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Two Optimization Techniques for Optimum Control of Energy Use in Comfort Conditions in an Air Conditioning Room

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Abstract

The purpose of this study is to present two optimization techniques in order to be able to decide the optimal control of energy use by staying within the limits of comfort in an air conditioning chamber. With the optimization techniques presented here optimum control is discussed to minimize the energy expenditure to be made by staying within the limits of comfort zone defined by ASHRAE for temperature, humidity, air velocity and air mixing ratio. For this two different optimization techniques are presented static and dynamic. These two optimization techniques are discussed for an established test facility. Optimization ensures comfort conditions and minimizes energy use. Static optimization provides the control point within the comfort zone and returns to the air ratio due to minimum energy usage. For the given external conditions and mixing ratio the control vector is determined so as to minimize the energy use. For the installed system it is appropriate to perform this operation as a static optimization every 20-40 minutes and to send the control vector quantities to the system by calculating at that time. With dynamic optimization there are optimum control points for the variables and feedback controls allow the desired values to remain at these optimum points. Feedback control is started and control is performed. Due to disturbans factors the control vector to be replaced is changed to minimize the performance criterion defined around these specified values. This optimization is done every 4-6 minutes and the control vector quantities are calculated at the end of these periods and sent to the system. The deviation of the control room from the optimum control point is corrected by feedback control and optimization techniques. The optimization techniques presented here are promising as a good alternative for optimum control.

Keywords - Air conditioning chamber, Optimal control, Static optimization, Dynamic optimization

1. Introduction

Increase in energy prices and environmental pollution in particular energy saving has always been on the agenda and kept on the agenda for many years.

As a result of increases in industrialization prosperity and standard of living in world countries energy demand is increasing rapidly. Oil which has been an abundant and inexpensive source of energy for many years and took the first place in world energy production has been a warning to show that the economic crisis brought by the Arab oil ambargos in 1973 is entering the energy bottleneck. Today despite the normal course of energy prices fossil energy resources will be consumed in the near future. In addition to searching for new and renewable alternative energy sources, considering the use of energy wisely, efforts to save energy and to use it in the most efficient way are continuing.

It is seen that when we are not paying attention to saving measures, we are not interested in energy negligence which is seen small in our daily life and as a result monthly or even yearly evaluations are made, big figures are emerging and small neglects reach big sizes.

In environmental spaces to be air conditioned it is expected that the air in these environmental spaces should be conditioned properly in order to keep energy, temperature, humidity and air speed in human health and comfort or in industrial processing. It is an inevitable necessity to provide suitable environmental conditions as a result of a manufacturing or processing, such as human health, improvement of working efficiency and feeling of comfort.

Building automation systems using digital computers are used to provide information functions such as monitoring equipment and ensuring safety in industrial buildings and buildings for human health and comfort. Recently these systems have been designed to provide information functions as well as control functions. In other words the automation systems that are made play a direct role in the operation of the air conditioning equipment. Here it is necessary to develop and apply appropriate control algorithms to control environmental volumes.

In this regard necessary electronic and computer technologies have developed rapidly in recent years, have been reduced prices and multi-purpose computers that will allow more flexible applications have been produced. These developments are pleasing making it possible for the processes to operate with more efficiency, quality and less energy consumption, less residuals and damaged product quantities. Specially designed controllers and computers designed for special processes are not available for serial production, so their prices have increased considerably, and in multipurpose computers, the prices of serial production have decreased. Thus, it is practically more convenient to control many processes with the same computer and to distribute the same type of controllers on a single serial production line.

Today a complex production line control regional control is commonly based on data base and information processing basis. So, locally placed computers the interference values are filtered, amplified and sampled at suitable intervals and transferred to the central control computer in digital or analogue use. These computers can perform control functions. There is a certain hierarchical order of communication between computers, and in this order there is a task in good agreement with the state of each computer.

As a result of technological developments, it is inevitable to provide human health and comfort together with energy saving in residential, workplace, high precision and technical vehicles and advanced industrial establishments. This work includes housing, workplaces, greenhouses, marine and air vehicles, etc. Two optimization techniques are described which are suitable for minimizing the energy consumption while staying in the comfort conditions. For these optimization techniques, the conditions of an established experimental room are taken into account and the necessary calculations are made according to these conditions and the results are interpreted.

2. Previous Studies

A photograph of the experimental chamber is shown in Figure1. The basic approaches of these systems are presented by the 1960s (Severns and Fellows 1958, Threlkeld 1962, Haines 1971). Despite the mutual interaction between them, the control of temperature and relative humidity variables was described by a model construction analogue simulation (Nelson 1965 and Magnussen 1971), each of these variables being considered in a separate control loop. It was also developed by analytical methods (Zermuehlen and Harrison 1965, Hemmi 1967). An analog simulation model, which uses analytical techniques to solve the control problem of this complex system, is then simplified and presented by the use of frequency characterization methods and aggregation in the air conditioning of workplaces and buildings by Kaya (1976). Furthermore, researches on energy saving have focused only on temperature control (Nelson and Tobias 1974, Bloomfield and Fisk 1976). The reciprocal interaction between the relative humidity and the temperature variables is recognized, the enthalpy of the enthalpy has been grasped and the enthalpy controller has been produced as a control device (Kaya 1968). Enthalpy control methods have provided more savings than temperature control methods, but have not succeeded in keeping within the bulk comfort zone (Nelson and Tobias 1974, Bloomfield and Fisk 1976). In addition, the dynamics of the humidifier were determined and the effect on heating costs was investigated (Bullock 1978). The reactions of people to changes in comfort conditions have also been investigated (Woods 1978, Berglund and Gonzalez 1978, Berglund 1978). None of these studies aimed at solving the optimal control problem by staying within comfort conditions. The conditions of a room in which humans are located are determined by the thermodynamic properties of the air with the clothing, activity area and level of those persons. The comfort conditions have been determined within a general relationship (Fanger 1970 and ASHRAE Handbook of Fundamentals 1972).

Figure 1. An environmental room to be air-conditioned.

