Developing a control algorithm for CEN indoor environmental criteria – Addressing air quality, thermal comfort and lighting

ARTICLE · JANUARY 2009

DOI: 10.1109/MED.2009.5164672

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17th Mediterranean Conference on Control & Automation
Makedonia Palace, Thessaloniki, Greece
June 24 - 26, 2009

Developing a control algorithm for CEN indoor environmental criteria – addressing air quality, thermal comfort and lighting

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Abstract - **In this specific paper a control algorithm for serving CEN's indoor environmental input parameters in building energy management systems is presented. In the proposed control system, techniques of natural ventilation and daylight penetration are exploited. Electric lighting as well as mechanical cooling and heating are used supplementary to the techniques mentioned above. This fairly simple controller works quite satisfactory on the given input levels reducing the need for high-energy solutions.**

Index Terms: CEN, control, intelligent buildings, building energy management systems.

I. Introduction And State Of the Art

The importance of saving electricity in the present "energy - starved" world can hardly be exaggerated [1]. During the last years, we observe a continuous effort for finding new solutions on energy – based – matters. These efforts, motivated by factors such as the rising cost of energy sources, the permanent reduction of their reserves, the uncontrollable pollution of the environment but also the climatic changes, have turned mainly to the production of energy from renewable sources and/or other forms of energy (e.g. nuclear power) and to the more efficient energy consumption.

The rapid growth in the fields of informatics and electronics is a big ally with the scientific community that deals with energy problems. From the one, the growth of informatics and artificial intelligence has provided a remarkable number of algorithms that can be used in an automation system. On the other hand, electronics provide reliable and cheap electronic components such as sensors, microcontrollers / microprocessors. The combination of the two has led to the idea also known as "intelligent buildings" [2].

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As the 'intelligent building' is passing nowadays its phase of maturity, a great number of manufacturers offer integrated solutions (e.g. the ORCA system of Delta Controls based in BACNET architecture, SIEMENS EIBUS, ABB, etc).

The uninterrupted system operation is based on the normal operation of each of the system parts. In building energy and indoor environment management systems these parts are: (i) sensors, (ii) actuators and (iii) interfaces and software [3].

In the present paper a development of a control algorithm that produces the microclimate suggested by CEN's new standards is presented. The hardware used in our lab is around the SIEMENS EIBUS architecture. The initial challenge in this work was to notice whether or not these standards could replace those conventional standards used so far in terms of energy consumption and thermal / visual comfort. In addition, a research took place in order to monitor occupants' behavior in a climate which supposed to be applied in naturally ventilated buildings while the office was equipped with mechanically cooling / heating systems [4]. The design was followed by an extended benchmark so that the proper function of the system was tested.

II. The Present Standards Of The European Committee For Standardization

The European Committee for Standardization (CEN) is a business facilitator in Europe, removing trade barriers for European industry and consumers. Its mission is to foster the European economy in global trading, the welfare of European citizens and the environment. Through its services it provides a platform for the development of European Standards and other technical specifications [5].

There exist national and international standards, and technical reports, which specify criteria for thermal comfort and indoor air quality (EN ISO 7730, CR1752) [6]. These documents do specify different types and categories of criteria, which may have a significant influence on the energy demand. These criteria are, however, mainly for dimensioning of building, heating, cooling and ventilation systems. They may not be used directly for energy calculations and year-round evaluation of the indoor thermal environment. New results have shown that occupant expectations in natural ventilated buildings may differ from conditioned buildings. These issues are not dealt with in detail in the above mentioned documents.

The present standard specifies how design criteria can be established and used for dimensioning of systems. It defines how to establish and define the main parameters to be used as input for building energy calculation and long term evaluation of the indoor environment.

