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ScienceDirect

Energy Procedia 112 (2017) 261 – 268

Energy Procedia

Sustainable Solutions for Energy and Environment, EENVIRO 2016, 26-28 October 2016, Bucharest, Romania

Indoor air quality evaluation in intelligent building

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Abstract

The paper presents a qualitative assessment of indoor air quality, using an electronic nose, for an intelligent control of the Heating, Ventilating and Air-Conditioning systems. The study is performed from the perspective of giving a unitary control method to ensure high energy efficiency and air quality improving. The gas sensors are sensitive to gases polluting the indoors air but they are sensitive to indoors temperature and humidity as well.The data acquisition system overtakes the sensors specific response and outputs a characteristic pattern to the pattern recognition system.

Peer-review under responsibility of the organizing committee of the international conference on Sustainable Solutions for Energy and Environment 2016

*Keywords:*indoor air quality,electronic nose,intelligent building,HVAC,.neural-control.

1. Introduction

Intelligent building is a construction that provides its occupants an optimal level of comfort in terms of minimum use of energy from outside sources and a good integration of the building into the environment. The comfort in intelligent building involves providing needs of the occupants in terms of ambient temperature, air speed, air humidity in the chamber, air quality, workplace lighting, noise level etc. Currently, the first four requirements of comfort: temperature, speed, humidity and indoor air quality are provided by installation and equipment of heating, ventilation and air conditioning (HVAC).

HVAC systems, be they individual or integrated into the building assembly are large consumers of electricity power, mainly from the national power network. It is estimated that the energy consumed by equipment for Heating, Ventilation and Air Conditioning is one third (33%)of world energy consumption .However, there is a big waste of

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Peer-review under responsibility of the organizing committee of the international conference on Sustainable Solutions for Energy and Environment 2016
doi:10.1016/j.egypro.2017.03.1095

energy in unoccupied rooms or hyperventilating and hypothermia of certain chambers which causes a high degree of discomfort, even leading to occupational diseases. Breathing air quality in the working chambers, be either office or industrial buildings, is very important in terms of comfort at work and labour productivity. For these reasons, the realization of smart building is conditioned on a strict air quality control in its various rooms. This control is achieved by controlling HVAC using an intelligent system for air quality assessment, an "electronic nose".

For the evaluation of subjective non measurable quantities, such quality of food, beverage and cosmetic products, the degree of air pollution, the environmental comfort, generally accepted method is only the qualitative assessment of the respective quantity. The division into classes and categories, specific activity only for human mind and senses, became currently accessible for "artificial intelligence" (AI), based on fuzzy logic and artificial neural networks.

Inspired by the workings of the human olfactory system, was proposed a new approach to assess comfort of a site, namely "electronic nose"[1]. A system of qualitative assessment of comfort consists of a network of gas electronic micro sensors, acting as receiver and acquisition circuit, responsible for information management and an artificial neural network for processing and quality classification comfort.

The quality of indoor comfort must be assessed in terms of thermal comfort, humidity and air velocity and quality in room. Evaluation of environmental comfort should be in the same time for both objective and subjective, some preferring dry air, cold and clean, brightly lit environment, others rather warm and humid air with high concentrations of volatile organic compounds and long shadows, each large individual presenting variations on this theme.

2. Electronic Nose

An electronic nose is an electronic system capable, in many cases, meet olfactory functions of the human nose. In principle, an electronic nose should include a network of sensors, conditioning circuits and electronic detection and analysis program signals provided by sensors. Electronic nose can be used to measure and monitor odours in any area, suggesting that it may have various applications, for example in the food industry, perfumes, household products, the monitoring of the environment in the tobacco industry, health products pharmaceuticals. The block diagram of an intelligent system for indoor air quality assessment using an electronic nose is shown in Figure 1. It is noted that the basic structure of an electronic nose comprising: a network of electronic gas micro sensors no selective but very sensitive, a data acquisition system and a system of pattern recognition (artificial neural network).