A number of optimization techniques are presented for the optimal solution of the closed-loop control problem, which controls the temperature, humidity and air velocity within the comfort conditions, which minimizes total energy consumption (Withmer 1976). However, in spite of the mutual effects of the variables, each of these variables is considered in a separate control loop. Based on the conditions of human activities, clothing and rooms, three models have been put forward that use the energy equilibrium equation to change the sensitivity of the human body to climate conditions and corresponding building conditions, taking into account energy saving.

These models give comfort conditions (Berglund 1978). A variable model has been developed to bring together the variables of air temperature, specific humidity and air velocity, volume variables, which affect the comfort conditions in a certain activity level and the problem of reducing the energy requirement to the minimum, in the comfort zone and keeping it constantly Kaya 1978). In this developed model driven study, the mathematical model was solved without taking into consideration the back-circulation of the air and the return-air mixture of the outside air and the model, and the plausibility of the model was shown (Parmaksızoğlu and Batur 1979). An energy use function based on the terms of comfort conditions and an optimal control problem have been developed and solution methods based on a sample have been demonstrated (Kaya 1981). Some experimental results have been given for energy savings achieved by further study of this work (Kaya et al., 1982). Energy conservation is provided in a chiller system as well as in the volume of air conditioning, and work is being done to increase the efficiency (Kaya et al., 1985).

Many researches have been carried out in the air conditioning systems in order to provide optimum comfort conditions and energy saving by using various methods. But the desired goal of achieving the mathematical model in which the variables affecting comfort conditions are included and the use of energy is described in terms of these variables has not been achieved. In order to bring the volume variables together in the comfort zone in an interdependent manner and keep them constantly at the desired values, efforts are underway to develop and solve the optimum control problem.

(Kaya 1978 and 1981), an optimal control problem has been developed which brings together the volume variables in the comfort zone in an interdependent manner and keeps them constantly at the desired values. This model was applied to an experimental installation and its results were interpreted (Akgüney 1994). (Akgüney 2016, 2017) continued to develop these studies. Akgüney started the experimental installation in Figure 1 in 1990 and completed it in 1994. This experiment belongs entirely to Akgüney. Later this experiment was used by some researchers.

3. The Purpose of This Study

The optimization techniques that can be used to implement the optimum control problem in a multivariate climate chamber established and completed at the Energy Laboratory tu M.U. by (Akgüney 1994) are given here. Two optimization techniques are considered in this study. An optimization technique is used to describe energy use as a function. The optimization required to reduce the energy consumption is described as a function of the control magnitudes, to stay within the limits of comfort and to minimize the most. Two optimization techniques for optimal control have shown that system control is inevitable.

3.1. Air conditioning and importance

Climate conditioning is the conditioning of the air in these volumes to maintain the temperature, humidity, cleanliness and air movement of the environmental spaces at optimal levels for human health and comfort or for industrial processing. The significance of these variables is seen in large measure in various fields.

3.1.1 Air conditioning for human health and comfort

The human body is also affected by hot and cold, as well as from extreme dry and extremely humid air. In particular, the negative effect of the humidity variable in the human body is more than the effect of the temperature difference.

For an air at moderate temperatures, when the air is stationary, there is such an equilibrium point for humans that at this point the body can maintain equilibrium without taking any physiological measures. At this point, people do not feel much warmth or coldness, and this is called comfort. If the air movement increases, the human body will have to take a physiological measure because heat loss will increase with convection. Besides, the nauseum on the comfort is great. As it is difficult to tolerate high-temperature humid temperatures, it is difficult to tolerate low-humidity chill. The increase in humidity also increases the effect of temperature difference on human body.

Surveys on human health effects of climatic conditions in environmental areas have shown that changing environmental conditions due to seasonal changes, together with various serious diseases, especially affect respiratory diseases in a significant way. It has been found that if the internal conditions are well controlled, the related diseases have declined significantly.

3.1.2 Airconditioning control for industrial purposes

If the ambient air is kept at a certain temperature, humidity, cleanliness and speed in the work places, it is possible to ensure the health and comfort of the employees and increase the quality and productivity in production.

Most of the materials in the industry can only be produced under certain weather conditions. Studies have shown that in chemistry, textile, sugar, tobacco, medicine, rubber industry, especially in the production of explosives, in the production of photographic and electrical goods, in bread production, in greenhouses, etc. If the air is kept at a certain temperature, humidity and velocity, the production is much more efficient and high quality. Particularly in information centers, submarines and space vehicles are required to comply with the appropriate climate conditions at the maximum level. It is possible to make precise measurements in the research laboratories independently of the weather conditions with climate facilities. In the mines, ventilation facilities are needed to cool the mines, provide respiration to employees, and prevent the accumulation of dangerous gases when the temperature increases by hundreds of meters. It is possible to reproduce these examples further. The developments have shown that the atomic-related industry is becoming more and more important to air conditioned by precision, precision, and all kinds of industries requiring high technical standards.

3.2 Classic Controls

The heating / cooling thermostat is installed in the room. A humidistat is also placed in the return air duct and the thermostat independently controls the nematode. At classic controls, the return air is completely re-circulated. In winter conditions, temperature is 21 °C and relative humidity is 40 %. In summer conditions, temperature is 24 °C and relative humidity is 50 %. The control of the conditioning equipment is provided by thermostats and humidistat, energized by the bobbins, and this is a typical system (Kaya 1978, 1981, 1982).

3.3 Optimal Controls

The optimal control system uses the same hardware and control relays. Relay end connections are made with a microprocessor control, not with conventional control equipment. In this case, the microprocessor takes over the control of the equipment. The output of the microcontroller is transmitted to the semiconductor relays via translators and the bobbin of the hardware relays there is energized. A general control loop diagram of the experimental setup shown in Figure 1, microprocessor is given in Figure 2.