III. System Overview

The main problem-challenge is the proper adjustment of the actuators in order to succeed the indoor environmental levels that our system receives as input but also an efficient use of electric power (artificial lights and the AC system) [7]. The representing equations are:

Nonlinear state equation: $x_{i+1} = f(a_i, x_i)$ (1)

Measurements with noise: $y_i = x_i + n_i$ (2)

Controller: $\alpha_i = g(r_i, y_i)$ (3)

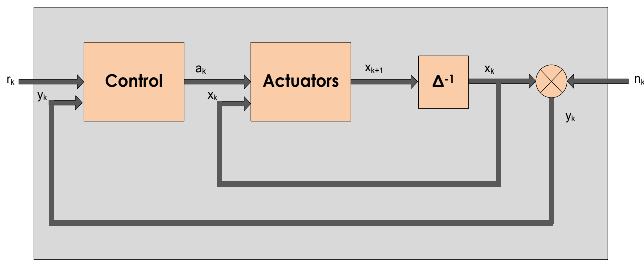


Figure 1. The control system diagram

The state space vector is:

$$x_i = \begin{bmatrix} x_{1,i} \\ x_{2,i} \\ x_{3,i} \end{bmatrix} = \begin{bmatrix} \theta_{in} \\ L_{in} \\ C_{in} \end{bmatrix} \qquad (4)$$

where,

θ_{in}: the indoor temperature (°C)
L_{in}: the indoor illuminance level (lux)
C_{in}: the indoor CO_2 concentration (ppm)

The control vector is:

$$a_i = \begin{bmatrix} a_{1,i} \\ a_{2,i} \\ a_{3,i} \\ a_{4,i} \\ a_{5,i} \end{bmatrix} = \begin{bmatrix} W \\ B \\ AC_{in} \\ AC_{out} \\ L \end{bmatrix} \qquad (5)$$

where,

W: the windows' function
B: the blinds' function
AC_{in}: the internal air conditioning sector's operation
AC_{out}: the external air conditioning sector's function
L: the adjustment of the artificial lighting level

The input vector is:

$$r_i = \begin{bmatrix} r_{1,i} \\ r_{2,i} \\ r_{3,i} \\ r_{4,i} \end{bmatrix} = \begin{bmatrix} \theta_{rm} \\ L_{set} \\ L_{out} \\ C_{set} \end{bmatrix} \qquad (6)$$

where,

θ_{rm}: the running mean temperature for today (°C)
L_{set}: the desired indoor illuminance level (lux)
L_{out}: the outdoor illuminance level (lux)
C_{set}: the desired indoor CO_2 concentration (ppm)

A. The Input Vector r_i

As mentioned above, the system's input environmental parameters are [6]:

1) θ_{rm}, is calculated as shown below:

$$\theta_{rm} = (1-a)\cdot\{\theta_{ed-1} + a\cdot\theta_{ed-2} + a^2\theta_{ed-3} + \ldots\} \qquad (7)$$

where, θ_{ed-1} is the daily mean outdoor temperature for the previous day, θ_{ed-2} is the daily mean outdoor temperature for the day before and so on. α is a constant between 0 and 1,with recommended value 0.8. The way θ_{rm} defines the indoor temperature levels is:

a) Naturally Ventilated Buildings

$$0.33\cdot\theta_{rm} + 18.8 - 3 \le \theta_{in} \le 0.33\cdot\theta_{rm} + 18.8 + 3 \qquad (8)$$

b) Buildings with Mechanical Cooling/Heating

In buildings with HVAC systems the acceptable indoor temperature levels do not contain θ_{rm}. CEN suggests $20 \le \theta_{in} \le 24^oC$ during heating season and $23 \le \theta_{in} \le 26^oC$ during cooling season.

2) L_{set}, is set to 500lux.

3) L_{out}, is a parameter from which the controller obtains the contribution, if existing, of the outdoor's luminance to the indoor's.

4) C_{set}, is set to 800ppm.

B. The Control Vector a_i

After the controller has processed the indoor environmental levels and executed the algorithm, a number of actions done to the actuators are produced. These actions are:

1) *W*, is a signal to open or close the windows. The only 2 possible positions of the windows are: completely closed or open.

2) *B,* is a signal to move the blinds ±10% of their full range which is 0-100%. This means that in 100% blinds are all the way up (full sun penetration) and in 0% blinds are down (no sun penetration).

3) AC_{in} , is a signal provided to the internal AC section. There are 3 possible actions: on/heating, on/cooling, off.

4) AC_{out} , is a signal provided to the external AC sector in order to start or stop.

5) *L,* is a signal to adjust the lights ±5% of their full range which is 0-100%. This means that in 0% lights are turned off and in 100% lights illuminate the maximum.

C. The State Vector x_i

To testify the proper work of the controller and the actions done to the actuators, the data provided by the state vector are used. These data are the feedback for the system in order to compare the optimal levels with the real ones and make adjustments, if needed, next time the control algorithm executes.

