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Smart Building Climate Control Considering Indoor and Outdoor Parameters

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Abstract. Heating, ventilation, and air conditioning (HVAC systems) account for the majority of the energy used in buildings. Consequently, any business has the potential to realize significant cost savings by improving control of HVAC operations and increase the efficiency of the system it uses. Using a highly efficient HVAC equipment can lead to significant energy and emissions savings. The entire structure of the building in combination with the enhanced comfort zone can produce a much greater savings. Extended comfort includes the use of concepts such as providing a warm, but drier air using a desiccant dehumidification in the summer, or the colder air from the warm walls of windows and warm in winter. In addition, high efficiency HVAC can provide enhanced thermal comfort for people, as well as to contribute to the improvement of environmental quality in the room. The paper explores thermal process and the affecting parameters, and introduce fuzzy logic based energy consumption model based on controlling of HVAC devices.

Keywords: HVAC systems; fuzzy logic; thermal balance; indoor microclimate

1 Introduction

Individuals spend most their time in an indoor environment and comfort is one of the most important issues with respect to staying indoors. Environmental quality of an interior environment is directly dependent on its organization and content. Therefore, the task of maintaining a comfortable environment is extremely important for health, good spirit, and human activity. Several parameters can be adjusted to achieve comfort in a room—air temperature, humidity, air quality, speed of movement of air throughout the room, oxygen content in the air, ionization of air, and noise level [2]. A deviation of the aforementioned parameters could result in the deterioration of the normal state of an individual. This can lead to the disruption of thermal balance as well as result in a negative impact on health and productivity.

Prior to determining the microclimate of a room and determining any adjustments, it is necessary to find a certain method to determine the real condition of several parameters, i.e., to conduct a study of the microclimate.

An important stage in creating a system to manage temperature and humidity conditions involves the development of greenhouse facility models. This reflects the processes occurring within a system from two different standpoints, namely the synthesis of algorithms and the analysis of management quality. If the model requirements are adequate from the second standpoint, then the development of models with respect to the first class of problems should consider the satisfactory requirements as well as the current level of scientific support task synthesis algorithms. According to this classification key [1, 4] there are two groups of climate models as follows:

a) A fundamental model aimed at solving problems of the object properties of analysis and quality control systems. The models in this group of physical phenomena are described by differential equations (usually in the state space). Parameters in the models of this group involve a physical interpretation.

b) Black box models involve solution-oriented control algorithms synthesis problems. They are based on the specific synthesis problem using either static models (regression, polynomial, based on the use of neural networks, fuzzy sets) or dynamic models (usually in the form of differential equations in which the coefficients are determined from experimental data by identification methods, and a clear relationship is absent between the physical parameters and structural parameters of the greenhouse).

The present study used a schematic model of the microclimate as a basis for the development of both classes of models.

2 Indoor Microclimate Thermal Balance

Individuals only experience wellness and comfort within a narrow range of thermal conditions. Hence, the natural climate of a limited number of geographical locations is conducive for the comfort of individuals. In most regions, climate conditions are comfortable only for a limited time daily and for a limited time period annually. A building is an enclosure that protects individuals against external conditions. Thus, the interior of a building should provide a comfortable environment. Thermal balance is a principle in which the entire building is considered an entity with a number of energy sources and sinks. A thermal balance corresponds to the net amount of all gains and losses. The energy efficiency of a building is defined through its thermal balance.

Typically, energy flows in cold climates are either welcome gains (sources) or unwelcome losses (sinks) based on the time of year and external conditions. It is necessary to balance the gains and losses that result in the residual energy to create comfortable indoor conditions.

Q_i – Internal heat gain corresponds to the total amount of internal energy gains. This includes heat emitted from human bodies, electrical devices, and artificial lighting.

$Q_{c,T}$ – Conductive heat loss corresponds to energy lost by the transmission of heat through the building envelope.

Q_s – Solar heat gain corresponds to the total amount of energy input induced by incoming solar radiation that heats indoor air and thermal mass in the building.