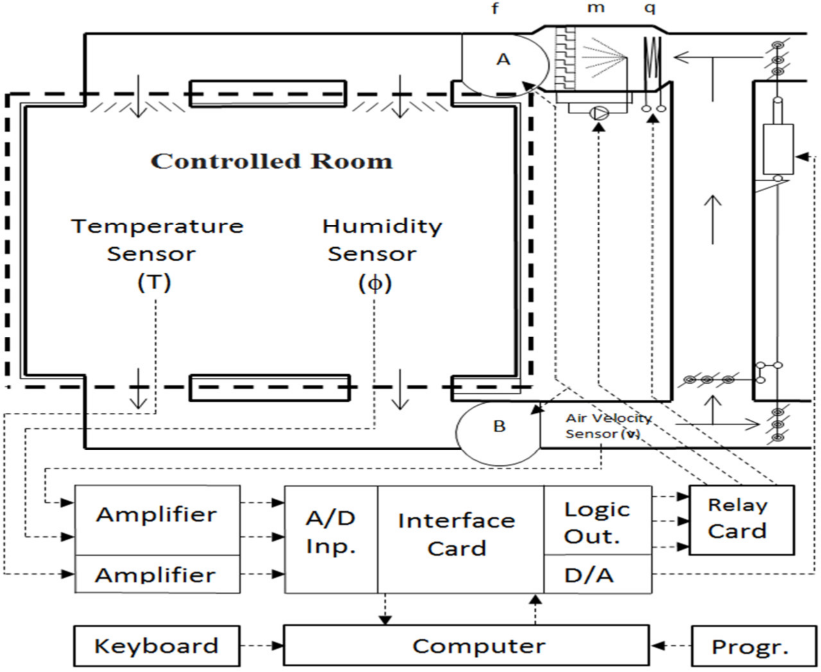

Figure 2. Side view of the test chamber and general control diagram (Akgüney 1994)

Internal and external temperature and relative humidity should be measured for optimum control. For temperature measurement, temperature-sensitive diodes and operational amplifiers are used. The output of the amplifier feeds the multiplexers.

In the relative humidity detection, a separate sensing element is used for the outside and a separate sensing element for the inside. The output of the relative node function in volts is taken with this sensor.

3.4 System Variables

A set of interacting or related elements that have functional links to form a whole that provides a specific purpose is called a system. The boundaries of the system are determined by the purpose of the creation of the system or the purpose of the system-wide review. Outside these boundaries, the system is called the environment. The system is affected from its periphery along these boundaries and its periphery along its boundaries. The behavioral characteristics of the system depend on both the behavioral characteristics of the elements and the interaction characteristics between the elements. Figure 1 shows the experimental chamber and Figure 2 shows a general control loop diagram with the microprocessor of the system.

In a physical system with boundaries, the minimum number of variables that need to be known to determine the state of the system from the beginning to the infinity are called state variables. The room condition is represented by the state vector $\{x\}$.

$$\text{State vector} = \{x\} = \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \begin{Bmatrix} v \\ T \\ w \end{Bmatrix} = \begin{Bmatrix} Air\ velocity \\ Air\ temperature \\ Humidity\ ratio \end{Bmatrix} \quad (1)$$

Among the inputs of a system, the inputs that can be changed as desired (controllable) and affect the outputs of the system the most, are called control variables. The control variables given at the input are represented by the control vector $\{u\}$.

$$\text{Control vector} = \{u\} = \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} = \begin{Bmatrix} f_e \\ q \\ m \end{Bmatrix} = \begin{Bmatrix} Air\ flow\ rate \\ Heater\ output \\ Moisture\ added \end{Bmatrix} \quad (2)$$

Among the variables that determine the behavior of a system, those that are most determinative in terms of design or observation are the output variables of the system. In this system, the variables that leave the room are output variables, which are represented by the output vector $\{y\}$.

$$\text{Output vector} = \{y\} = \begin{Bmatrix} y_1 \\ y_2 \\ y_3 \end{Bmatrix} = \begin{Bmatrix} d \\ T \\ \phi \end{Bmatrix} = \begin{Bmatrix} Air\ flow\ rate \\ Air\ temperature \\ Relative\ humidity \end{Bmatrix} \quad (3)$$

An input of a system that is not controlled between its inputs and can not be predicted to change is called destructive variables. In this system, disturbing fresh air is drawn and the inlet air vector is represented by $\{y_e\}$.

$$\text{Disturbance inlet fresh air vector} = \{y_e\} = \begin{Bmatrix} y_{e1} \\ y_{e2} \\ y_{e3} \end{Bmatrix} = \begin{Bmatrix} f_e \\ T_e \\ \phi_e \end{Bmatrix} = \begin{Bmatrix} Air\ flow\ rate \\ Air\ temperature \\ Relative\ humidity \end{Bmatrix} \quad (4)$$

Disturbances in the non-controllable environment are represented by the disturbance vector $\{y_a\}$.

$$\text{Disturbance inlet environment air vector} = \{y_a\} = \begin{Bmatrix} y_{a1} \\ y_{a2} \\ y_{a3} \end{Bmatrix} = \begin{Bmatrix} v_a \\ T_a \\ \phi_a \end{Bmatrix} = \begin{Bmatrix} Outside\ air\ velocity \\ Outside\ air\ temperature \\ Outside\ air\ relative\ humidity \end{Bmatrix} \quad (5)$$

Variables from the air circulation and fresh air mixture are represented by the mixture vector $\{x_e\}$.

$$\text{Mixing vector} = \{x_e\} = \begin{Bmatrix} x_{e1} \\ x_{e2} \\ x_{e3} \end{Bmatrix} = \begin{Bmatrix} v_e \\ T_e \\ \phi_e \end{Bmatrix} = \begin{Bmatrix} Mixing\ air\ velocity \\ Mixing\ air\ temperature \\ Mixing\ ait\ relative\ humidity \end{Bmatrix} \quad (6)$$

Bir sistemde, o sistemin dışından uygulanan, diğer değişkenlerden bağımsız biçimde değişebilen ve sistemin davranışını etkileyen değişkenlere, sistemin giriş değişkenleri denir. Bunlar, iç değişkenlerden bağımsız olarak değişirler ve giriş vektörü $\{x\}$ ile temsil edilirler.

$$\text{Room entry vector} = \{x\} = \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \end{Bmatrix} = \begin{Bmatrix} v \\ T \\ w \end{Bmatrix} = \begin{Bmatrix} Air\ velocity \\ Air\ temperature \\ Humidity\ ratio \end{Bmatrix} \quad (7)$$

The overall development of the generalized analytical relationships is based on the internal interaction between these values.