IV. The Controller

The basic component of the system presented in Fig.1 is the controller. The importance of a well designed control algorithm is double:

- Proper regulation of the actuators as far as accomplishing the desired indoor climate and lighting are concerned.
- Efficient use of the systems that use electrical power in order to operate, such as lights, air conditioning systems etc.

The algorithm developed for the specific problem is shown in Fig.2.
The colors in the flowchart represent the following:

- *Pink*, measurements from the sensors and calculations.
- *Green*, actions done to the actuators.
- *Yellow*, checkpoint values.

This control algorithm represented in Fig.2 is executed to produce an indoor thermal environment as if the building was naturally ventilated (although it uses the AC units). The second algorithm that was developed in this project for buildings with mechanical cooling and heating is by 99.9% the same. The only difference is that the temperature limits are constant and independent from θ_{rm}.

V. Diagnostic Results

Many simulations took place in order to validate the systems' stability and proper response. On the other hand, crucial results about the occupants' comfort, under the specific circumstances, were exported during the simulations.

The majority of the experiments were performed during the summer, especially in July, where the temperatures in Chania/Crete, Greece were high and the daylight was the possibly maximum.
Finally, the sample that was subjected to this project's microclimate was 54 people.

A. Thermal Comfort and Air Quality

1) Naturally Ventilated Buildings

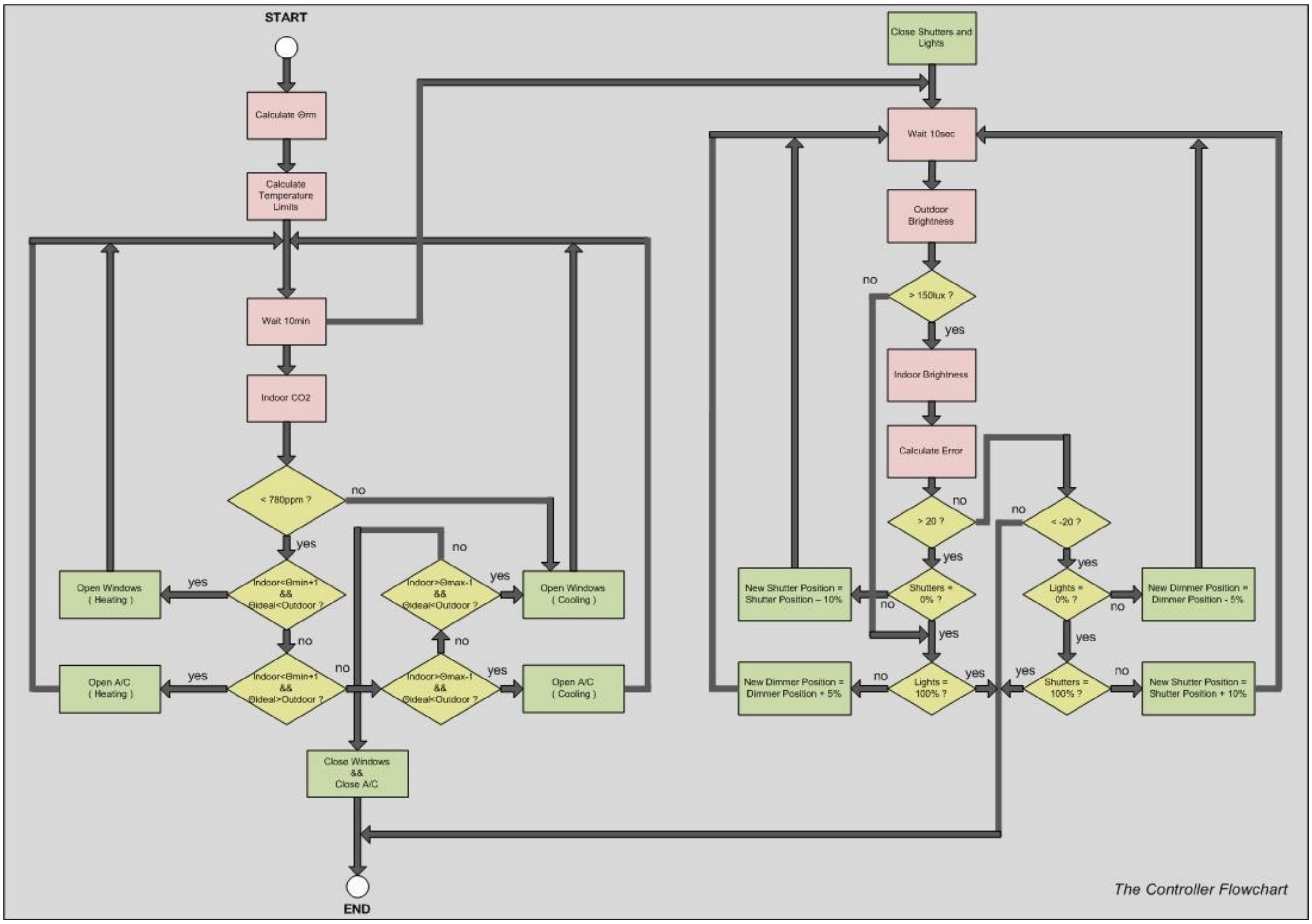
a) The simulations of 2 days are shown in Fig.3 and Fig.4.
b) We obtained very efficient energy consumption due to the rather high temperature limits which reduced the need for mechanical cooling.
c) Occupants seemed not to feel comfort working under those conditions. More than 60% of the sample admitted that felt warm.