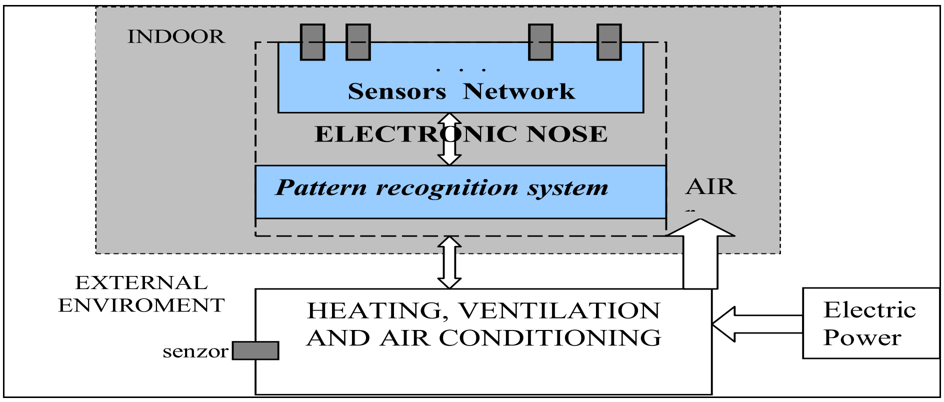

Fig. 1. Intelligent system for indoor air quality assessment.

Sensors network

Networks of gas sensors, the basic constituents of an electronic nose can be designed in different technologies for electronic gas micro-sensors. Both aesthetic requirements and the objective of implementation of instrumentation, require transducers (sensors) that make up the network of sensors to be practically "invisible". This can only be achieved only by using integrated micro-sensors, realized on semiconductor structures, in technology for manufacturing integrated circuits, or using biosensors. By analogy with biological sense organs (nose, eyes, skin), the sensors must be in large numbers, less selective but very sensitive.
The relatively large number of sensors (12 to 24), less selective, very sensitive but with different sensitivities allows a different form response for each study case.
These functional requirements require miniaturization and integration in micro-sensor networks composed of identical sensors but whose sensitivity is slightly modified by providing, across the network, a temperature gradient. Practical realization of such networks uses micro gas and temperature sensors with semiconductors (SnO_2 sensors) or biosensors with conducting polymer (polypyrole, for example). A network of SnO_2 semiconductors sensors, non-selective, but slightly different sensitivities can be achieved by an electronic micro technology providing temperature gradient in the semiconductor structure [2]. Due to the different sensitivity of sensors with SnO_2 at different gases and at different temperatures the answer of each sensor from network will be slightly different from the others. Semiconductor gas sensors are sensitive to air pollutant gases, but their sensitivity depends on the ambient temperature and humidity. The answer of a semiconductor sensor network, in a given situation, is "*a form*" that can be categorized by the artificial neural network. The response of the sensor network is an analogical vector of equal size with the number of sensors.
The answer of air quality assessment system, the "electronic nose" is pure qualitatively [3]. The output vector of sensors network, for each case, is taken as the feature vector of respective class. Feature vectors are used to train the artificial neural network.
Data acquisition system multiplexes, sampled, quantizes and stores sensors network response. The data acquisition system provides to pattern recognition system a numerical vector to be classified.

Pattern recognition system

Pattern recognition system takes the digital vector from Data acquisition system, compares this vector with the known vectors received before through learning process and classified the vector in one of the defined classes. Pattern recognition system may be based on a variety of classification techniques. They can be linear type, such as "Principal Component Analysis", or non-linear as "Artificial Neural Network algorithms." Dependence of sensors network response to a specific stimulus being generally non-linear, non-linear classification techniques are more successful in implementing electronic nose assessing environmental comfort. In general, for odours evaluating the use of classical neural networks and neuro-fuzzy networks leads to particularly good achievements.
An electronic nose should disseminate among certain odours within certain states [4].
Electronic nose falls into the great family of classifiers.
In terms of information, a classifier must perform essentially the following:

1. a) Establish classes of objects in the training set X; b) Establish prototypes of these classes;

2. Let the rule assignment of an unknown object (of the same kind, but not belongs to the set X) in one of the specified classes.

Establishment of classes of odours and their prototypes, in an electronic nose, is achieved by training the neural network constituent. Allocating a certain new response, previously unknown to a certain class involves the application of known rules of classification. These rules allow usually correct classification of the object x, if the shape of this does not differ greatly from one form that was trained network.
After training network, any sensors network response noise affected or not, will be assigned to one of the classification categories namely in the form of vector class response is closest to the characteristic shape of the vector.

3. Evaluation of environmental comfort

In the environmental comfort assessment should be considered: air temperature and humidity, it velocity, chemical or biological air pollution, amount of dust in the atmosphere, noise level, room lighting, electromagnetic radiation level. Subjective evaluation of environmental comfort is closely linked to individual physical and mental state (sad, happy, sick, stressed, etc.), the activity taking place in the space (work, study, feeding, entertainment, rest, sleep, etc.) and social environment in which it operates (alone, with family, at school, in society, at work, etc.).The quality of indoor comfort must be assessed in terms of thermal comfort, humidity, air velocity in the room, air quality, its pollution, lighting, noise, aesthetic etc.

