SYSTEM FOR CONTROLLING VARIABLE AMOUNT OF AIR ENSURING APPROPRIATE INDOOR AIR QUALITY IN LOW-ENERGY AND PASSIVE BUILDINGS

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ABSTRACT

In low energy buildings and passive houses due to very low heating demands integrated heating and ventilation (VAV or DCV) systems are used to provide proper indoor climate conditions – thermal comfort and indoor air quality. Dynamic changes of indoor conditions result in permanent changes in air flow. Control systems have to follow those changes and on the other hand have to minimize energy consumption for the system as a whole.
The article presents advanced simulation methods and the results of experimental investigation of control of variable volume system installed in passive house located in Poznań, Poland.

KEYWORDS

Low energy and passive buildings, VAV and DCV systems, Simulation

1 INTRODUCTION

In low-energy buildings, ventilation and heating systems are the main elements that form the microclimate due to a very low heat load. This requires the application of integrated systems that form indoor climate quality, i.e. thermal comfort (TC) and indoor air quality (IAQ). The systems of Variable Air Volume (VAV) and Demand Control Ventilation (DCV) are the examples of such solutions. In these systems dynamically changing internal conditions enforce continual change of air volume. Therefore, on one hand control systems must maintain a given CO_2 concentration at a predefined level and on the other hand they must minimize energy consumption. At the same time variable air volume along the whole operated ventilation line must result in stable and optimal performance of the source itself (air handling unit). Undoubtedly, proper and predefined usage schedules for given zones and algorithms supporting e.g. footfall systems are helpful in case of control systems for CO_2 concentration.
The article presents the application of advanced calculation and simulation methods together with the results of real measurements of variable air volume control using different configurations of connections between controllers.

2 CLIMATE COMFORT IN LOW-ENERGY AND PASSIVE BUILDINGS

Nowadays over 80 percent of the time is spent by a human being in confined spaces (houses, offices, shops, schools, etc.) [31], the objective function of buildings for people should be to ensure and maintain, in variable conditions, climate comfort and user's comfort. It is the main task of heating, ventilation and air condition devices and systems to ensure wellbeing in a building. There are several various physical and chemical parameters, very often time-changing, which determine the microclimate and have direct impact on living organisms. Microclimate parameters are usually grouped in two categories:

- *heating and humidity* conditions, creating the feeling of thermal sensation related to heat exchange between a human being and close environment,
- *health and sanitary* conditions covering indoor air quality in a broad sense [19].

One of the main components determining climate comfort is thermal comfort. It is an ideal temperature condition of a room that guarantees people in there that a sustainable thermal balance is kept [11,27,28,29,32]. Creating certain microclimate in rooms facilitates such thermal conditions in which every present person would feel thermal comfort, i.e. satisfaction from thermal conditions of the environment. [1,2,3,4].

The next important element of climate comfort is good quality of indoor air (IAQ - Indoor Air Quality) that defines such an air condition which is free from contaminants and does not cause any irritation, discomfort or illnesses of the users [3,16].

The role of contamination of a given kind which occurs individually or in coexistence, is decisive for Sick Building Syndrome or Building Related Illness to occur or not [17].

2.1 Correlation of main climate comfort parameters

The results of the microclimate research proves that as a consequence of correlation of individual parameters being the components of a thermal balance equation, it is necessary to steer and control several factors concurrently. Only in this way it is possible to improve the perceived climate comfort. In recent years there have been many unconventional approaches to microclimate issues. As an example, in air quality research the influence of temperature and humidity is considered jointly, as the effect of enthalpy of humid air on the perception of the environment quality [8]. A similar approach to analyses can be noticed when taking into consideration the effect of carbon dioxide concentration which defines air freshness of a given space. The effects and mutual influences of the main regulation parameters may lead to establishing a “golden mean” that gives the required comfort. At the same time it may result in elimination of at least one of the regulation parameters and therefore significantly reduce costs already at the stage of investment.

One of the dependencies in correlations with other basic parameters for climate comfort regulation is CO_2 concentration which, when changing along the changes of temperature and relative air humidity in the space (therefore identifying the presence of a human being), has a great influence on indoor microclimate and comfort perception. As an example the papers [7,12] present these dependencies in detail. Figure 1 presents percentage share of increasing satisfaction from climate comfort in a ventilated space depending on CO_2 concentration.

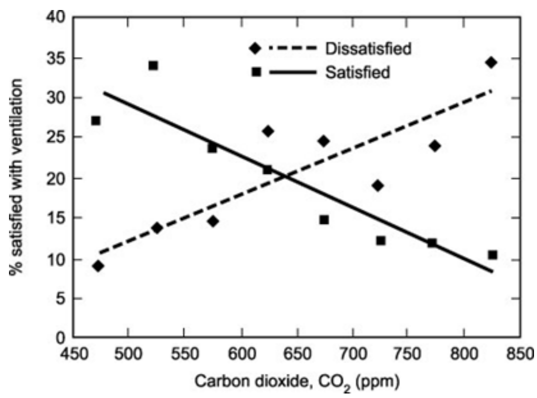


Figure 1: Percentage of occupants that were satisfied or dissatisfied with ventilation at each level of carbon dioxide concentration [39].

3 SYSTEMS FOR MAINTAINING CLIMATE COMFORT IN LOW-ENERGY AND PASSIVE BUILDINGS

Thanks to significant reduction of heat demand, in low-energy buildings, and first and foremost in passive ones, it is possible to eliminate a traditional static heating system – a convection-radiant or radiant system – to use an air heating system. Therefore a ventilation system is the main structure that provides climate comfort in passive building spaces. Its task is to keep thermal parameters at an appropriate level and at the same time to provide fresh air.

Thanks to good insulating power and tightness of a passive building, combined supply and exhaust ventilation has a defined and targeted cascading flow. Fresh air is supplied to so-called occupant's "clean" spheres – bedroom, living room, guests room, office, laboratory, and it is removed from these spaces where the level of contamination is higher – kitchens, bathrooms, toilets. In passive buildings a ventilation system delivers all functions of climate comfort at the same time. This is a system that provides fresh air through ventilation itself but concurrently ensures thermal comfort by air heating in winter or providing cool air in summer (e.g. using a ground-coupled heat exchanger).