2) Buildings with Mechanical Cooling/Heating

a) A single simulation is shown in Fig.5
b) Energy consumption was increased significantly due to the low temperature limits (almost 4^{o}C lower than the first case). This resulted in an extended use of the cooling systems. (during a 10-day execution of the 2 controllers , the first caused about 830kWh - almost 68% - less electric energy consumption comparing to the first system)
c) Occupants seemed to feel comfort enough during their daily activities. Some of them (about 17-20%) felt slightly cool, mainly during the night. Overall, the specific indoor thermal environment was totally accepted by the research sample.

B. Visual Comfort

Along with the indoor thermal environment, the visual environment was also needed to be tested. As far as the indoor illuminance is concerned it must be always set to 500lux regardless of what kind of thermal environment is applied.



a) The simulations of 2 days are shown in Fig.6 and Fig.7.
b) We obtained very efficient energy consumption due to the good sun penetration during almost 10 hours per day.
c) Occupants seemed to feel comfort during their daily activities. Nothing farther to mention as the majority of the sample answered that would prefer nothing to change as far as indoor luminance was concerned.

VI. Conclusions

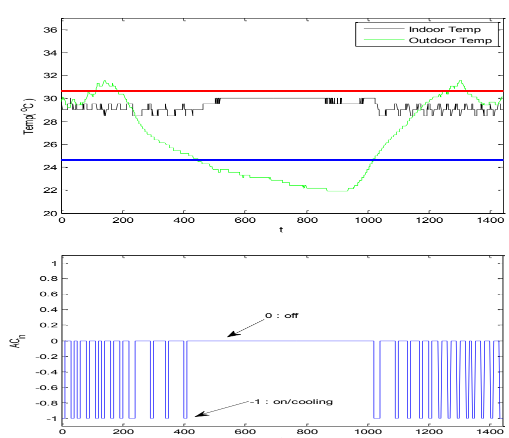
The proposed system satisfies in very big degree the initial choices. At the same time, after big period of continuous operation exceptional stability in both hardware and software was observed.

In the controller level, the results are also quite satisfactory as the algorithm is executed with success and selects really good solutions taking into consideration always the approach in the optimal input levels and energy saving. The system uses simple (not unsophisticated) algorithm of control which is executed in a personal computer (PC).

Recommended expansions to this project would be the following:

- Year-round simulations to test the systems' behavior during all seasons so that the control algorithm is improved or replaced if needed (e.g. PID control for the lights, fuzzy control for the thermal environment adjustment etc)
- More people participation in those simulations in order to provide safer research results as far as the CEN criteria are concerned.