4. Optimal Control Method

In order to describe the optimal control method, it is necessary to describe the optimization problem. A thermal model for the control volume and an energy use index are described.

4.1 Comfort Conditions

Based on the work done by (Akgüney 1994), (Kay 1994, 1981 and 1982), a multivariate mathematical model of the dynamic behavior of the system was established. Bu kurulan model, bazı kabuller ve sınırlamalar arasında geliştirildi. Bu sınırlamaların yanında, konfor koşulları sağlanması gereken en önemli sınırlamalardır. (Fanger 1970) tarafından modifiye edilerek geliştirilmiş ve önerilmiş, (ASHRAE 1972) tarafından da kabul edilmiş konfor eşitliği şöyledir.

$$f(I_{cl}, f_{cl}, D_u, \eta, v_r, v, T, P_w, T_w) = 0 \quad (8)$$

The first four parameters for a given activity and clothing conditions are given and are considered fixed. In general, the T_m variant T and the v_r variant can be written as equals or equivalent. Otherwise, w can be used in place of the variable p_w. The p_w value can also be written in ϕ. Under these conditions and assumptions comfort equality or the comfort conditions of a room can be reduced to a three variable function for the given garment and activity. Thus the general equality for comfort conditions is rewritten as The comfort conditions of a room are given through a general equation that can be reduced to a function of three variables (Kaya 1978, 1981, 1982).

$$f_m(v, T, \phi) = 0 \quad (9)$$

In this equation, w can be written instead of ϕ. The different groups of v, T and ϕ are found to provide equation (9). These group values are for the region providing equality (9) for normal activity and light clothing, and for a region named as comfort zone as shown in Figure 3 (ASHRAE 1972).

4.2 Mathematical Model of Room

The mathematical model of the room for the experimental installation is given by (Akgüney 1994). This room air model (Kaya 1978, 1981 and 1982), the following three equations were established again by (Akgüney 1994).

- Humidity balance equation

$$\frac{dw}{dt} = \frac{1}{V}\{K_1\, \dot{m}\, \bar{T}\, \bar{w} + \frac{f}{P}\, \frac{\bar{T}\, \bar{w}}{\bar{T}_e} \lambda_e - A\, v\, w\} = \dot{x}_3 = f_3(x_1, x_2, x_3; u_1, u_2, u_3;\ y_e, y_a) = f_w(V, w, T, m, A, v, \phi_e, T_e, f) \quad (10)$$

- Energy balance equation

$$\frac{dT}{dt} = \frac{K_1\, \bar{T}\, \bar{w}}{V\,(c_{pa}+c_{pw}\, w)}[q + \frac{f\, E}{K_1} + m\, h_w - Q] - \frac{A\, v}{V}\frac{[c_{pa}\, T + w(h_g + c_{pw}\, T)]}{(c_{pa}+c_{pw}\, w)} - \frac{(h_g+c_{pw}\, T)}{V(c_{pa}+c_{pw}\, w)}[K_1\, m\, \bar{T}\, \bar{w} + \frac{f\, \bar{T}\, \bar{w}}{P\, \bar{T}_e}\lambda_e - A\, v\, w] \quad (11)$$

$$\frac{dT}{dt} = \dot{x}_2 = (x_1,\ x_2,\ x_3,\ u_1,\ u_2,\ u_3;\ \ y_e, y_a) = \ f_T = (V,\ w,\ q,\ m,\ T_w,\ Q,\ T_e,\ w_{e,}\ f,\ T,\ A,\ v) \quad (12)$$

- Mass balance equation

$$v = \frac{f}{A}\, \frac{(P-\lambda_e)}{K_2}\, \frac{\bar{T}\, \bar{w}}{\bar{T}_e} = \ x_1 = f_v(x,\ u,\ y_e,\ y_a) = f_v(A,\ T,\ T_e,\ w,\ f) \quad (13)$$

There are two separate heat conductions from the walls of the control volume, convection and conduction. For the value in Equation (12), steady-state heat transfer expression is used here because the deviations in and out of the room are low.

$$Q = U\, S\, (T - T_a) \quad (14)$$

The room conditions are defined by the variables v, T and ϕ. However, these are done on the return air channel. There is also a relationship between ϕ and w. For this reason, the following conversion expressions are used.

$$d = A\, v\,; \quad T = T\,; \quad \phi = \frac{P\, w}{(0.622+w)\alpha\, e^{\beta T}}\,; \quad P_s = \alpha\, e^{\beta T}; \quad \alpha\ = 652.747, Pa\,; \quad \beta = 0.06115\ ,\ 1/^0\text{C} \quad (15)$$

The mathematical model of the control volume system can be written with the following vector expression.

$$\frac{dx}{dt} = \dot{x} = f(x, u, y_e, y_a) \quad (16)$$

$$y = g(x) \quad (17)$$

Where f and g are nonlinear vector functions. These functions must be linearized around specific values of the respective vector components. Equations (16) and (17) rewrite the steady-state model for an environmental room of the equation as a result of linearization for values of some variables after some intermediate operations in system equations in the form below.

$$\dot{x} = Ax + Bu + Cy_e + Dy_a \quad (18)$$

$$y = Hx \quad (19)$$

A, B, C, D and H are matrices with constant values obtained in the specific values of the variables. In equations (18) and (19), the variables are different from a given condition and are represented by the same symbols. When confusion is neglected, the relationship between input and output is given by the system transfer matrix.

$$G_{ij}(s) = \frac{Y_i\,(s)}{U_j(s)} \quad (20)$$

This equation can be rewritten as follows.

$$Y(s) = G(s)\, U(s) \quad (21)$$

A relationship similar to G(s) is developed between y, y_a and output y. The values of the matrices in Equations (18) and (19) are Jacobians which can be found by linearization. The block diagram of the linearized system is given in Figure 4.