Q_v – Ventilation heat loss or gain is caused by supply of fresh air; removal of stale indoor air to remove smells, CO_2, and other contaminants; infiltration of cold air and exfiltration of warm indoor air through cracks in the building envelope; mixing of air from different temperature zones; and mechanical ventilation. This is expressed as follows:

Heat Losses: $Q_{Tv} + Q_{i,Sink} + Q_s = Q_{sink}$

Heat Sources: $Q_s + Q_T + Q_v + Q_{i,Source} = Q_{source}$

A thermal equilibrium exists when $Q_{sink} = Q_{source}$

If $Q_{sink} < Q_{source}$, then the temperature inside the building increases.

If $Q_{sink} > Q_{source}$, then the building cools down.

Additional systems and technologies are required for heating or cooling in buildings in which a thermal system is not naturally in equilibrium. It is necessary for the net heating energy to be provided by a heating system. The heating system experiences losses when heat is produced from a primary energy source. The total heating energy demand of a building corresponds to the sum of heating energy and heating equipment losses.

Parameters for sources and losses of energy can be categorized into building, environmental, legal, and usage parameters. The possibility of increasing the energy efficiency of a building exists when buildings are designed by considering given and fixed environmental and usage parameters.

How to ensure desired temperature in the room? An automatic temperature control system was used to formalize the description of the temperature regime of the process as the initial model. With respect to temperature control, it is necessary to consider the heat flows entering and exiting the system as well as the accumulation of thermal energy due to the cumulative capacity of the object. It is necessary to consider the existence of the following three thermal flows:

1. Q_{gain} – heat gain from the heating system.
2. Q_{env} – heat loss through the building envelope.
3. $Q_{fr.air}$ – heat loss for heating of fresh air.

Given the volume of the indoor air (V), air density (ρ), the specific heat capacity of air (C) and using the procedure of drawing up energy balance [1-3] results in the equation of heat that affects the change in air temperature inside a room as follows:

$$\rho VC\frac{dT(t)}{dt} = Q_{gain}(t) - \left(\sum Q_{env}(t) + Q_{fr.air}(t)\right) \qquad (1)$$

where ρ – air density (kg/m^3); V – air volume (m^3); C – specific heat of air (J/°C·kg); (t) – indoor air temperature (°C); $Q_{gain}(t)$ – Heat proceeding from the heating system (W); $\Sigma Q_{env}(t)$ – heat loss through the building envelope (W); $Q_{fr.air}(t)$ – heat loss for heating of fresh air (W).

Define heat loss through the building envelope [4]:

$$Q_{env}(t) = \sum k \cdot F \cdot T_{air}(t) - T_{outdoor}(t) \qquad (2)$$

where k – heat transfer coefficient of building envelope (J/ (m^{2}s ·°C)); F – the building envelope square (m^2); $T_{\text{air}}(t)$ – air temperature inside the building (°C); $T_{\text{outdoor}}(t)$ – outdoor air temperature (°C).

Heat losses for heating fresh air [4] are given by the following expression:

$$Q_{fr.air}(t) = G_{fr.air}(t) \cdot C_{air} \cdot T_{indoor}(t) - T_{outdoor}(t) \qquad (3)$$

where $G_{\text{fr.air}}(t)$ – fresh air consumption for ventilation premises (kg/s); C_{air}– specific heat of air (J/kg·°C); T_{air} – air temperature inside the building (°C); T_{outdoor} – outdoor air temperature (°C).