Metal oxide semiconductor sensors are sensitive to both combustible and toxic gas concentrations and air temperature and air humidity. This triple sensitivity metal oxide semiconductor sensors makes them very useful in assessing environmental comfort. Combining sensors metal oxide semiconductor network with some sensors sensitive to noise and several light sensors is obtained a new network able to characterize the full comfort of a particular site [5].

The answer of a complete network of sensors is an analogue vector which, passed through the data acquisition system, is transformed into a "form" and provides pattern recognition system, where it will be classified. The classification is made according to user needs and desires.

To assess *environmental comfort* may be suggested different classes, for example:

a. fresh air, pleasant temperature, good comfort for rest or sleep;
b. pleasant atmosphere, cool, good lighting, favourable for study;
c. warm atmosphere, less polluted with smoke, noise, favourable for party;
d. hot air, stale, polluted with volatile organic compounds, noise, ventilation is required;
e. favourable conditions of work;
f. improper conditions of work;
g. cold, damp, dark, cold and frost danger;
h. dry air, hot, polluted with combustible gas, fire hazard;
i. a danger of explosion, rapid evacuation is necessary.

Pattern recognition system implementation can be done with an *artificial neural network multilayer perceptron type*. An Electronic Nose for Indoor Air Quality Assessment was simulated. The modelling of the Pattern Recognition System has been made by a multilayer perceptron artificial neural network, presented in Figure 2.

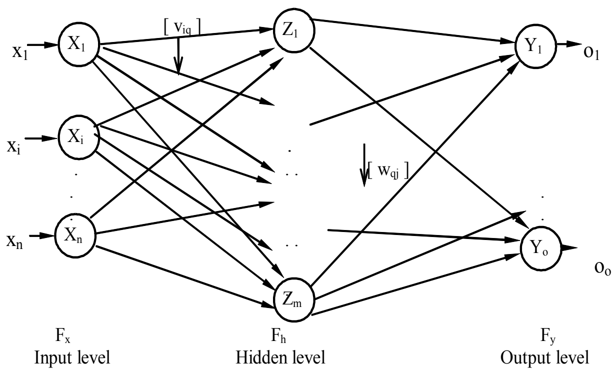

Fig. 2. Multilayer perceptron artificial neural network.

The entry level consists of ***n*** neurons, equal to the size of the input vector (number of sensors in the network). Hidden layer consists of 3n neurons with a bipolar activation function. The output level consists of ***o*** decision neurons, equal to the number of classes, and having a binary activation function.

Network training was done by the method of back propagation of error.

The known data, separated by classes mentioned above are divided into two groups: the training data, respective test data in the ratio 80% to 20%.
Network response, after training at different input values close or different from the training data is 100% in extreme cases, clean atmosphere and explosion hazard, respective 87-96% in other cases. It is true that in these last cases, even senses and the human mind often assess wrong.

4. Neuro -fuzzy air quality evaluation

In cases where, in training the neural network, it reaches a local maximum (network saturation occurs), it is necessary to introduce fuzzy surveillance which translates in forced jump to another classification class and resumption of training to obtain optimum.
Since the human sensation of comfort is vague and subjective, fuzzy logic theory is well adapted to describe it linguistically depending on the state of the thermal comfort dependent variables. In terms of the problems stated above, fuzzy logic control is an excellent controlling choice. Since fuzzy logic control is based on the operational experience of human expert, the system is robust to changes in environment.
The HVAC system is a nonlinear time- variable system with many uncertainties, so it is difficult to find a mathematical model to describe the process over operating range.
In Figure 3 is presented a physical model refers to the system operating on the cooling mode (air-conditioning) [7]. The systems include components like thermal space, heating/cooling coil, humidifier/dehumidifier, mixing box, air filter supply and return fans, filters, dampers, and ducts.

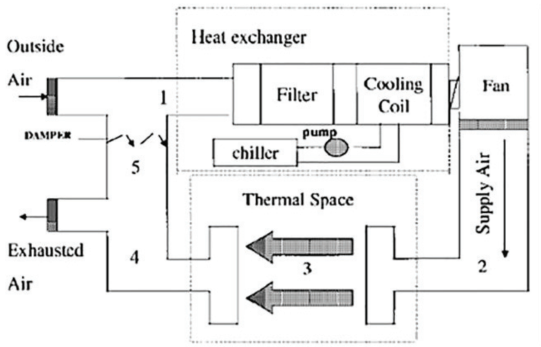

Fig. 3– HVAC system operating as air-conditioning system [8]