When analysing ventilation systems in passive and low-energy buildings in terms of regulation and control, two solutions can be distinguished:

- ***Centralized heat-ventilation system***: where the supplied air is prepared to suit appropriate technological parameters, most frequently in a compact device, based on one measurement from so called "equivalent sphere", or a point of reference representative for the whole building and supplied in a cascade manner to all regulation spheres; the operation of such a system ensures rather a permanent air flow fulfilling maybe several saving functions (such as e.g. reduction planning, etc.),
- ***decentralized heat-ventilation system***: where every regulation sphere e.g. a space or a group of spaces that have the same or similar functions is measured separately; additionally in each of the regulation spheres there is a separate system that prepares the supplied air (local heater) and a controller, e.g. VAV (Variable Air Volume) that makes it possible to provide proper doses of air stream to a given sphere; the system is fully integrated with the central unit where the supplied air is initially prepared (central heater) based on adaptive regulation connected with air temperature sucked from the outside and current parameters of individual regulation spheres (spaces in a passive building); additionally, the central unit by maintaining a pressurization level in a central ventilation duct operates in a master (air supply)-slave (air exhaust) configuration, changing the supplied air stream in the central duct depending on current needs of air streams in all spheres (forced by the location of VAV controllers).

The first solution of the centralized heat-ventilation system gives quite small possibilities of control optimization with a concurrent climate comfort maintained in every of control spheres. Maintaining the supplied air stream at the permanent level that ensures appropriate temperature and fresh air may on the other hand lead to dry air. However, limiting the overall air stream will automatically cause the increase of CO_2 concentration in occupied spaces or worsen thermal comfort.

In this respect it seems reasonable to use a decentralized heat-ventilation system. This solution gives much bigger possibilities of steering and control optimization, making it possible to dynamically influence climate comfort in a given regulated sphere (spaces of a passive building) depending on a current load.

From the control point of view a given system of ventilation, heating and air conditioning should be perceived as a dynamic multidimensional system which at a given point of time is influenced by any internal ($X_{intern1} \div X_{extern}$) and external ($X_{intern1} \div X_{extern}$) input signals as well as by disturbances ($Z_1 \div Z_O$), but also as a system which at the same time should generate output signals ($Y_1 \div Y_k$) causing first and foremost stability of performance and the control optimum in terms of any control factors. In Figure no.2 such a dynamic system has been symbolically depicted. [based on 36].

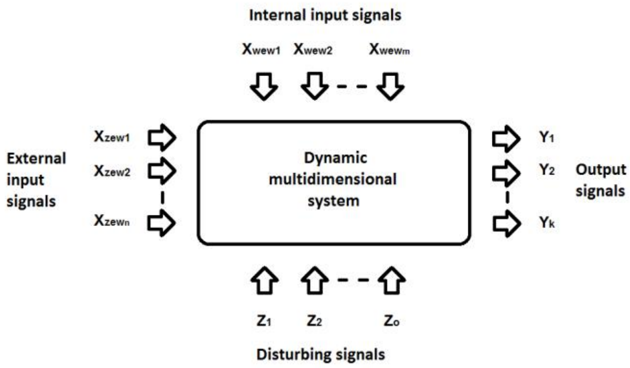


Figure 2: Symbol of HVAC system as a dynamic multidimensional system.

4 SYSTEM FOR CONTROLLING CLIMATE COMFORT PARAMETERS IN PASSIVE AND LOW-ENERGY BUILDINGS

When talking about control and all the more its optimization, at the very beginning a question must be asked: *„What is in fact to be controlled and how the regulation itself can be conducted?"*. When it comes to passive and low-energy buildings, it is necessary to start the analysis from a definition of the required climate comfort parameters, meeting of which is the main task when using technical building equipment [30].

When designing the technology of the air preparation process only two courses of the process are analyzed for two calculation parameters of internal and external air: one for winter and one for summer. In both cases the condition of external air and nominal values of heat gains, humidity, CO_2 emission and other contaminants are applied as input parameters and output parameters encompass a target status of supplied air and air status in a space [37,38].

In order to provide climate comfort in passive and low-energy building spacer, first and foremost appropriate regulation must be performed:

- of the temperature in a room,
- of relative air humidity in a room,
- of CO_2 concentration in the air,

by delivering the prepared air for the mechanical ventilation system of a building. This process needs technically advanced systems together with an automatic steering and control system already in case of several or more spaces. Variable Air Volume Systems (VAV) or Demand Control Ventilation Systems (DCV) are the examples of such structures.

Air parameters in spaces are a derivative of internal and external disturbances [6] which must be taken into consideration by the control system.

The whole control system of a given parameter should be resistant to any internal and external disturbances which may include, among others:

- changes of external air parameters,
- changes of thermal and humidity load of chambers,
- changes of energy parameters of factors which feed the air supply system itself.

An example of a block diagram showing an automatic control system for climate comfort in a passive building has been outlined in Figure no. 3.

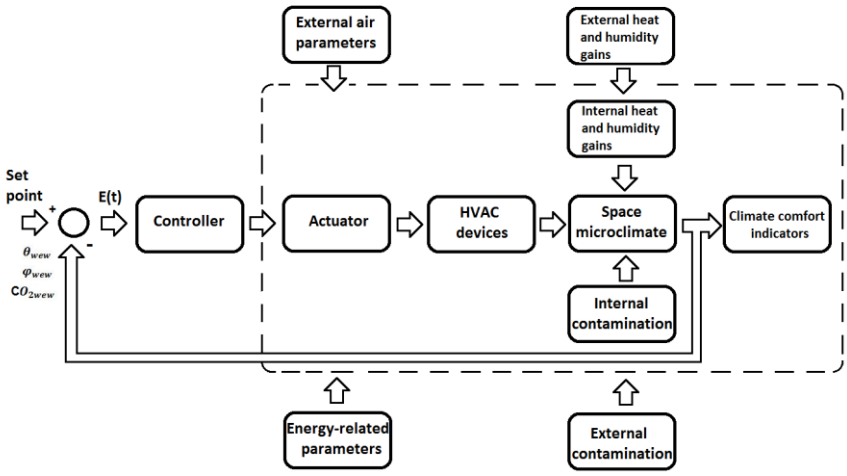


Figure 3: An example of an automatic climate comfort control system in passive and low-energy buildings.