The initial equation (1) for the temperature change is specified as follows:

$$\rho VC \frac{dT(t)}{dt} = Q_{gain}(t) - \sum kF\left(T_{air}(t) - T_{outdoor}(t)\right) - G_{fr.air}(t) C_{air} \Delta T \qquad (4)$$

The $T_{\text{outdoor}}(t)$ is accepted for the current temperature in the room $T(t)$. Additionally, (t) is expressed as follows:

$$\rho VC \frac{dT(t)}{dt} + kFT(t) = Q_{gain}(t) + kFT_{outdoor}(t) - G_{fr.air}(t) C_{air} \Delta T \qquad (5)$$

Dividing both sides by kF results in the following expression:

$$\frac{\rho VC}{kF} \frac{dT(t)}{dt} + T(t) = \frac{1}{kF} Q_{gain}(t) + \frac{kF}{kF} T_{outdoor}(t) - \frac{1}{kF} G_{fr.air}(t) C_{air} \Delta \qquad (6)$$

Equation (6) corresponds to a first order differential equation describing the temperature change as a function of defining and disturbances. It is assumed that $TT = \frac{\rho VC}{kF}$ is a time constant. The equation was expressed in operational form as follows:

$$\left(T_T p + 1\right) T(t) = \frac{1}{kF} Q_{gain}(t) + T_{outdoor}(t) - \frac{1}{kF} G_{fr.air}(t) C_{air} \Delta T \qquad (7)$$

Hence, it follows that T(t) was influenced by $Q_{\text{gain}}(t)$, $T_{\text{outdoor}}(t)$, and $G_{\text{fr.air}}(t)$. The next section investigates the influence of these parameters.

3 Algorithmic process to ensure desired air temperature and humidity

1. Specifically, $T_{outdoor}$ denotes the value of outdoor temperature. The average annual temperature was determined by the schedule for a particular geographic location premises [4, 5]. The transfer function to change the inside and outside temperatures specified in Equation (7) is as follows:

$$W_{T1}(p) = \frac{T(p)}{T_{out}(p)} = \frac{1}{(T_T p + 1)} \quad \textbf{(8)}$$

where $T(p)$ is the Laplace image for the indoor temperature, Toutdoor(p) is the Laplace image for the outdoor temperature, and TT is the time constant.

Temperature changing process includes an inertia property and describes a typical inertial link. In the winter, the process can be characterized by cooling the building with no active heating system and other sources of heat flows affecting the temperature balance.

2. Component $\frac{1}{kF} Q_{gain}(t)$ considers the effect of the heating system that provides the heat necessary to maintain the heat balance of the room. The transfer function for adjusting the inside air temperature that is influenced by heat is as follows:

$$W_{T2}(p) = \frac{T(p)}{T_{gain}(p)} = \frac{k_1}{(T_T p + 1)} \quad \textbf{(9)}$$

where $T(p)$ is the Laplace image for the indoor air temperature, Qgain(p) is the Laplace transform for the heating system, and $k_1 = \frac{1}{kF}$ is the heating system efficiency factor, TT is the time constant.

This temperature change process also presents a typical inertial link.

3. Component $-\frac{1}{kF} G_{fr.air} C_{air} \Delta T$ considers the cost of heat that is caused by changes in temperature compensation ΔT supply and indoor air in the room. The consumption of fresh air $G_{fr.air}$ depends on the performance of the ventilation system and considers the value set by the control loop to stabilize the value of the qualitative composition of the air. The relationship between the change in air temperature $T(p)$ and the flow of fresh air $G_{fr.air}$ (p) is describedwith the following equation:

$$W_{T3}(p) = \frac{T(p)}{G_{fr.air}(p)} = \frac{k_2}{(T_T p + 1)} \qquad \textbf{(10)}$$

where T (p) – Laplace transform for the indoor air temperature, $G_{\mathrm{fr.air}}(p)$ – Laplace image for fresh air consumption, $k_2 = -\frac{1}{kF} G_{air} \Delta T$ – ventilation system efficiency factor, and TT – time constant.

The process is inertial and presented by an inertial link. Increases in air flow led to decreases in air temperature, and vice versa, given a condition in which a positive temperature differential was present.

The complex influence of external factors on the indoor air temperature can be described by a block diagram as shown in Fig. 1.