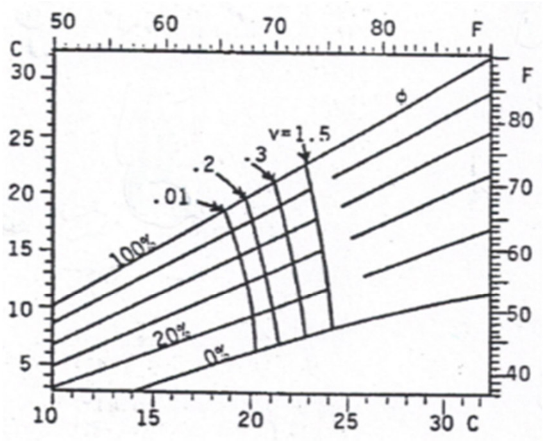

Figure 3. Comfort zone for medium activity and light weight clothing (ASHRAE 1972)

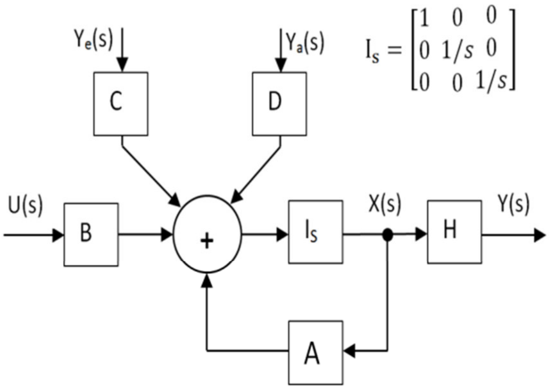

Figure 4. Block diagram of the mathematical model (Kaya 1978, 1981 and 1982)

Here the matrix I_s has the relation expressed.

$$I_s = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1/s & 0 \\ 0 & 0 & 1/s \end{bmatrix} \tag{22}$$

Transfer function matrix G_s is as follows.

$$G(s) = [H\, I_s^{-1} - A]^{-1}\, B \tag{23}$$

The first term in Equation (18) can be written in place of the two relations shown below for simplicity. The first term is cebirs.

$$x_1 = a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + b_{11}u_1 + b_{12}u_2 + b_{13}u_3 + c_{11}y_{e1} + c_{12}y_{e2} + c_{13}y_{e3} + d_{11}y_{a1} + d_{12}y_{a2} + d_{13}y_{a3} \quad (24)$$

4.3 Energy Consumption

The energy consumption in the system is a function of the variables f, q, and m, whose deviations form the u control vector. Depending on these variables the energy consumption function can be written as.

$$\varepsilon(f, q, m) = e_1(f) + e_2(q) + e_3(m) \tag{25}$$

Here, the functions e_2, e_2 and e_3 are as follows (Kaya 1978, 1981 and 1982).

$$e_1 = e_f\, f^3 \qquad (f \geq 0 \text{ holds}) \tag{26}$$

$$e_2 = e_q\, q \;\; ; \quad q \geq 0, \quad e_2 = -e'_q q \;\; ; \quad q < 0 \tag{27}$$

$$e_3 = e_m\, m \, ; \quad m \geq 0, \quad e_3 = -e'_m\, m \, ; \quad m < 0 \tag{28}$$

Where e_f, e_q, e_q’, e_m and e_m' are positive constants. An energy cost function is obtained by multiplying the values e_1, e_2 and e_3 by the unit energy cost.

As the above index, the energy use will be minimal when the outside air and the return air are mixed in a certain area. If r is the function of the air returning to the room (0 ≤ r ≤ 1), the incoming air will contain the r function of the rotating air and the 1 - r function of the fresh air. After that, r is set to reduce energy usage to the minimum. r values affect the values of f, q and m.

4.4 Determination of Comfort Zone

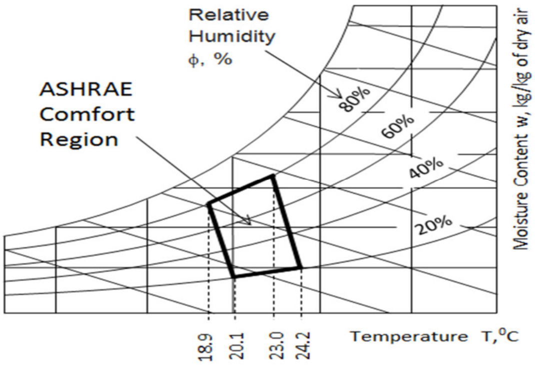

Figure 5. Comfort zone in the psychrometric diagram

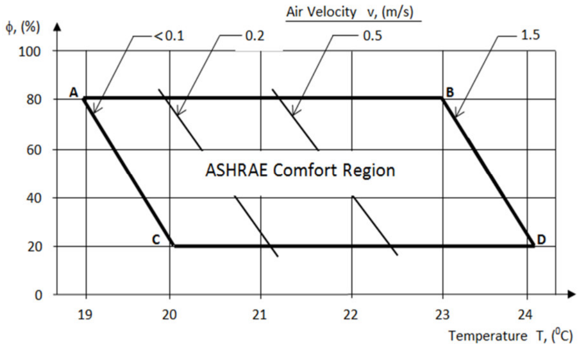

Figure 6. The boundaries of the comfort zone

As shown in Figure 4 it is limited between $0.20 \leq \phi \leq 0.80$ and $0.1 \leq v \leq 1.5$. The comfort conditions are determined by staying within the ABCD region shown in this figure. In order to maintain comfort conditions certain air velocities must be provided for the values T and ϕ. These correlations can be obtained from ASHRAE publications. The values of v, ϕ and T in the ABCD diagonal of the comfort zone are given below (Akgüney 1994).