5 MODELLING OF THE STRUCTURE AND OPTIMIZATION OF CONTROL SYSTEMS

If a fragment, for which it is possible to define the input and output signal, is separated from the automatic control system, then this fragment can be called an element of the system. It can be a single set or a subset, it can be a measuring instrument or a larger element of the system. It is important to ensure that the operation of the element is triggered by a certain reason and results in the required effect. For every element defined this way, one can define its intended use because it has a strictly defined distinctive function. In order to be able to assign a given element in the appropriate manner, its static or dynamic characteristics must be known as well as its function defined as a quotient of the function which defines the output signal and the function which defines the input signal.
The mathematical description of the control system encompasses descriptions of it components. The mathematical description of continuous element or automation system covers two parts:

- **an equation** or **a diagram of static characteristics** defining the dependency of the output signal on the input signal in defined situations.
- **a differential** or **an operator equation** that describes static and dynamic properties in the environment of performance point selected on a static characteristics.

Dynamic properties are evaluated based on y(t) curve as a response to the defined input signal x(t). Theoretically, plotting these curves, known as responses to a typical force, requires a solution of an equation of a dynamic system, which can be carried out by two methods:

- **classical method** consists in calculation of the root of an equation and setting constants based on initial conditions;
- **operator method** – commonly used in automation – consists in application of a transformation which would make it possible to replace an integral-differential equation with an ordinary algebraic equation. This is a Laplace transform. It assigns a transform (a transformation image) to a given function and the other way round f(t) ↔ F(s).

5.1 Modelling of an automatic control system using a simplified transfer function

Each complex system may be converted to a simplified transfer function. It can be performed by dividing the system into its individual parts. Then for each of the created subsystem individual elements are described and combined using appropriate controllers, which results in modelling of the automatic regulation system. For the climate comfort systems a model consisting of a pure time delay and a series of n intertial elements of 1st order is very often used [34,36]. Taking advantage of the fact that a Laplace transform of the function adjusted by τ time units equals:

$$L\left(f(t-\tau)\right)=e^{-\tau s} \tag{1}$$

which, when using Padé approximation, can be converted to adopt the following form:

$$e^{-\tau s}\approx\frac{1-\frac{\tau}{2}\cdot s}{1+\frac{\tau}{2}\cdot s} \tag{2}$$

the equivalent transfer function of such an element adopts the form of:

$$G_{sys}(s)=\frac{k_0}{\left(T\cdot s+1\right)^n}\cdot e^{-T_0 s} \tag{3}$$

or

$$G_{sys}(s)\approx\frac{k_0}{\left(T\cdot s+1\right)^n}\cdot\frac{1-\frac{T_0}{2}\cdot s}{1+\frac{T_0}{2}\cdot s} \tag{4}$$

where:
k_0 – equivalent gain of the plant
T – equivalent time constant of the plant,
T_0 – equivalent time delay of the plant,
n – interial order.

By adopting basic data in a simplified way, time constants and time delay of individual elements of the whole system have been set and then the parameters of the simplified equivalent transfer function of the whole system have been defined. For the controlled system defined in this way, there have been simulations carried out of the automatic control systems with classical controllers (P, PI, PID) as well as fuzzy controllers (Mamdani type P, PI and Tagaki-Sugeno type P, PI).

5.1.1 Classically controlled systems

Looking for optimal settings for classical systems of automatic control, advanced optimization methods have been used – namely gradient and hessian algorithms with the application of NCD-Outport Block in the Matlab/Simulink software. In the simulation tests for all modelled automatic control systems a unit step has been given as a standard signal which activate automation systems.
When analysing the received quality of control, apart from linear indexes read from the control run, in the simulation process additionally integral indexes have been used in a dynamic calculation of an integral from the product of a control error signal and an integral from the module of a control error signal.
An example of a model of a continuous automatic control with a PID controller has been depicted in Figure 4a and Figure 4b shows the response of the control system.

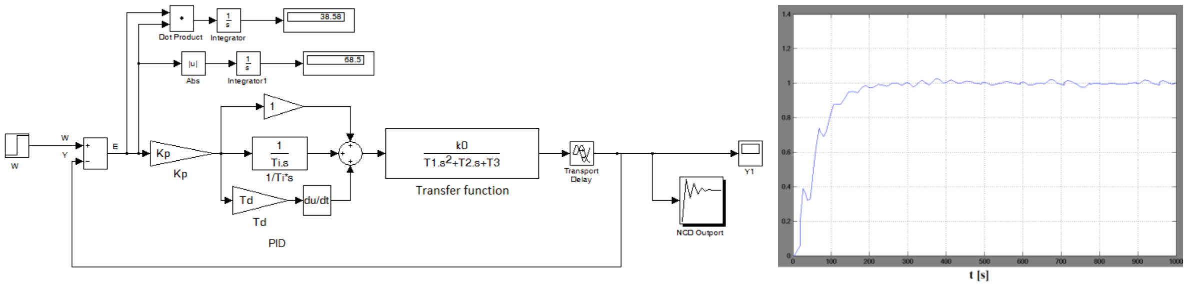


Figure 4. Model of the tested automatic control system with a PID-type controller (a) and the response of the control system as a simulation result (b).