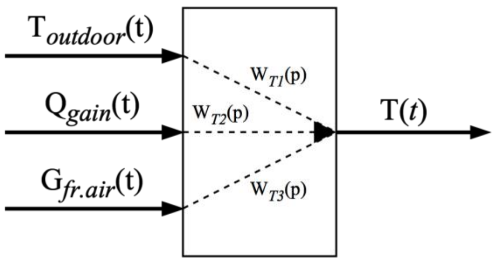

Fig. 1. The relationship structure between indoor temperature and influencing factors

Thus, the indoor air temperature T(t) is an object of control that can represent a dynamic system. It is influenced by three input values, namely a value controlling action $Q_{gain}(t)$ and two perturbing $T_{outdoor}(t)$ and $G_{fr.air}(t)$ values. The control action represented by the feed of heat from the heating system with the transfer function WT2(p) described the transfer function of WT1(p), and heat loss during operation of the ventilation system for the preparation of fresh outdoor air. The control function was aimed at compensating disturbances in the form of heat loss through the building envelope (with a positive differential indoor $T_{indoor}(t)$ and the outside temperature Tout(t)). The consumption of fresh air $G_{fr.air}(t)$ was determined by the process of stabilizing loop air quality and its impact on the temperature T(t) as described by the WT3(p) transfer function.

Ensure predetermined air humidity in the room

The approach discussed above was used to describe the dynamic relationship between air humidity in the rooms with the control actions and influence disturbances. The initial equation involved using an equation given in a previous study [6] to describe the moisture content in the air as follows:

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$$\rho V \frac{dX(t)}{dt} = G_{fr.air}(t) X_{fr.air}(t) - G_{outgoing\_air}(t) X_{outgoing\_air}(t) + G_{steam} \quad \mathbf{(11)}$$

where

ρ – air density (kg/m^3); V – air volume (m^3); X(t) – absolute humidity in the room ($\frac{m_{water}}{m_{air}}$); $G_{\mathrm{fr.air}}(t)$ – fresh air consumption (kg/second); $X_{\mathrm{fr.air}}(t)$ – absolute humidity of fresh air (kg$_{water}$/kg$_{air}$); $G_{\mathrm{outgoing\_air}}(t)$ – outgoing air consumption (kg/s); $X_{\mathrm{outgoing\_air}}(t)$ – absolute humidity of the outgoing air ($\frac{m_{water}}{m_{outgoing\_air}}$; kg$_{water}$/kg$_{air}$); $G_{\mathrm{steam}}(t)$ – steam consumption (kg/s).

With respect to once-through ventilation systems, fresh air flow $G_{\mathrm{fr.air}}(t)$ was approximately equal to that of the outgoing air flow $G_{\mathrm{outgoing\_air}}(t)$ given that the air is not compressed and has a constant density (ρ = $const.$) and given that the size of the room was unchanged (V = $const.$)). As a first approximation, it was assumed that the humidity of the outgoing air from the room was equal to the actual value of the humidity $X_{\mathrm{outgoing\_air}}(t)$=$X(t)$. The initial equation can then be expressed as follows:

$$\rho V \frac{dX(t)}{dt} = G_{outgoing\_air}(t) X(t) - G_{fr.air}(t) X_{fr.air}(t) + G_{steam}(t) \quad \mathbf{(12)}$$

The equation is transformed by dividing it into $G_{\mathrm{outgoing\_air}}(t)$ as follows:

$$\frac{\rho V}{G_{outgoing\_air}} \frac{dX(t)}{dt} + X(t) = \frac{G_{fresh\_air}}{G_{outgoing\_air}} X_{fr.air}(t) + \frac{G_{steam}(t)}{G_{outgoing\_air}(t)} \quad \mathbf{(13)}$$

It is assumed that $\frac{\rho V}{G_{outgoing\_air}} = T_X$ and the equation is expressed in an operational form as follows:

$$\left(T_X p + 1\right) X(t) = \frac{G_{fresh\_air}}{G_{outgoing\_air}} X_{fr.air}(t) + \frac{1}{G_{outgoing\_air}} G_{steam}(t) \quad \mathbf{(14)}$$

Air density X(t) depends on the inflow of fresh air $\frac{G_{fresh\_air}}{G_{outgoing\_air}} X_{fr.air}(t)$ and the steam supply $\frac{1}{G_{outgoing\_air}} G_{steam}(t)$.

