are capable of communication with each other and functionally integrated into a complete whole, which may ultimately also known as the core of intelligent buildings.

Integrated management of the building means that the enterprise which is engaged in this activity, control of all actions across the entire life cycle of the building. So in the beginning stage of building a company even guarantee the customer a fixed price maintenance with certain correction factors for energy until the end of its life cycle. In this way falls in charge of the maintenance company that specializes in integrated building management, which greatly relieves the client, in addition, this approach allows the parties to long-term planning of expenditure on the premises.

In first part of this paper physical model for simulation of DDC regulation and monitoring of specific HVAC system is presented. Monitoring is performed with SCADA application that allows real time monitoring and control of system performance, because it uses real algorithms for system functioning. Part for fresh air preparation for air-conditioning of specific room and control of mainstream components operation with Direct Digital Control (DDC) unit is simulated. The simulation model and SCADA application can be used to develop applications, simulation and testing of direct digital control of various models of HVAC systems. These models of applications can be directly applicable to real HVAC systems.

In second part of this paper design of CO_2 based demand controlled ventilation is presented. From design system can be concluded that DCV impacts overall building sustainability through influence on the total and peak energy consumption of the HVAC system and indoor air quality.

REFERENCES

[1] N. Peter, P. Drago: Racunalnisko vodenje in nadzor ogrevanja in prezracevanja v novi osnovni soli Grosuplje Domzale - Slovenia, Johnson Controls, 2003.
[2] Recknagel, Sprenger, Schramek, Čeperković: Heating and Air-Conditioning, Interklima, 2006.
[3] Air-handling unit for commercial and industrial ranges – TRANE. PROD-PRC005-E4, USA, 2003.
[4] Direct Digital Control (DDC) system for control of HVAC system in Government of the Republic of Macedonia, Main project, INVEST A - Skopje, Macedonia, 2004.
[5] L.A. Bryan, E. A. Bryan: Programmable Controllers-Theory and Implementation, Second Edition, USA, 1997.
[6] PLC Siemens S7-200 user's manual and installation, Siemens, 2005.
[7] Gebaudeautomation /System-Beschreibungen - Feldgerate, Weishaupt/Neuberger, Germany, 2006.
[8] A. S. Morris: Measurement and Instrumentation Principles, 3rd Edition, London, 2001.
[9] MicroWin Step 7, User's manual, Siemens, 2004.
[10] SIMATIC WinCC flexible, Getting Started Options, Siemens Edition 04/2006.
[11] Steven T. Taylor: CO2-Based DCV Using 62.1-2004D, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (www.ashrae.org). ASHRAE Journal, Vol. 48, May, 2006.
[12] Mike B. Schell, Stephen C. Turner, Omar S.,: Application of CO2-Based Demand-Controlled Ventilation using ASHRAE Standard 62: Optimizing energy use and ventilation ASHRAE Transaction Symposia.
[13] FEMP: Demand-Controlled Ventilation Using CO_2 sensors, produced for the U.S. Department of Energy Efficiency and Renewable Energy, by Oak Ridge National Laboratory, 2004.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.