5.1.2 Control system with unconventional control (fuzzy logic control)

Publications [8,10,23] show the modelling of fuzzy logic control dedicated to the process of forming the microclimate of the room.
In the first stage, when creating an automatic control system with a fuzzy logic controller, the construction of the FLC model (Fuzzy Logic Control) is important. Depending on a type of a given controller, input and output data must undergo fuzzification.
Figure 5a depicts an example of an automatic control system with FCL of PI type (Mamdami) modelled in Simulink (Matlab). Figure 5b however shows a response signal of given control during ongoing simulation.

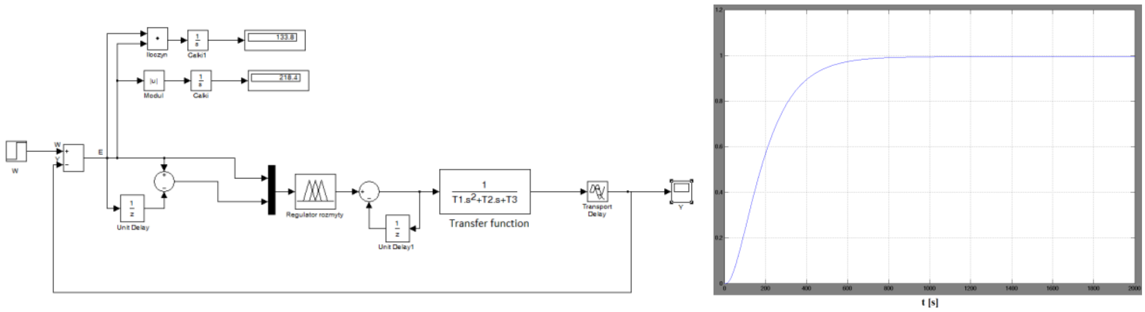


Figure 5. Model of the tested automatic control system with a fuzzy logic controller PI (a) and the response of the control system as a simulation result (b).

Simulation tests that have been conducted explicitly indicate that it is possible for continuous PID controllers with a precise selection of the parameters of the controller itself and fuzzy logic controllers with fuzzy values of the control process to be optimally controlled for the systems under test.

5.2 Modelling automatic control systems using system equations

Every automatic control system can be described in terms of equation constituents, equations describing process that take place in the system as well as equations describing the whole analysed system. In case of the climate comfort analysis in a passive building, energy balance equations based on individual spheres' load can become a starting point to mathematical modelling and simulation.
The whole modelling and simulation process has been performed using Matlab v 7.10 and its subprogram Simulink v.7.5 of Mathworks for dynamic system modelling.
Based on the VDI2078 guidelines [33], the load of the whole building can be determined using two methods:

- ***simplified*** – statically calculating individual internal and external loads, and

- ***advanced*** – allowing for dynamics and based on combination of recursive filters.

5.2.1 Building loads – simplified method

According to VDI2078 [33] the whole building load will be in line with the equation no. 5.

$$\dot{Q}_{KR} = \sum_{j=1}^{n} \dot{Q}_{KRj}(t) \tag{5}$$

where: $\dot{Q}_{KRj}$ – loads of a given j-th room,

n – number of rooms in a building.

The load of a given space consists of internal loads ($\dot{Q}_I$) and external loads ($\dot{Q}_A$). This relation is depicted in the equation no. 6:

$$\dot{Q}_{KR} = \dot{Q}_I + \dot{Q}_A \tag{6}$$

where:

$\dot{Q}_I$ – cooling loads coming from internal sources,

$\dot{Q}_A$ – cooling loads coming from external sources.

Load calculations for all spaces in a given passive building have been programmed and modelled based on the algorithm as defined in VDI2078 guidelines, using all climate data and also in line with the character of a passive building under test. An example of individual load constituents for one room and for a selected period of time has been depicted as daily and hourly diagrams in Figure 6.

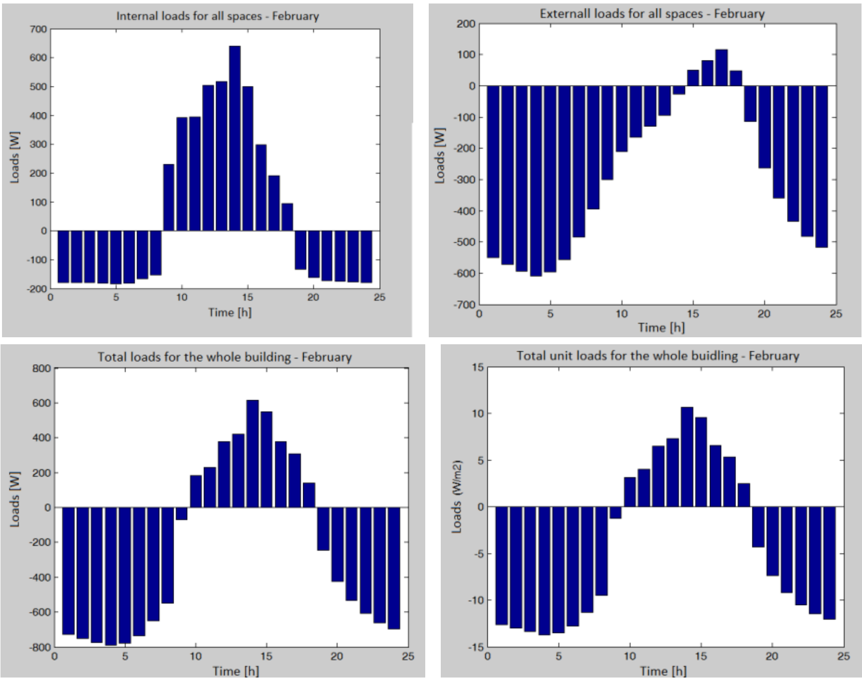


Figure 6. example of loads (for February) for a passive building under test:
a-internal, b-external, c-total, d-unit.

Calculations and simulations that have been carried out explicitly imply a huge domination of internal loads. The results of the simulations for the whole calculation year together with the use of standard data for calculations, the application of use profiles in line with the requirements in the norm and the adoption of given accumulation matrices imply that basically the examined passive building should be cooled all year round as a result of higher values of internal load. This however does not correspond to the actual situation. Therefore it should be explicitly stated that it is a mistake to adopt standard calculation data connected with cooling and heating loads for general building industry also in case of low-energy buildings and especially for passive ones.