Operations performed in the system will be reflected in the mathematical modelling. In this system, fresh air enters and mixes with 75% of the return air (position 5) at the flow mixer (position 1), and remaining air is exhausted.
The purposes of confort and hygiene are considered in this system-to-fresh-air volumetric flow-rate ratio. Then, mixed air passes through the heat exchanger components and finally by supply fan enters the thermal space as supply air (position 2), to offset (compensate) the sensible (actual heat) and latent (humidity) heat thermal loads acting upon the system; specifically, by changing of thermal load, the system controller simultaneously varies volumetric flow rate of air and water, so that the desired setpoints in temperature and relative humidity are maintained. Finally, the air in the thermal space is drawn through a fan (position 4), 75% of this air gets recirculated and the rest is exhausted from the system.
The differential equations describing the dynamic behavior of the HVAC system in Figure 3 can be written [8] as follows:

$$\dot{T}_3 = \frac{q_a}{V_3}\left(T_2 - T_3\right) - \frac{h_{wv} q_a}{c_p V_3}\left(W_2 - W_3\right) + \frac{1}{\rho c_p V_3}\left(Q - h_{wv} M\right) \tag{1}$$
$$\dot{W}_3 = \frac{q_a}{V_3}\left(W_2 - W_3\right) + \frac{M}{\rho V_3}$$
$$\dot{T}_2 = \frac{q_a\left(0.25T_o + 0.75T_3 - T_2\right)}{V_{he}} - \frac{q_a h_w}{c_p V_{he}}\left(\left(0.25W_o + 0.75W_3\right) - W_2\right) - \frac{\rho \Delta h_w q_w}{\rho c_p V_{he}}$$

The constitutive assumptions of the mathematical model are the following: 1) ideal gas behavior; 2) perfect mixing; 3) constant pressure process; 4) negligible wall and thermal storage 5) negligible thermal losses between components; 6) negligible infiltration and exfiltration effects; and 7) negligible transient effects in the flow splitter and mixer.

We introduce the following notations for system's parameters, constants and variables: ρ – air mass density [kg/m^3]; h_w–enthalpy of liquid water [J/kg]; Δh_w – variation of enthalpy of water vapour [J/kg]; h_{wv} –enthalpy of water vapour [J/kg]; W_o – humidity ratio of outdoor air; W_2 – humidity ratio of supply air; $W_3(t)$ – humidity ratio of thermal space; V_{he} – volume of heat exchanger [m^3]; c_p – specific heat of air [J/(kg $^{\circ}$C)]; $T_o(t)$ – temperature of outdoor air [$^{\circ}$C]; $T_2(t)$ – temperature of supply air [$^{\circ}$C]; $T_3(t)$ –temperature of thermal space [$^{\circ}$C]; V_3 – volume of thermal space [m^3]; M – humidity (moisture) load [kg/s]; Q – sensible heat load [W]; q_a – volumetric flow rate of air [m^3/s]; q_w – flow rate of chilled/heated water [m^3/s].

The HVAC system is a nonlinear time- variable system with disturbances and uncertainties, so it is very difficult to find a mathematical model to describe the process over an operating range.

The problems in HVAC systems are variable conditions, the nonlinear factors, interaction with climatic parameters and impossibility of accurate modeling of the system.

The primary goals in the control of HVAC systems are occupants' comfort and energy efficiency. In most cases, the achievement of one of these goals requires that the other be sacrificed. If the relative importance of the two goals can be established, optimal control can be used to determine the minimum operating cost for the system to achieve the desired comfort level [9].

Fuzzy reasoning is define by a fixed set of control rules (or rule base RB) normally derived from the knowledge of experts. For example, tracking control, building a database of rules embodies the idea of a ratio between the error signal e_1 and the required fuzzy control u_f. In this case, the regulator controller type, base construction rules approach is different. A fuzzy logic controller (FLC) is called adaptive if any of its tuneable parameters changes when the controller is used; otherwise it is a non adaptive or conventional FLC. If FLC is automatically adjusted by changing his RB's, then it is called a self-organizing FLC. A fuzzy supervised neural-control (FSNC) is presented in figure 4. The FSNC operates as fuzzy logic control u_f in the case when neuro-control u_n is saturated. In the case of fuzzy control operating, the fuzzy neuro-control u_n is concomitantly updated in the context of the real acting fuzzy control u_f.. To obtain the rigor and accuracy of regulated process tracking, fuzzy logic control switches on neuro-control whenever readjusted neuro-control u_n is not saturated [10], [11].