VII. Simulations



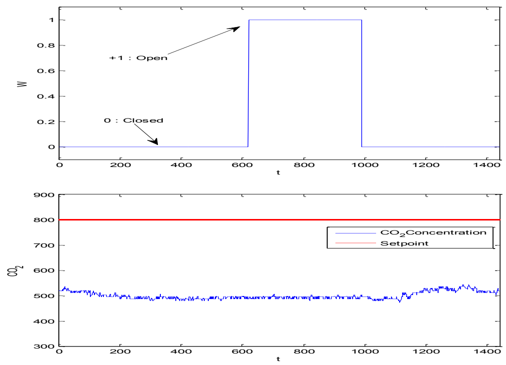


Figure 3. Evolution of indoor temperature and indoor CO_2 concentration for a 24hour July simulation (N.V.B)

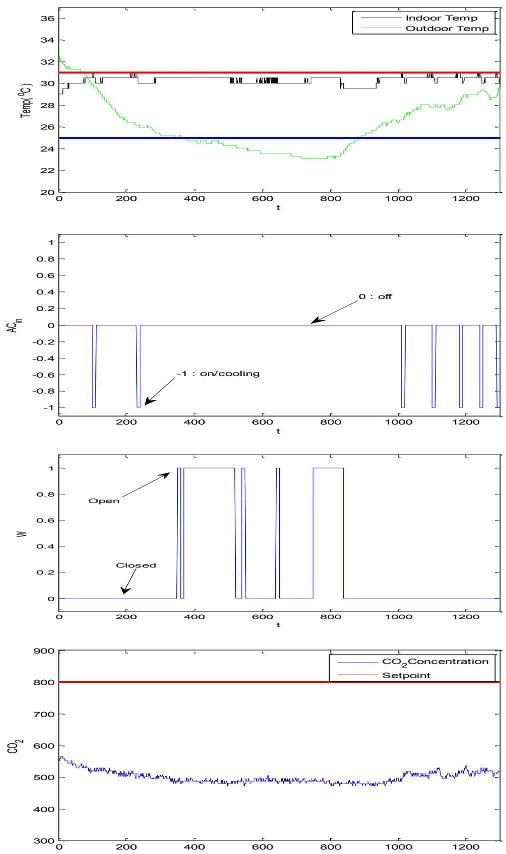
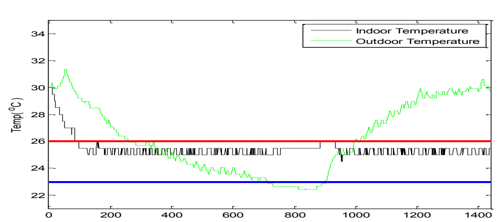


Figure 4. Evolution of indoor temperature and indoor CO_2 concentration for a 24hour August simulation (N.V.B)



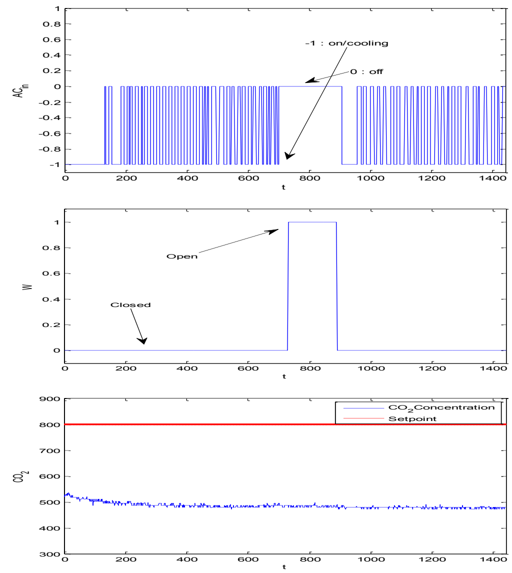


Figure 5. Evolution of indoor temperature and indoor CO_2 concentration for a 24hour August simulation (B.M.C/H)