Very good thermal insulation of all bulkheads and high tightness are the reason why the biggest influence on formation of the microclimate in passive buildings refers to internal loads. Therefore, all constituents which have this impact on internal load must be very precisely defined for all analyses, research and calculations.

Similar conclusions can be drawn when applying the methods for calculating design heat load for passive buildings as set forth in PN-EN 12831 [21,22,24,25,26]. In the publication [20] calculations made based on this method show a design heat load for a passive building of about 2500W and in case of a unit heat load – of about 35 $\frac{W}{m^2}$.

Therefore, as far as a passive house is concerned, it would be necessary to properly modify accumulation matrices providing a detailed description of internal loads which give the possibility to make calculations in a continuous utilization profile. Regardless of accumulation matrices, this utilization profile of a given room in a passive building must be precisely defined: its occupation, using of lighting as well as any machines and devices.

5.2.2 Building loads - advanced method

Another possibility of comprehensive load setting is the simulation method suggested in [33] and its modification included in [18].

This calculation method is based on the combination of so called recursive filters. The definition of the combination defines the values of the output function (in a given point) as an integral of the weighted function multiplied by the input function calculated one stage earlier:

$$y(t) = \int_0^\infty g(\tau) \cdot u(t-\tau) d\tau \tag{7}$$

where:

- u – input function,
- y – output function,
- g – weighted function,
- t – calculation time (in a given moment).

Transforming the equation (7) to the discrete sum we will receive:

$$y_k = \sum_{i=0}^{\infty} g_i \cdot u_{k-1} \tag{8}$$

where:

- g – weighted coefficient,
- y – calculation time (in a given moment).

By using recursive filters the number of necessary weighted coefficients is significantly reduced. If dynamic conversion is approximated by the second-grade model, then a discrete filter equation is obtained (9).

$$y_k = \sum_{m=0}^{3} a_m \cdot u_{k-m} + \sum_{n=1}^{2} b_n \cdot y_{k-n} \tag{9}$$

where:

a – load coefficient for u,
b – load coefficient for y.

The results of the simulations based on the method described above have been depicted in Figure 7 as daily diagrams of internal and external loads as well as total and unit loads for the whole year (all months separately) for the whole building in question. The share of convection and radiation has been adopted according to [35].

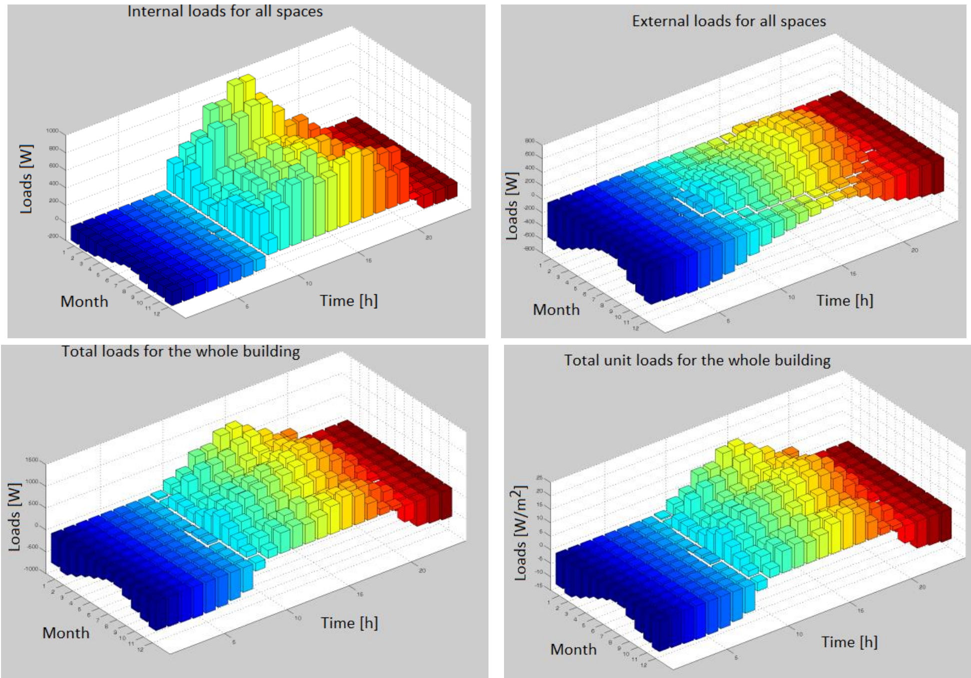


Figure 7. Daily loads of a passive building in question set for the whole year:
a-internal, b-external, c-total, d-unit.

5.3 Setting an air stream that provides the climate comfort

Having all loads set for each and every rooms in a given passive building using a load criterion and when it is wished to control a given value, it is possible to set an optimal air stream variable in terms of demand:

- Based on sensible heat balance of temperature control,
- Based on latent heat balance of relative humidity control,
- Based on contamination balance (CO_2 emission) for control of carbon dioxide (CO_2) content in the air.

For example, in control for which carbon dioxide concentration is the main parameter, first and foremost one should take into consideration CO_2 concentration emitted by a human being and contamination of the air in the inlet duct of a ventilation system.

Taking these factors into account, the process of setting a ventilating air stream will adopt the following form:

$$\dot{V} = \frac{C}{k_w - k_n} \left[\frac{m^3}{h}\right] \tag{10}$$

where:

$$C = n \cdot s_{co} \cdot S_i \tag{11}$$

k_n – CO_2 concentration in the supply air,

k_w – CO_2 concentration in the exhaust air (in a controlled room),
C – amount of CO_2 concentration emitted by a human being,
S_i – human co-presence coefficient,
n – number of people in a room [person],
s_{co} – carbon dioxide concentration emitted by a human being [$\frac{dm^3}{h\ os.}$].