These relationships can be specified as follows:

The value of the air humidity is determined by climatic conditions of a region. The impact of a parameter is considered via a transfer function that follows from a differential equation as follows:

$$W_{X1}(p) = \frac{X(p)}{X_{fr.air}(p)} = \frac{1}{(T_{Xp} + 1)} \quad \mathbf{(15)}$$

where

(p) – Laplace image for indoor humidity,

$X_{\mathrm{fr.air}}(p)$ – Laplace image for indoor humidity, and

$T_X = \frac{\rho V}{G_{outgoing\_air}}$ – time constant of humidifying process.

As observed from the transfer function, the process was described by the standard inertial and inertial element. The process involved room ventilation with outside air in the absence of external factors affecting the change in room humidity that led to indoor humidity values similar to the outdoor air humidity value.

Steam consumption is a reference variable that compensates for humidity deficit in the air. The parameter of the transfer function that binds air humidity (t) and exposure $G_{\mathrm{steam}}(t)$ is considered as follows:

$$W_{X2}(p) = \frac{X(p)}{X_{steam}(p)} = \frac{k_3}{(T_X p + 1)} \quad \mathbf{(16)}$$

Where:

$X(p)$ – Laplace image for indoor air humidity,

$X_{steam}(p)$ – Laplace image for steam consumption,

$T_X = \frac{\rho V}{G_{outgoing\_air}}$ – time constant of humidifying process, and

$k_3 = \frac{1}{G_{outgoing\_air}}$ – transformation coefficient of the steam consumption.

The process is also inertial and described by a typical inertial link.

The relationship between air humidity and air flow from the ventilation system is considered. It is assumed that $\frac{1}{G_{outgoing\_air}(t)}$ corresponds to G`(t) and the transfer function for the relationship between air humidity and a flow rate of fresh air G`(t) is derived as follows:

$$W_{X3}(p) = \frac{X(p)}{G^{'}(p)} = \frac{k_4}{(T_X p + 1)} \tag{17}$$

where $X(p)$ – Laplace image for indoor air humidity,

$G^{'}(p)$ – Laplace image for fresh air consumption,

$k_4=G_{steam}$ – the transformation coefficient for the fresh air consumption, and

$T_X = \frac{\rho V}{G_{outgoing\_air}}$ – time constant of humidifying process.

Based on the transfer functions, the dependence of air humidity on the influencing factors can be described by the structure shown in Fig. 2, which corresponds to a structure of multiple connected systems.

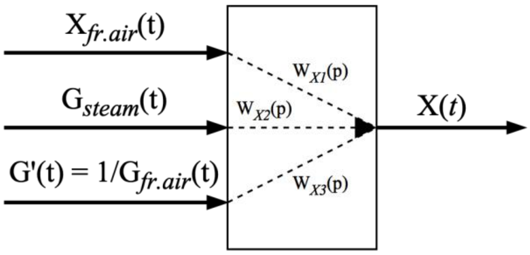


Fig. 2. Structure of the relations between the indoor humidity and influencing factors

The indoor air humidity X(t) was represented by a dynamic system with three input variables, namely a manipulated variable $G_{steam}(t)$ and two perturbing variables $X_{fr.air}(t)$ and G'(t). The control action described the transfer function $W_{X2}(p)$ and was aimed at compensating air humidity due to operation disturbances described by transformation functions $W_{X1}(p)$ and $W_{X3}(p)$, as a result of the ventilation system with $G_{fr.air}(t)$ performance and $X_{fr.air}(t)$ fresh outdoor air humidity.

4 Experiment Results

The experiments were conducted at the Artificial Intelligent and Smart City laboratory in Gachon University. In the laboratory space, an area of 3×6 m^2 with a height of 2.5 m on one of the outer walls included six work areas separated by translucent partition walls (with a height 1.5 m) with personal computers. Fig. 3 illustrates the plan of the laboratory.