A = (0.10, 0.80, 18.90); B = (1.50, 0.80, 23.00); C = (0.10, 0.20, 20.10); D = (1.50, 0.20, 24.20)
A-B between: $\phi = 0.80$; $0.10 \leq v \leq 1.50$; $v = 0.01863\,T^3 - 1.07493\,T^2 + 20.75681\,T - 134.03082$ (29)
C-D between: $\phi = 0.20$; $0.10 \leq v \leq 1.50$; $v = 0.02253\,T^3 - 1.39050\,T^2 + 28.70684\,T - 198.10089$ (30)
A-C between: $v = 0.10$; $0.20 \leq \phi \leq 0.80$; $T = -0.0185\,\phi + 20.44$ (31)
B-D between: $v = 1.50$; $0.20 \leq \phi \leq 0.80$; $T = -0.0194\,\phi + 24.56$ (32)

The energy index values of m and q are given by w_e and T_e expression (Akgüney 1994) as follows.

$$m = \left(w - \frac{0.622\,\phi_a\,\alpha\, e^{\beta T_a}}{P-\phi_a \alpha\, e^{\beta T_a}}\right)\frac{348.289\,A\,v(1-r)}{\bar{T}+r\,(T_a-T)} \tag{33}$$

$$q = \frac{348.289\,A\,v\,(1-r)}{\bar{T}+r\,(T_a-T)}\left[c_{pa}(T-T_a) + w\left\{c_{pw}\,T + h_g - \frac{0.622\,\lambda_a}{P-\lambda_a}\left(c_{pw}\,T_a + h_g\right)\right\}\right] + K\,S\,(T-T_a) \tag{34}$$

$$w_e = \frac{348.289\,r\,w + (1-2)\rho_a w_a \bar{T}}{348.289\,r + (1-r)\rho_a \bar{T}} \tag{35}$$

$$T_e = \frac{348.289\,r\,[c_{pa}+w\,c_{pw}]\,T + (1-r)\,\bar{T}\,\rho_a\,[c_{pa}+w_a\,c_{pw}]\,T_a}{348.289\,r\,[c_{pa}+w\,c_{pw}] + (1-r)\,\bar{T}\,\rho_a\,[c_{pa}+w_a\,c_{pw}]} \tag{36}$$

4.5 Definition of Optimum Control Problem

The optimal control problem consists of two phases.

4.5.1 Static optimization

For the given external conditions and mixing ratio, the control vector is determined so as to minimize the energy use. For the installed system, it may be appropriate to perform this process as a static optimization every 20-40 minutes and to calculate the control vector sizes at this time and send them to the system.

Energy use is calculated for outside air, return airspeed and room conditions. If the outside air is in the comfort zone, it can be mixed with the room air as required and it is possible to stay in the comfort zone without using energy (q = 0, m = 0). Since the outside air is usually out of the comfort zone, the variables v, T, and ϕ for the least energy use fall within the limits of the comfort zone. Based on this basic formula, optimal values over the comfort limit are found using the research method. The following operations lead us to optimum solution.

a- T_a and ϕ_a values are known.
b- A point is selected on the boundaries defined by equations (29) and (31), which are explained by means of Figure r is increased by staying within the limits of $0 \leq r \leq 1$. For each r value, q and m are found by using equations (33) and (34), and by using equation (25). This also has a minimum ε and a corresponding r value.
c- The point on the boundary is moved by small increments and the same as in (b) is repeated. (b) is selected.
d- At the end of the study, the minimum ε value and corresponding v, T, ϕ and r optimum values are

obtained.

4.5.2 Dynamic optimization

The optimum steady state, which minimizes energy use, was studied in the static optimization section. In order to ensure optimum conditions, the energy is controlled by feedback control and the worst is reduced. Optimum feedback linear regulator problem is developed and applied for linearized model.

It is necessary to change the control vector, which must be replaced immediately, with the detrimental factors so as to minimize the performance criterion defined around these determined values, to make a dynamic optimization every 4-6 minutes and to send the control vector quantities to the system at the end of these periods. That is, feedback control is necessary so that the system can remain in the optimum conditions calculated in the first step. The energy consumption should also be minimized in the feedback control. This is the phase in which the optimum feedback gain of the linearized model of the system is determined.

If the outside air is assumed to be stable within a short time, it can be used as either y_a= 0. This acceptance generally requires no loss. Or at the same time, when there is a noticeable change in outdoor weather conditions, an optimum value for the optimum steady state can be calculated. Thus, for the given external conditions, the ratio r, y_a and y_e should be written. (19) can be written in a manner similar to equality.

$$y_e = H_e\, x_e \tag{37}$$

The elements of H_e are calculated with similar conditions used for H matrix. Apart from these equations, w_e and T_e are also accountable. w_e and T_e values are found from (35) and (36). The x_e value found in $x_e = E\,x$ is used at the x_e value in equation (37).

$$y_e = H_e\, E\, x = M\, x \tag{38}$$

Using Equation (13), the following expression is obtained.

$$\frac{dx}{dt} = F\, x + B\, u \tag{39}$$

Where F = A + C M. Equation (39) will be used for the optimum regulator problem. The optimal index is the optimal index, which is determined from the optimal conditions.

$$J = \frac{1}{2} \int_{t_0}^{\infty} [x^T Q\, x + u^T\, R\, u]dt \tag{40}$$

Optimal control is determined by the presence of u control vector (40) which gives the equation (39) where J is the least significant one. Even if the control period is limited, the system used here is dimensionally sufficient in terms of dynamics. For this reason, the upper limit of the integration of equation (40) is infinite. The solution of the optimal linear regulator problem is available in standard books. The problem described here is a special case of the general problem. Here u is described as follows.

$$u = -R^{-1}\, B^T\, K\, x \tag{41}$$

When matrix K constantly performs the following relation.

$$-K\, F - F^T\, K - Q + K\, B\, R^{-1} B^T\, K = 0 \tag{42}$$

$$\frac{dx_1}{dt} = 0 = v - 0.173\, T + 4.141(10^{-3})\, w + 5\, f = 0.173\, T - 4.141(10^{-3})\, w - 5\, f \tag{43}$$

$$x_1 = 5.194\, (10^{-4})\, e^{-71.5} - 0.17883\, e^{-12201.023\, t} - 5\, f \tag{44}$$

Figure 7 shows the block diagram of the optimal control. When K is constant, optimal control with analogue devices is possible. In digital controls, the calculation time is greatly reduced.