It has been assumed in calculations that a carbon dioxide concentration emitted by a human being is proportional to the emitted heat stream [14] and equals $4{\cdot}10^{-5}$ $\frac{dm^3}{sW}$ [9,13] 0. The calculation is made based on the assumption of a unit CO_2 concentration coming from persons at the level of 18 $\frac{dm^3}{h\ os.}$. In the simulation examination the inlet air contamination has been assumed at the level of 350ppm and as an expected value of CO_2 concentration inside a room the value of 750ppm has been adopted.
Carbon dioxide concentration in a room after τ time can be set from the relation (12) [15]

$$k_w(\tau) = \left(\frac{C}{\dot{V}} + k_n \right) \cdot \left(1 - e^{-n\tau}\right) + k_n \cdot e^{-n\tau} \tag{12}$$

where n – is the multiplication of air exchange after τ time.

Figure 8 shows a model for CO_2 concentration control with classical PID control and with PI fuzzy control. Figure 9a shows a defined optimal air stream and subsequently in Figure 9b – the result of stream control simulation with classical PID control and in Figure 9c – the result of stream simulation with a FLC fuzzy control (Mamdani type).

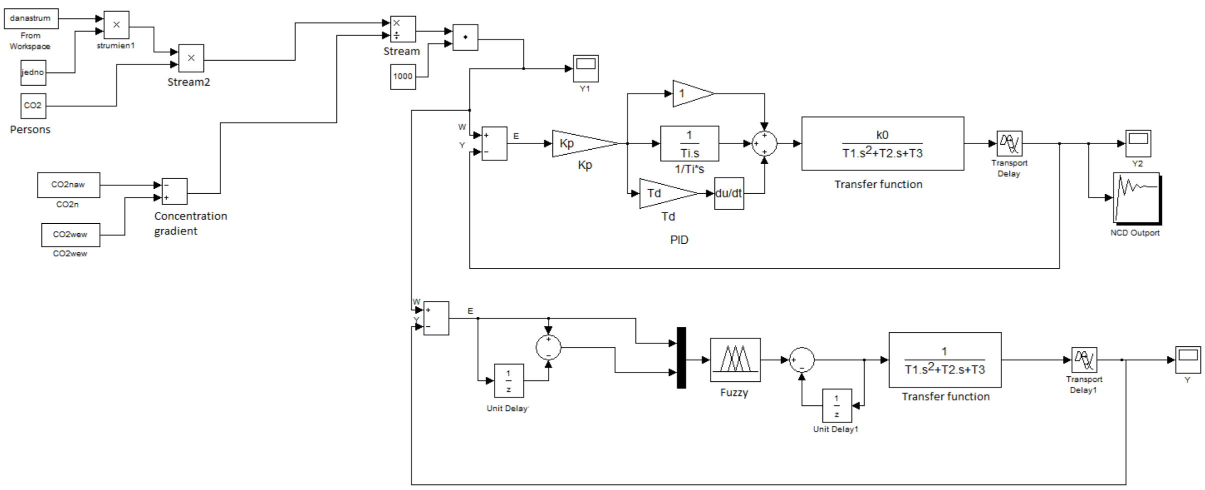
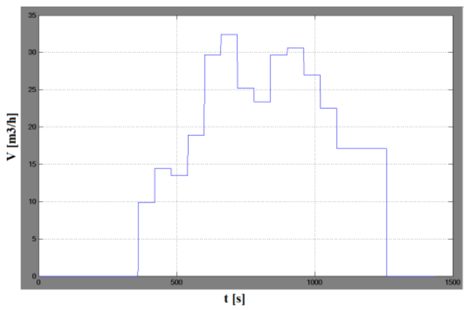


Figure 8. CO_2 concentration control model with classical PID control and PI fuzzy control.



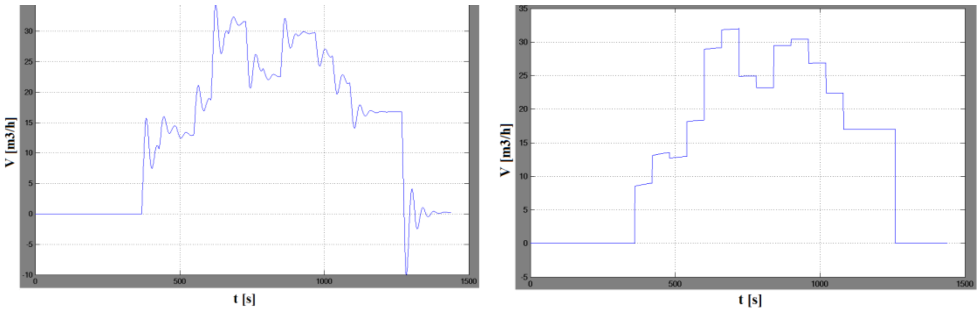


Figure 9. Setting the optimal air stream based on the CO_2 concentration balance (a) and the result of the simulation of the requested air stream control with a PID controller (b) and FLC Mamdami fuzzy controller (c).

6 EXPERIMENTAL TEST

As part of the experimental test a number of measurements have been carried out on a real controlled system – in a passive building located at the premises of the Technical University in Poznan. The research has been divided into two parts: in the previously existing centralized structure and in a decentralized structure specially created for the purpose of this test. When configuring the centralized system the attention has been drawn to the measurements only, but in case of decentralized system, apart from continuous daily measurements (within one year), the control system has been tested in different configurations.

6.1 Description of the test site

The real passive building is located at the campus of the Technical University in Poznan. It is a one-storey detached building. It has a basement where all devices have been installed for the preparation of the appropriate air to maintain the climate comfort in the rooms of the ground floor which function as offices for the employees of the Environmental Engineering Institute of the Technical University in Poznan.
The building has a wooden construction. DZ-3 technology has been used for the ceiling over the cellar. The roof has a wooden construction with a metal roofing thatch. The foundation grillage made of wooden beams with the size of 100 x 60 mm forms the structural elements of the walls. The spaces between the beams have been filled with mineral wool. The external walls have been constructed using ecological and recyclable products [5].
The ground floor level after the modernization of the building in question has been constructed in the passive building technology. It has 5 office spaces (rooms), a bathroom, a toilet and a hall.
Each of the office spaces has become a separate VAV control sphere and the rooms 4 and 5 create so called “an open space” with an “artificial” separation of the rooms from one another and from the hall.
The projection at the level of the ground floor is depicted in Figure 10a. The photograph of the building itself in presented in Figure 10b.