The room provided fresh air supply through the three dimension 400x400mm windows. The experimental studies indicated that at an outside temperature below $T_{outdoor}$ (-5 °C) during heating and ventilation operations, the air temperature significantly exceeded the critical temperature, and the relative humidity was in the range of 5-10%. Also, Fig. 4 shows the results of measurements of the relative humidity at elevations of 1.5 m above the floor space at $T_{outdoor}$ = -11 °C. The low relative humidity primarily negatively affected the respiratory organs. Furthermore, humid air is a poor conductor of static electricity. This contributed to the accumulation of humid air on the surface, and this exceeded the performance of the electromagnetic field with respect to the remote control at the workplace with PC and led to failure of the electronic equipment. Humidification units were installed to ensure standardized relative humidity values in the installation of central air conditioning. Nevertheless, the generation of vapor or fine water required significant energy costs.

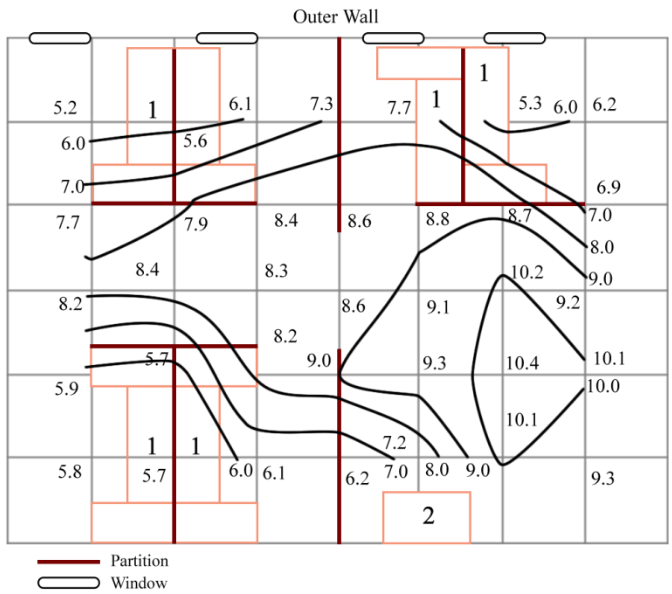


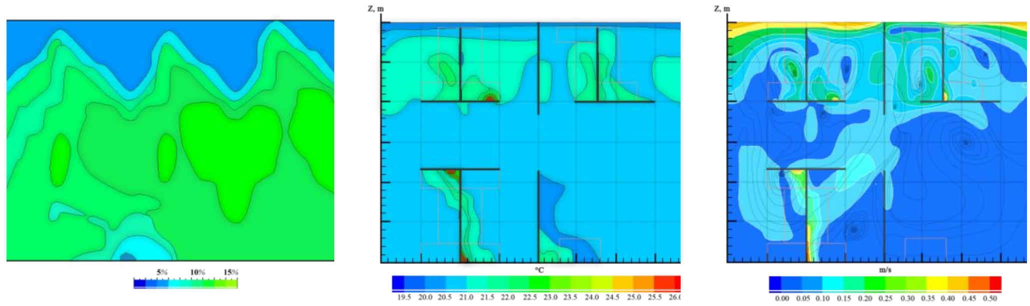
Fig. 3. The results of experimental studies of the distribution of the relative air humidity. 1 – desktops with PC; 2 – partitions; 3 – copying equipment

Furthermore, as shown by field studies, the humidified air flowed in the duct and over obstacles (e.g., silencers, etc.). There were significant losses due to moisture condensation on solid surfaces. Thus, a power saving humidification process is necessary to determine the minimum amount of normal air and water supply wherein the relative humidity of indoor air was given. For this purpose, a numerical simulation of the spatial distribution of relative humidity in the room was initially conducted through corresponding field experiments.

In the study, the results indicated the minimum amount of moisture in the supply air by which it was possible to determine the rated value of relative humidity of internal air. The moisture content corresponded to $d = 5 \cdot 10^{-3}$.

The numerical simulation results shown in Fig. 4 include temperature field distribution, air velocity, and relative humidity in the horizontal plane data distance of 1.500 m from the room floor.

