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LINKING PHYSICAL MODELS TO SYSTEM IDENTIFICATION IN MICRO-ENVIRONMENT CONTROL

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Abstract. A new model concept is described to model the three dimensional energy and mass transfer in an imperfectly mixed ventilated space. The concept consists of a model based on physical laws combined with a mathematical identification procedure. The physical laws are applied in the well mixed zones while a mathematical identification procedure is used to estimate energy and mass transfer to the well mixed volume(s).

Key Words. Modelling, Air conditioning, Environment Control, Flow Control, Ventilation

1. INTRODUCTION

From previous work it can be stated that the existing models on imperfectly mixed fluids have at least one of the following shortcomings when used for control purposes (Christianson, 1989; Murakami, 1992). They are based on the overall assumption of a perfectly mixed airspace in which no fluid flow pattern is considered; they assume that the fluid flow rate is constant; they do not consider the dynamic response of the process to variations of the control inputs; they are not usable as a basis for control strategies since they are not compact enough to be implemented in a controller; they are not achievable for control purposes since they need too much calculation power and time; they are not generally applicable since they need the values of specific coefficients and boundary conditions.

2. OBJECTIVES

The objective of this paper is to present a model concept that permits to model the process of micro-environment in a non-perfectly mixed three-dimensional fluid, in this case an imperfectly mixed ventilated air space. In this concept: the existence of three-dimensional fluid flow patterns in a non-isothermal space is considered; the total (including transient) response of the micro-environmental variables to non-linear variations of the process inputs is modelled; every parameter has a physical meaning to gain deeper understanding; the dynamic behaviour of fluid flow pattern should be modelled; the model should be compact enough to be implemented in a controller.

3. METHOD: MODEL CONCEPT

The **total volume** of the ventilated space is considered to be a **non-perfectly mixed air space.** Consequently it is assumed that there is a three-dimensional air flow pattern in the total volume and gradients in the local micro-environmental variables (temperature, humidity,...). The considered local micro-environmental variables to be controlled are inside temperature and inside humidity. Although the building volume is a non-perfectly mixed air-volume, it is always possible to define a **control volume** as being the maximum three-dimensional volume in which, by definition, there is "perfectly mixed air". This means that within this control volume there are no gradients of temperature, humidity, gas concentration, air velocity etc. Consequently from the theoretical viewpoint this control volume is supposed to be infinitely small. It has been shown however by experimental results that in reality this is not the case. When this concept is applied in reality the theoretical "perfectly mixed volume" indeed is a "better mixed zone" with acceptable gradients. The definition of "acceptable gradients" is depending on the application.

Accordingly to this definition the well mixed volumes can be positioned anywhere in the global non-perfectly mixed building volume. Since it is the objective to achieve a model for control purposes we consider the control volume which is positioned around the sensor of the control system.

When fresh air enters the building volume much of this air passes over, under, or alongside the control volume. Only a part V_{cv} of the global ventilation rate V enters the control volume (Figure 1). The rest of this global ventilation rate V leaves the building without ever passing through the considered control volume at the specified position. Similar behaviour is assumed for the internal moisture production by the occupants. Only the part W_{cv} of the total moisture production W in the building volume enters the control volume. The same occurs with the internal heat production Q where it has to be noted that there are three sources of heat production: the internal heat production, the heating system to supply additional heating (or cooling) and the building envelope. Only the part Q_{cv} of the total heat production enters the defined control volume. The remainder of the global heat production Q leaves the building volume without passing through the considered control volume. This means that Q_{cv} is considered to be the sum of the total heat flow arising from the three different sources and entering the three dimensional control volume.

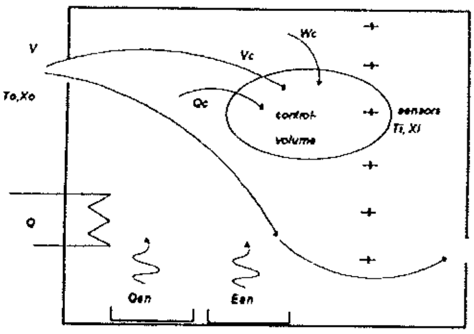


Figure 1. Representation of the energy and mass flows in the building volume and to the control volume as modelled in this model concept

In this model concept there are two types of input variables: "global inputs" and "local inputs" (Figures 1 and 2). Initially the **global inputs** are ventilation rate V through the building volume and the heat supply Q from the heating system to the building volume. In addition to these, the **local inputs** to the control volume are the part V_{cv} of the global ventilation rate that enters the control volume, the part Q_{cv} of the total internal heat production Q that enters the control volume and the part W_{cv} of the total moisture production that enters the control volume.