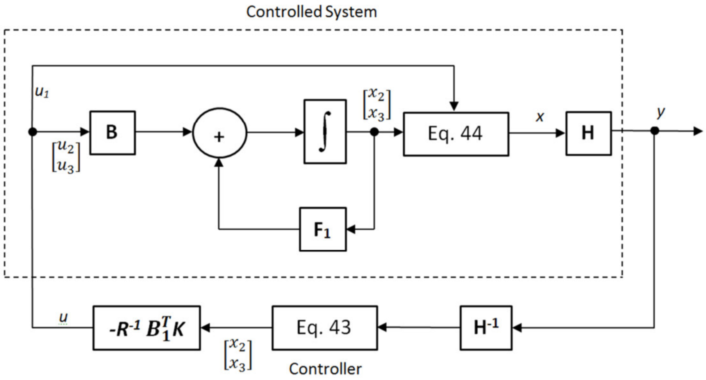

Figure 7. Optimal control block diagram (Kaya 1978, 1981 and 1892)

6. Conclusion and Discussion

The volumes to be checked for air conditioning are housing, workplace, greenhouses, sea and air vehicles, etc. like environmental spaces. In the climate systems in these places, it is possible to supply the required conditions with different energy expenditures. The goal is to operate and control the system in the event of minimal energy expenditure, provided that it remains within comfort conditions.

For a given activity level and clothing conditions, the problem of achieving comfort conditions and minimizing the energy requirement involves an environmental volume model with multiple inputs and multiple outputs of variables of temperature, humidity and air velocity. In addition to these variables, the mixture of outside air and return air must also be taken into consideration.

The optimal control problem involves multivariable simulation, control and environmental volume optimization. The problem is created in two stages.

1- The control vector is determined in such a way as to minimize the energy consumption for the given external conditions and mixing ratio. For the installed system, it is appropriate to perform this process as a static optimization every 20-40 minutes and to send the control vector quantities to the system by calculating at that time.
2- Disruptive factors must be changed so that the control vector to be replaced has a minimum performance criterion. As a dynamic optimization, it should be done every 4-6 minutes and the control vector sizes should be calculated and calculated at the end of these periods. This means that feedback control is necessary so that the system can remain at the optimum conditions calculated in the first step. The energy consumption should also be minimized in the feedback control. This is the phase in which the optimal feedback gain of the linearized model of the system is determined.

Optimum control with the optimization techniques presented here must be tested over a long period of time to compare various control methods. These experiments should be weekly, monthly or even annual experiments. The necessary information for the end of the experiment should be recorded for comparison. According to the results of the comparative experiments, these errors will be normalized by seeing the possible errors in some results of the optimum control made by considering the optimization techniques presented here. The search for comparative values is an appropriate application for normalizing possible errors. However, it is estimated that there will not be a serious error in the comparative experiments for the controls made according to the optimization techniques there, according to the results obtained over a long period of time. Research and experimental studies in this area need to be developed and implemented in real-world settings in order to obtain more accurate results. The optimization techniques presented here are promising as a good alternative for optimum control.

This is the operation of the system in the computer program that is used in the study.

For static optimization, it does the following in 20-40 minutes:

- Temperature and humidity values outside the control volume are measured. These data are converted to digital information and entered into the computer.
- The mixture ratio is determined taking into account the air pollution level and this value is entered in the computer.
- Computes the humidity (w) and temperature (T) values on the comfort zone boundaries, according to the computer program. The air velocity (v), the air quantity (f), the temperature control variable (q) and the humidity control variable (m) are calculated in this area. In this field, f, q and m determine the values.

For dynamic optimization, it performs the following operations every 4 to 6 minutes:

- The temperature (T) and relative humidity (ϕ) in the control volume are measured and entered into the computer.
- The linearized form of the mathematical model forming the system and the defined performance criterion are used.
- The changes (u) in the control vector are calculated and the optimum control vector is found.
- The specified optimum control vector (u) magnitudes are converted to analog and sent to the control elements.

Within the comfort limits, there are some values that are calculated within a program for the optimum continuous regime conditions and continuous regime control magnitudes.

Table 1. In certain outdoor weather conditions the calculated change of the internal conditions and the control magnitudes along the comfort limits for optimum continuous regime conditions and continuous regime control magnitudes

Features of the Inlet Air			Optimum Internal Conditions and Control Sizes in Continuous Regime						
ϕ_a (%)	T_a (^{0}C)	r (%)	T (^{0}C)	ϕ (%)	v (m/s)	d (m^3/s)	q (kJ/h)	m (kg/h)	ε (kJ/h)
50	18	50	19.59	46	0.10	0.1969	0.4068	$8.8\ (10^{-3})$	0.4136
10	10	70	20.07	20	0.10	0.1087	2.3290	$1.4\ (10^{-1})$	2.4413
90	22	30	18.90	80	0.09	0.1877	-2.4149	$-6.0\ (10^{-1})$	19.3615
90	15	60	19.33	71	0.10	0.1964	0.9273	$9.2\ (10^{-3})$	0.9344
90	22	80	18.90	80	0.09	0.1906	-0.9546	$-1.7\ (10^{-5})$	5.6020
15	22	40	20.90	20	0.18	0.3486	-0.0420	$1.4\ (10^{-1})$	0.1262
90	20	30	22.00	80	0.76	1.4779	2.9158	0.03363	2.9439
80	12	35	19.50	51	0.10	0.1942	2.0931	$-1.0\ (10^{-3})$	2.1241
70	14	65	19.55	48	0.10	0.1974	1.1543	$-7.3\ (10^{-3})$	1.1599
60	16	80	19.59	49	0.10	0.1996	0.6072	$2.9\ (10^{-3})$	0.6090
40	8	10	20.07	20	0.10	0.1920	4.1176	$1.77\ (10^{-2})$	4.1311
40	6	40	20.07	20	0.10	0.1939	3.9046	0.056174	3.9475

Graphs of some experiments for optimal continuous regime conditions and continuous regimen control magnitudes within comfort limits are given in Figures 8 and 9.