Field temperatures (Fig. 4b) confirmed the impact of rising convective flow from heating devices, individuals, and PCs. Accordingly, downward flows were also observed near the outer wall. All heat flows corresponded to limited translucent partitions. In the workplace, the temperature values and variations in the range of 20-22°C satisfied the requirements of regulatory documents [8].



a) Distribution of relative humidity

b) Distribution of air temperature

c) Distribution of moving air speed

Fig. 4. Horizontal plane simulation results

Holistic project explores the specific climate of the building open state of the climate zone, as Fig. 4c illustrates distribution of moving air speed. In the workplace, air velocity satisfied the requirements of normative documents [8]. The rate of change of range of motion of air was in the range of 0.05–0.2 m/s, and it also satisfied the aforementioned requirements. The average values of relative humidity corresponded to the normal values. The range of changes in the relative humidity of the air in the occupied zone corresponded to 33-35%, as illustrated in Figure 4c. Minimum relative humidity in the range 30–32% was observed in the zones of influence of convective flows and translucent structures.

5 Conclusion

Holistic project explores the specific climate of the building open state of the climate zone, as well as the cultural characteristics that lead to the development of specific requirements. Sustainable energy management requires a focus on the environment and economic efficiency of users. Combined monitoring of comfort and energy consumption is set to gain a better understanding of the reaction of the building to a particular climate, as well as user behavior and acceptance of users. It shows how the extreme conditions in the building can be designed and effectively as refrigeration and air conditioning can be optimized in view of the hot/cold temperatures and high/low humidity.

Acknowledgements

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References

1. A. Chaouachi, R. M. Kamel, R. Andoulsi, K. Nagasaka, "Multiobjective Intelligent Energy Management for a Microgrid," IEEE Transactions on Industrial Electronics, vol. 60, no. 4, pp. 1688-1699, 2013
2. D. Arcos-Aviles; J. Pascual, L. Marroyo, P. Sanchis, F. Guinjoan, "Fuzzy Logic-Based Energy Management System Design for Residential Grid-Connected Microgrids," IEEE Transactions on Smart Grid, vol. PP, no. 99, pp. 1-1, 2016. (doi: 10.1109/TSG.2016.2555245)
3. L. Chuan, A. Ukil, “Modeling and Validation of Electrical Load Profiling in Residential Buildings in Singapore,” IEEE Transactions on Power Systems, vol. 30, no. 3, pp. 2800-2809, 2015.
4. H. Zhang, A. Ukil, "Framework for Multipoint Sensing Simulation for Energy Efficient HVAC Operation in Buildings," 41st IEEE Annual Conf. on Industrial Electronics-IECON, Yokohama, Japan, Nov. 2015.
5. Veronika Földváry, Hana Pustayová Bukovianska, Dušan Petráš. Analysis of Energy Performance and Indoor Climate Conditions of the Slovak Housing Stock Before and After its Renovation. Energy Procedia. Volume 78, November 2015, Pages 2184-2189. 6th International Building Physics Conference, IBPC 2015.
6. Yu, T., Lin, C.: An intelligent wireless sensing and control system to improve indoor air quality: monitoring, prediction, and preaction. International Journal of Distributed Sensor Networks (2015).
7. Abraham, S., Li, X.; A Cost-Effective Wireless Sensor Network System for Indoor Air Quality Monitoring Applications. Procedia Computer Science. 34, pp. 165--171 (2014)
8. Boduch M, Finche W. Standards of human comfort: relative and absolute. University of Texas at Austin School of Architecture; 2016.
9. Omarov, Batyrkhan; Suliman, Azizah; Kushibar, Kaisar. Face recognition using artificial neural networks in parallel architecture. Journal of Theoretical and Applied Information Technology; Islamabad 91.2 (Sep 2016): 238-248.
10. Altayeva, A., Omarov, B., Jeong, H.C., Cho, Y.I. 2016. Multi-step face recognition for improving face detection and recognition rate. Far East Journal of Electronics and Communications 16 (3), pp. 471-491.