3.1 Equation for inside humidity in the control volume (mass equation)

Applying the law of mass conservation on the control volume defined above results in the water mass equation (Berckmans 1986):

$$\frac{dXi}{dt} = -\alpha \cdot v_{cv} \cdot X_i + \alpha \cdot v_{cv} \cdot X_o + \frac{c_{cv}}{\gamma_i \cdot \varepsilon_i} \quad (1)$$

With:

Q_{an} : Latent heat production or moisture production (J/s)

$c_{cv} = W_c/Vol_{cv}$: the volumetric concentration of moisture production in the control volume by the occupants (J/s m^3)

γ_o : density of fresh air entering the control volume (kg/m^3)

γ_i : density of inside air in the control volume (kg/m^3)

t : time (s)

V_{cv} : Ventilation flow rate entering the control volume (kg/s)

Vol_{cv} : volumetric content of the control volume (m^3)

$v_{cv} = V_{cv}/Vol_{cv}$: volumetric concentration of fresh air flow in the control volume (kg fresh air/s.m^3)

X_o : humidity ratio of the fresh air (kg H_2O/kg dry air)

X_i : humidity ratio of the inside air in the control volume (kg H_2O/kg dry air)

$\alpha = \gamma_o/\gamma_i$

ε_i : heat of vaporisation of water at inside temperature (J/kg H_2O)

3.2 Equation for inside temperature (energy equation)

Applying the general law of total energy conservation (internal, kinetic and potential energy) results in a **temperature equation** to be written as (Berckmans, 1986):

$$\frac{dTi}{dt} = -\beta \cdot v_{cv} \cdot T_i + \beta \cdot v_{cv} \cdot T_o + \frac{w_{cv}}{\gamma_i \cdot cl_i} \quad (2)$$

With:

cl_i : specific heat of inside air (J/kg °C)

γ_i : density of inside air (kg/m^3)

T_o : inside temperature in control volume (°C)

T_i : outside temperature in control volume (°C)

w_{cv} : volumetric concentration of total sensible heat flow in the control volume (J/s m^3)

β : physical constant

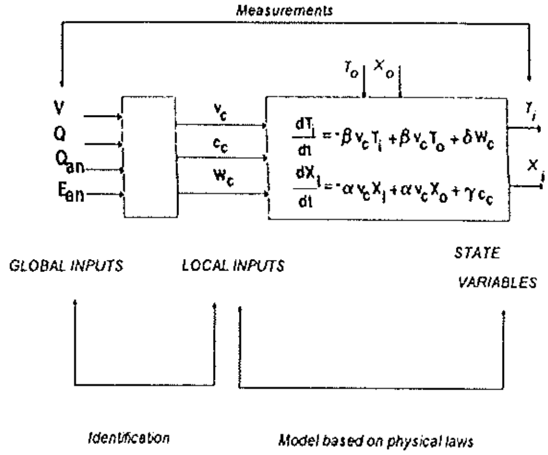


Figure 2. Schematic representation of the two model parts

Greek Symbols: Physical constants

C_c: volumetric concentration of moisture flow in the control volume (J/s, m^3); V_c: volumetric concentration of fresh air flow rate in the control volume (m^3/s, m^3); W_c: volumetric concentration of total sensible heat flow in the control volume (J/s, m^3); t: time (s); Q_{an}: animal heat production (W); E_{an} : animal moisture production (W); Q : heat supply from the heating element to the building volume (J/s, m^3); V: ventilation rate through the building (m^3/s); T_i: inside temperature in control volume (°C); T_o: outside temperature in control volume (°C); X_i: humidity ratio of inside air in control volume (kg water/kg dry air); X_o : humidity ratio of outside air in control volume (kg water/kg dry air)

3.3 Physical meaning of this model concept

The passage of the ventilation rate V_{cv} through the control volume generates the volumetric concentration of fresh air flow v_{cv} in the control volume. Similar behaviour is assumed for the internal heat and moisture production in the building volume. In this way there is generated the v_{cv}, w_{cv}, c_{cv} which consequently have a physical meaning in the equation (1) and (2). In these equations the Greek symbols a and b are well-known physical constants such as density, specific heat, heat of vaporisation etc.