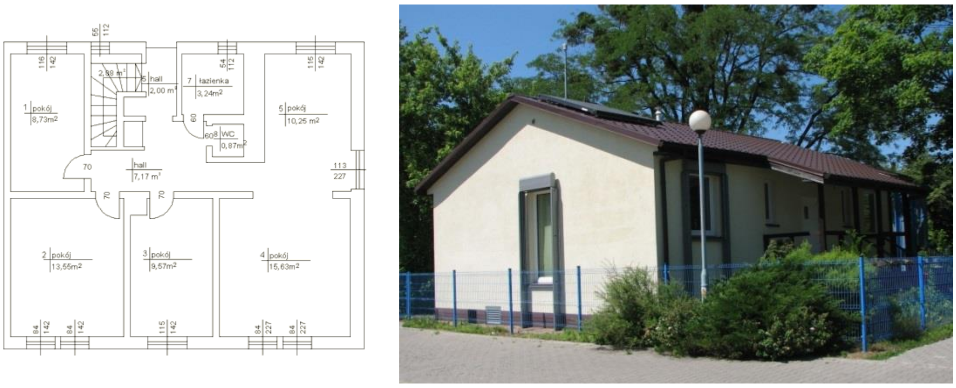


Figure 10. Projection of the ground floor (a) a photograph (b) of a real passive building.

In the passive building in question at the level of the ground floor there are five rooms which function as office spaces. Each office has been treated as a separate control area.

6.2 Real measurements

Research has been carried out based on two measuring and ventilation systems:

- Viessmann’s Vitotres 343 heat and ventilation unit as an example of a centralized system,
- Swegon GOLD air handling unit with a control, measuring and operating system by Siemens and Trox – as an example of a decentralized system.

6.2.1 Centralized system

The first variant – so called a measuring and control variant – referred to the analysis of the centralized control based on a representative measurement in the selected representative sphere of the whole passive building. The heat and ventilation central unit is located in the cellar of the building in question. It provides power supply to the air heating system and ventilation unit.

The control algorithm in the first variant consisted in measurement of the representative temperature, theoretically corresponding with the one present in the whole building. Then, based on this temperature, the central unit adjusted the temperature of the air supply in the central ventilation duct according to internal control algorithms with a continuous air stream of 150m3/h for the whole passive building.

An example of the changes of measured CO_2 concentration for each of the sphere has been presented in Figure 11.

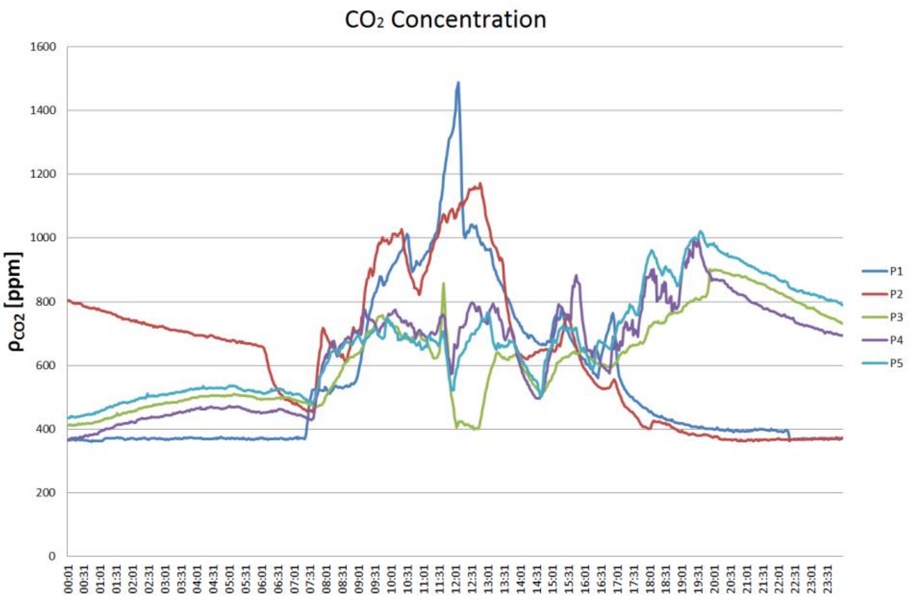


Figure 11. Example of daily changes of CO_2 concentration for each sphere (room)

6.2.2 Decentralized system

In the second measurement and control variant the analysis has been focused on the decentralized system. Each sphere (office room) has been treated as a separate controlled system. Therefore the whole system has been significantly extended. The comprehensively modernized system has been symbolically depicted in Figure 12.