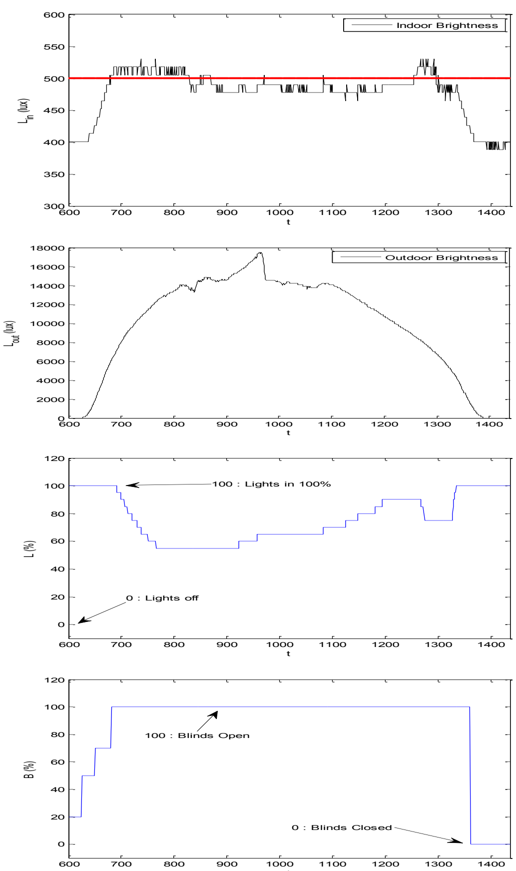


Figure 6. Evolution of indoor illuminance for a 24hour July simulation

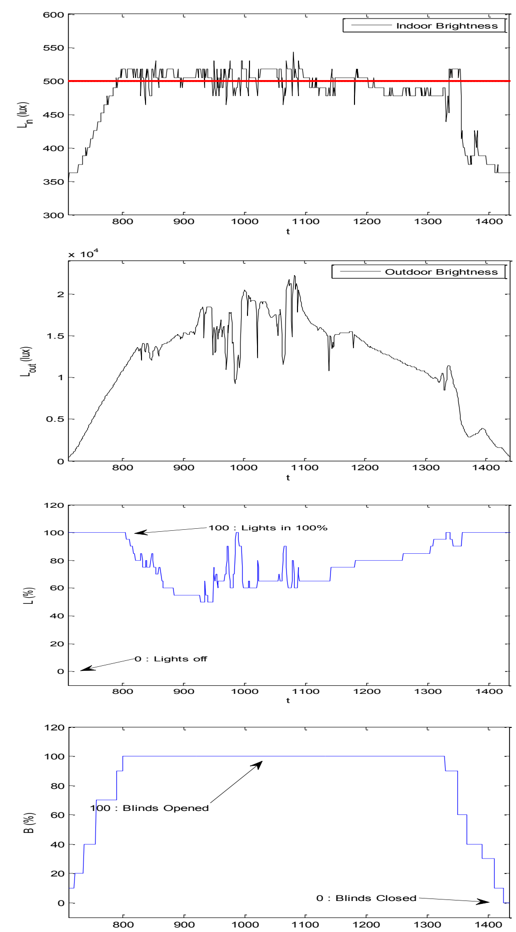


Figure 7. Evolution of indoor illuminance for a 24hour August simulation

VIII. COMPARISON TO OTHER WORK – SIMPLE VS COMPLEX

The aim of this project is to show that simplicity in both development techniques and hardware can sometimes be preferable in addition to more advanced ones.

As far as response and energy consumption are concerned the current controller works very closely to others used in the same research such as advanced fuzzy [8],[9] and predictive controllers [10]. Although its simplicity, the simulation results seem convincing.

Finally, the proposed controller is applicable in any building without taking into account the specific building characteristics and without any modifications to the controller's structure.

IX. APPENDIX – THE LAB AND SOFTWARE/HARDWARE SYSTEMS INSTALLED

The BEMS in which the control scheme is tested, is installed in the Industrial Control Laboratory of the Department of Production and Management Engineering of the Technical University of Crete at Chania, Crete, Greece (35˚N latitude). The laboratory has 125 m^2 area with almost 3.5 m height, thus 437.5 m^3 volume.

1) Building Services

i. Air Conditioning (split type)
ii. Fluorescent lamps (electric lighting)

2) Hardware (Sensors)

i. Indoor luminance (200-1900lux, ±7.68lux)
ii. Indoor temperature (-25 – 70^{o}C, ±0.5^{o}C)
iii. Indoor air quality (CO_2 and TVOC, 0-2000ppm, ±20ppm)
iv. Relative humidity (0-100%, ±1%)

v. Weather Station
- Raining detection sensor
- Outdoor luminance sensor
- Outdoor temperature sensor
- Wind speed, sensor

3) Hardware (Actuators)

i. Electronic ballasts for the fluorescent lamps of 18W and 58W
ii. Digital Addressable Lighting Interface
iii. Shutter switch (for blinds' and windows' control)
iv. Binary output (for AC control)

4) Software

i. ETS (EIB Tool Software)
ii. EIB OPC Server
iii. MATLAB R2006b

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