The equations deduced in the previous sections and figure 1 can be represented schematically as in figure 2. The model part describing the control volume is based on physical laws. It has three unknown parameters v_{cv}, w_{cv}, c_{cv} whose physical meaning have been explained. As concentration variables there value is directly related to the so called input variables as explained above.

3.4 Parameter estimation

The value of these three unknown variables v_{cv}, w_{cv}, c_{cv} has to be determined before they can be used to model the process outputs T_i and X_i (figures 1 and 2). Since neither the size nor the shape of the control volume is known, these three unknown parameters can never physically be measured.

The process outputs, inside temperature T_i and inside moisture X_i, however can be measured as well as the process inputs, ventilation rate V through the building volume and the heat supply Q by the heating element (figure 2).

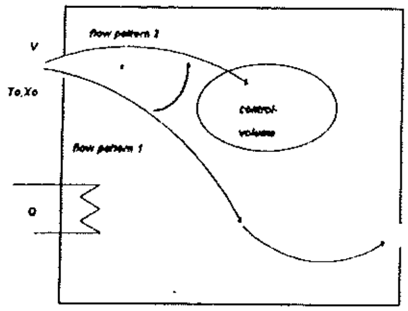
The problem can now be split up into two steps.

1. Determination of the values of the variables v_{cv}, w_{cv}, c_{cv} starting from measurement results of T_i, X_i, T_o, X_o. This is a problem of parameter estimation of the model given by equations (1) and (2).
2. Determination of the relationship between the total process inputs V and Q and the three variables v_{cv}, w_{cv}, c_{cv} . This is a problem of mathematical identification of the physical system that relates the total process inputs and the local concentrations v_{cv}, w_{cv}, c_{cv} . In other words the modelling of the energy and mass transport by the fluid in the three-dimensional space to the control volume.

4. RESULTS

The reasoning behind this model concept is that within every imperfectly mixed fluid space zones of acceptable mixing can be considered. This more general part can be modelled by equations based on physical laws (figure 1 and 2). This part describes the dynamic behaviour of the micro-environmental variables of interest. A second part is the relationship between the control inputs and the parameters to be used in the first model of the (more general) control volume. This relationship consists of a complex physical process and is changing constantly as a function of time and of space. This physical process is too complex to be modelled in an accurate or useful way by a model based on physical laws. The specific model part is modelled with an (on-line) mathematical identification procedure. The combination of the model based on physical equations (equation (1) and (2)) with the mathematical identification procedure results in a model concept that models the dynamic response of the physical micro-environment to variations of the process control inputs.
In this way the relationship between the control inputs V and Q on the one side and v_c, w_c and c_c

on the other side is calculated at every time step. It can be shown that these relationships between local and global inputs allow modelling of the transient behaviour of air flow pattern (Berckmans et al. 1986; 1989) (Figure 3).



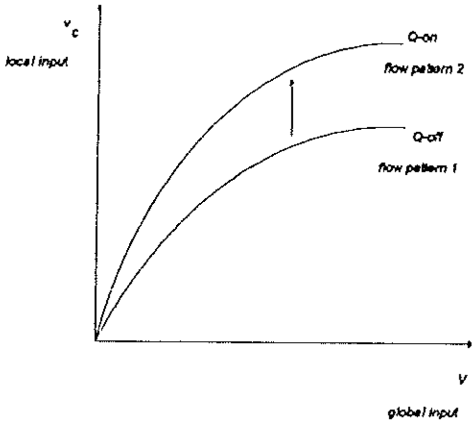


Figure 3. The relationship between local and global inputs as a measure for the air flow pattern.

In experimental work in a commercial livestock building and in a laboratory test installation this model concept has been validated. It has been shown that the inside temperature and humidity can be modelled with an accuracy of 0.5°C and 0.005 kg water/kg dry air (Berckmans et al., 1989).

5 CONCLUSIONS

It can be concluded that:

1. A model concept has been presented to model the dynamic response of physical micro-environmental variables (air temperature and air humidity), to variations of the control inputs ventilation rate and heat supply.

2. The model concept is based on a mathematical model based on physical laws in combination with a mathematical identification procedure. The general part of the air space is described by equations based on physical laws: an energy-equation (temperature) and a mass-equation (moisture). The more specific physical process of energy and mass transport related to the individual fluid space is modelled by a mathematical identification procedure.

3. Although the model concept is partly based on an identification technique, every parameter has a physical meaning. Consequently a deeper physical understanding of the process is generated and wider application of the concept is possible.

4. The concept applies to imperfectly mixed gases and liquids and can be applied to different variables (dust, gas concentration, etc.).

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