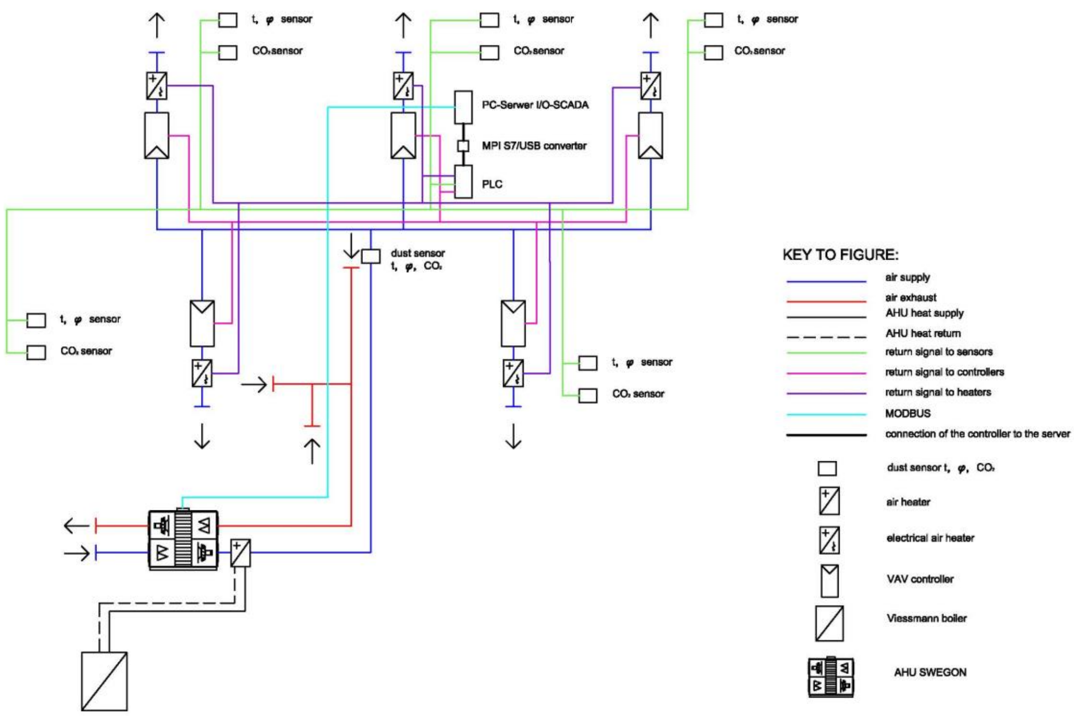


Figure 12. Symbolic diagram of a modernized system with all measurement devices, actuators and control

For control with CO_2 concentration priority as a controlled value, the algorithm checks the occupation of the building in question. If there are no people inside, then VAV controllers are closed to leave minimum air flows, so called representative air flows, that only keep the airing of given spheres. In the opposite situation, what is compared is the current CO_2 concentration with the set one and then VAV controllers are used to ensure the air flow control. An example of the CO_2 concentration regulation curve for the examined spheres has been depicted in Figure 13a (April) and 13b (May).

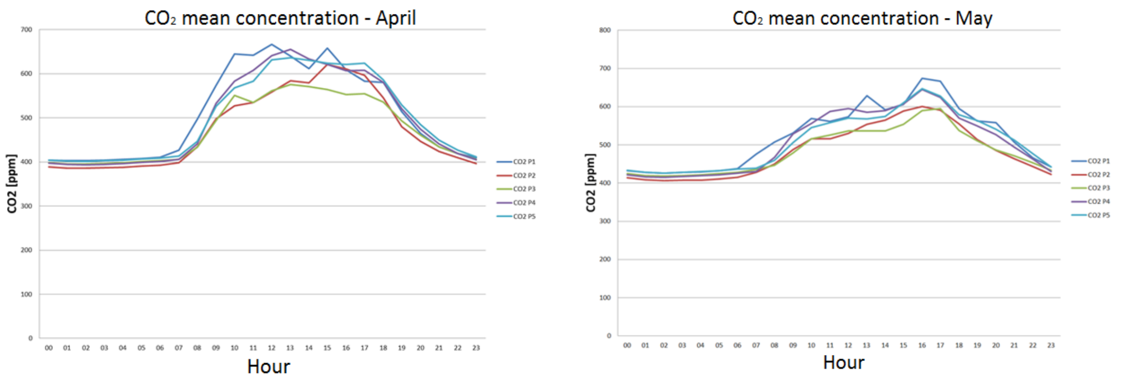


Figure 13. Daily changes of CO_2 concentration in each of the controlled spheres of a passive building: April (a) and may (b).

So far conducted measurements and research unequivocally show that the decentralized system used gives the possibility of more stable performance, fixed set point control of the parameters, thus it allows for optimal formation of the climate comfort in a given space. In case of the decentralized system with so-called measurement in an equivalent sphere, it often happened in the heating period that in case of temporary load caused by a larger group of people, continuous air stream delivered to a given room was insufficient. Therefore, the CO_2 concentration value of 1000ppm was very often exceeded and sometimes even reached the value of 1500ppm or more.

7 SUMMARY AND CONCLUSIONS

The article has presented the analysis of the process of variable air volume control which was to ensure the required freshness of air as one of the main elements of climate comfort in low-energy and passive buildings. Concurrently it must be stated that heat and ventilation systems can shape the microclimate in rooms of passive buildings because of very low heat demand.
The starting point to optimization of the control process of the main components of the climate comfort in the presented research was modelling of heat load of the passive building in question. The standard data adopted from different calculation methods have shown that internal loads are dominant as a result of big insulation and tightness of a passive building.
Generating internal heat gains have such a huge influence that standard calculation methods proves insufficient. Therefore, what should be very precisely defined is the profile for using a particular sphere in a passive building with a concurrent indication of internal gains emission.
Simulation research that has been carried out show that for a proper and optimal control of the parameters that define the climate comfort, continuous PID control must be used together with control parameters precisely set or control with the use of e.g. fuzzy logic controllers (FLC). Application of fuzzy logic controllers with the appropriate fuzziness of signals used in the control process gives much more stable results (without overshoot), however, sometimes with longer control time.

Undoubtedly, more stable and more precise reflection of signals increases the efficiency of control itself and at the same time results in bigger savings in energy consumption.
So far conducted measurements and research unequivocally show that the decentralized system used offers the possibility of more stable performance, fixed set point control of the parameters, thus it allows for optimal formation of the climate comfort in a given space.
The application of the decentralized system facilitated precise control separately for each of the spheres. In every controlled sphere the user was able to define different requirements. The possibility of dynamically variable air volume coming to the sphere on one hand ensures given air freshness kept at a high level (below the assumed level of 750ppm) and on the other hand reduces energy consumption of useful energy of a given system and in case of lack of load the flow decreased to the set level, so called equivalent level, fulfilling only the function of airing of a given sphere.

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