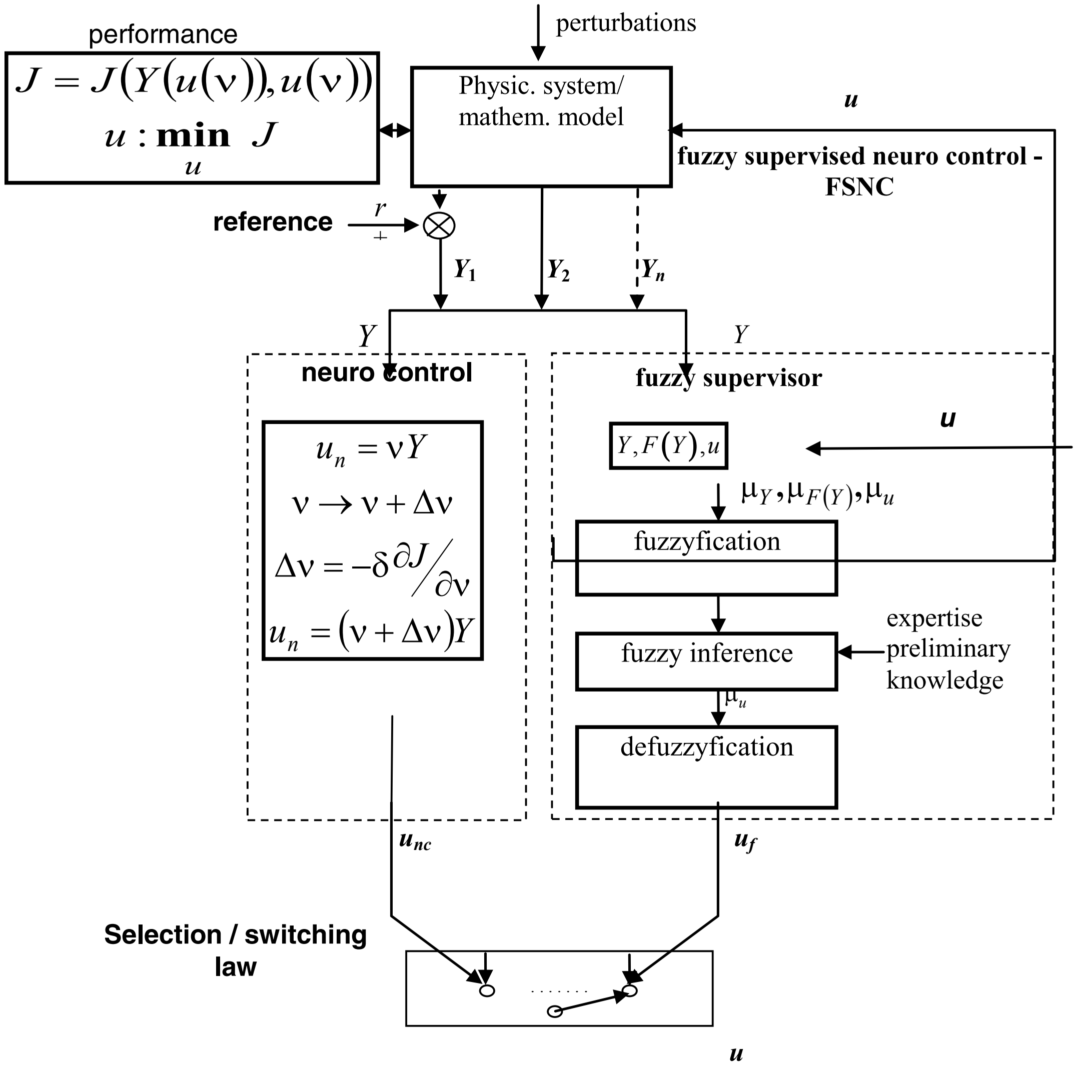

Fig. 4. Sketch of the fuzzy supervised neural-control (FSNC)

6. CONCLUSIONS

Using the "electronic nose" for evaluating indoor air quality and comfort in buildings, allows a purely qualitative assessment of these sizes, in generally immeasurable. In addition, it allows the introduction of the subjective factor in the comfort, each user being able to choose their favourite comfort class.

Introducing the "electronic nose" to control the heating, ventilation and indoor air conditioning (HVAC system) allows, in the same time with the comfort, an important energy savings and a quickly adaptation to outside conditions.

Qualitative assessment of air quality provides comfort and introduction of artificial intelligence (AI) in building management systems (BMS) is an important step towards the "intelligent building".

This can be considered that intelligent assessment system of air quality, thus realized performs the tasks for which it was proposed to implement in intelligent building.

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