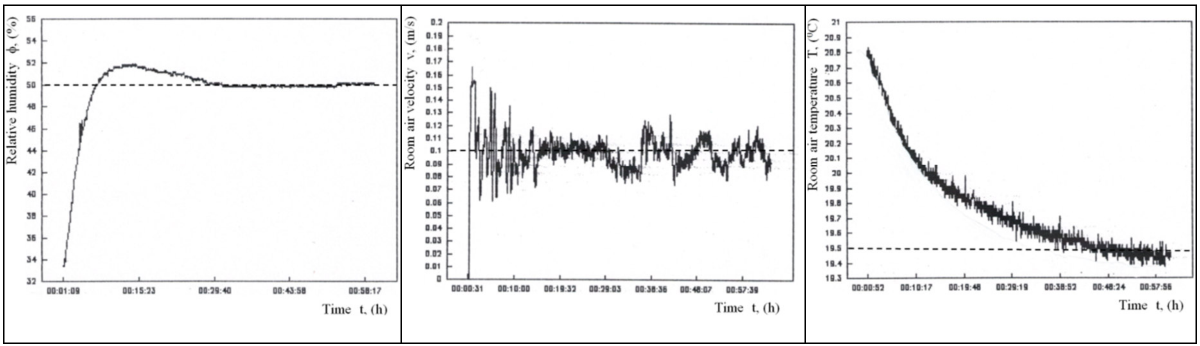

Figure 8. Experimental graphs at conditions of T = 19.50 ^{0}C, v = 0.1 m/s, ϕ = 50 %, r = 10 %, t = 1 h, T_a = 20.8 ^{0}C, ϕ_a = 33 % and v_a = 0 m/s

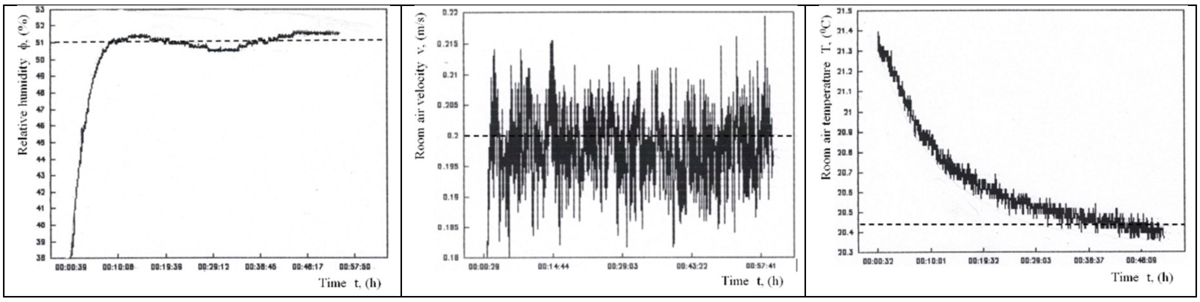

Figure 9. Experimental graphs at conditions of T = 20.45 °C, v = 0.2 m/s, ϕ = 51 %, r = 10 %, t = 1 h, T_a = 21.4 ° C, ϕ_a = 38%, v_a = 0 m / s

The values obtained as a result of the application of the two optimization techniques presented here to the optimum control practices in the air conditioning control systems are highly promising. If these optimization techniques are applied to optimum control problems, it is seen here that it is a good alternative to other control theories, especially analog control systems.

7. Symbols

A Cross-sectional area of chamber (m^2), System matrix

R_a Gas constant for air
R_w Vapor gas constant

B	Control matrix
c_{pa}	Air specific heat (kJ/kgK)
c_{pw}	Specific heat of water vapor (kJ/kg K)
C	Entrence air matrix
d	Average airfow at outlet (m^3/h)
D	Environment disturbance matrix
e_1, e_2, e_3	Energy functions
f	Total air flow (m^3/h)
f_c	Control flow
f_{cl}	Clothing function
f_e	Return air flow (m^3/h)
f_m	A function
f_r	Return air flow (m^3/h)
G	Sistem transfer function matrix
h	Room air enthalpy content (kJ/kg)
h_g	Specific enthalpy of water vapor (kJ/kg)
h_w	Enthalpy of the water (kJ/kg)
I_{cl}	Heat transfer resistance of the garments (m^2h^0C/kJ)
m	Humidity control variable (kg/h)
m_a	Mass of dry air
m_w	Mass of moisture
P	Atmospheric pressure (kPa)
P_a	Partial pressure of dry air (kPa)
P_s	Partial pressure of vapor in saturated air (kPa)
P_w	Partial pressure of water vapor in humid air (kPa)
q	Heat control variable (kJ/h)
Q	Heat loss (kW/h)
r	Return air mixture ratio (%)
S	Room area (m^2)
t	Time (h)
T	Room temperature (^{0}C)
$\overline{T}$	T + 273.15 (^{0}C)
T_e	Mixed air temperature (^{0}C)
Ta	Outside or room temperature (^{0}C)
T_m	Room average radiation temperature (^{0}C)
T_w	Water temperature (^{0}C)
u	Control vector
v	Air velocity in room (m/s)
v_r	Relative velocity of the air and the human body (m/s)
V	Voluma of chamber (m^3)
w	Moisture content (kg moisture/kg of dry air)
y	Output vector $[d, T, \phi]^T$
y_a	Environmental vector $[v_a, T_a, \phi_a]^T$
y_e	Fresh air vector $[v_r, T_r, \phi_r]^T$
ϕ	Relative humidity (%)
α	Constant (P_a)
β	Constant (1/^{0}C)
ε	Energy function
η	Ratio of heat production rate of the human body mechanical power
λ	$\phi\ \alpha\ e^{\beta T}$
ρ	Density of air (kg/m^3)
ρ_e	Density of enterin air (kg/m^3)
ρ_w	Density of wall material (kg/m^3)

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