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CONTROL STRATEGY FOR A NON-PERFECT MIXED LIVESTOCK BUILDING, BASED ON ADAPTIVE ON-LINE IDENTIFICATION.

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In several applications of climatic control, there is a great internal production of gases, heat and moisture within the confined space such as in modern livestock buildings, greenhouses, industrial spaces, space stations, ... In these confined spaces the global ventilating rate and the (positive or negative) heat supply to the space are the control inputs to regulate inside climate (temperature, humidity, gasconcentration). The importance of a good control of these inputs in order to optimize the inside climate and to minimize the global energy use has been described (Cole, et al. 1981). Moreover in some typical applications, such as in modern pig houses, the internal gas-, heat, and moisture production of living creatures and the desired inside climatic conditions are time varying (due to bio-cycle, age, activity, external climatic conditions, ...). A modern pig house, in which the free-cooling principle is used, can be considered as a more general case of those applications.
Although a lot of modern hardware is used in those spaces, actual control equipment seems not to contain more advanced control algorithms (Udinck ten Cate et al. 1985). As compared to buildings without control equipment, modern pig houses in general don't give the expected improvement of the production results (Goedseels et al. 1984 ; Geers et al. 1984). The main objective of using control strategies in this application is to control the inside climate by regulating the control inputs : the ventilating rate $\dot{M}$ through the global space, the heat supply $\dot{Q}$ to the space and the air flow pattern (figure 2). The second objective of using control strategies in this application is to minimize the energy use : the heat supply of the heating system, the electricity use of the ventilating system and the feed intake by the animals. As a consequence of these objectives, a model for performance estimation of control systems in these applications should permit to study the response of the inside temperature and humidity to the control inputs as they are generated by the control system and to calculate the corresponding energy use.
In literature several simulation models have been proposed to study the behaviour of inside climate. In published models to study the inside climate in (livestock) buildings the following assumptions are made (Zermuehlen et al. 1965 ; Fan et al. 1970 ; Nakanishi et al. 1973 ; Albright, 1981) :

- it is supposed that there is a perfectly mixed air volume in the space ;
- the inside temperature and humidity are considered to be homogeneous in the air volume ;
- the air flow rate is considered to be constant or to vary linearly as a function of inside temperature ;
- no further assumptions are made concerning the air flow pattern.

It has been shown however that the assumptions of a perfectly mixed airspace and of a constant ventilating rate do not hold anymore in those applications (Timmons, 1980). Furthermore it has been proven that the influence of the air flow pattern is of crucial importance for the resulting inside climate (Barber et al. 1982, Randall, 1981).

OBJECTIVES

From the problem posed in the introduction it can be seen that the most difficult part of a global model for performance estimation of control systems in those applications, is the submodel that describes the response of the inside climate to the higher mentioned process inputs. To become a model that is usable for performance estimation of control systems for ventilated confined spaces, the model has to simulate the high-frequency behaviour of inside climate in a non-perfectly mixed air space. The importance of air flow rate and air flow pattern in those applications has been stated while the constant air flow rate assumption does not hold in applications with free-cooling. The objective is to present a mathematical model to simulate the response of inside temperature and humidity in a confined space. Instead of the usual hypotheses of : a perfectly mixed airspace, a homogeneous inside humidity and temperature, an air flow rate that is considered to be constant or vary linearly with inside temperature and no further assumptions about the air flow pattern ; a new approach is proposed. As contrasted to these usual hypotheses, in this model the following hypotheses are made :

- there is non-perfectly mixed air in the space ;
- as a consequence there are differences in inside temperatures and humidities ;
- the air flow pattern is considered to be controlled accordingly to the criterion of the Corrected Archimedes Number (Randall et al. 1979, Barber et al., 1982).
- Ventilating rate and heat supply can vary as a non-linear function of inside temperature.

A model is set up that models the local climate concentrated around the fixed position(s) of the control systems' sensor(s). The main problem to apply this model-concept is the estimation of the local inputs of this model. The more specific objective of this paper is to show the model concept that has been applied.

METHOD

The global simulation model consists of different submodels that describe the behaviour of the subsystems as shown in figure 1 (Berckmans, 1986). As mentioned before, the most difficult part is the submodel that models the response of inside temperature and humidity to the process inputs : ventilating rate $\dot{V}$ and heat supply $\dot{Q}$. As can be seen from figure 1, the inside climate (temperature and humidity) can in this case be defined as the temperature and the humidity as they are measured by the sensor(s) of the control system. In order to model the non-uniform distribution of temperature and humidity in the non-perfectly mixed airspace, the following concept is used. Although the non-perfectly mixed air in the global space, there always can be defined a control volume as the volume that is enveloping the temperature sensor and in which there is at the same time a perfectly mixed air volume. From theoretical viewpoint this control volume is considered to be infinite small but from measurements it can be seen that this control volume can be rather great for certain values of the process inputs (Berckmans, 1986). In this concept there are two types of inputs (figure 2) : firstly the global inputs of the

As mentioned higher, the three unknown local inputs in the model, $\dot{v}_{cv}$, $\dot{c}_{cv}$ and $\dot{w}_{cv}$ have been estimated using the technique of singular value decomposition. Figure 3 gives as an example the measured signal of the global inputs ventilating rate $\dot{V}$ and heat supply $\dot{Q}$. Figure 4 shows the local inputs $\dot{v}_{cv}$, $\dot{c}_{cv}$ and $\dot{w}_{cv}$ as they have been estimated. The fact that in this case the local input $\dot{v}_{cv}$ is increasing while the global input $\dot{V}$ is decreasing (figure 3) can be perfectly explained by the changes of the air flow pattern (Berckmans, 1986). Figure 5 gives a representative result as they were found on these 18 different data-sets, all of them for the animal weight of 80 kg. Each data-set had a different combination of input level of the global control inputs ventilating rate and heat supply. Temperature can be modelled with a mean accuracy of about 0,2°C and humidity with a mean accuracy of 0,0005 kg H_2O/kg dry air.

CONCLUSIONS

A model that is based on physical laws and in which every parameter has a physical meaning, is proposed to calculate the inside climate in confined spaces. This model makes the assumption of a NON-perfectly mixed airspace. Furthermore the ventilating rate and the heat supply are supposed to change as a non-linear funciton of inside temperature.
To estimate the model-parameters the technique of singular value decomposition has been used. To locate the data-parts that can be used for identification, a criterion has been applied to measure the ratio between signal dynamic and noise. Using this technique, the model gives results that are accurate enough to use the global model (figure 1) for evaluating control strategies. The process-model and the higher mentioned criterion are very compact and therefore they can be used as a basis for an on-line control-algorithm.

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LIST OF SYMBOLS

C_1 : physical constant : ratio of the specific mass of the outside air and the inside air.
C_2 : physical constant (14)
C_3 : physical constant : inverse value of the product of the specific mass of inside air and the evaporation heat of water (kg(water).m^3.J^{-1}.kg^{-1})
C_4 : physical constant : inverse value of the product of specific mass of inside air and the specific heat of inside air (K.m^3.J^{-1})
e_{cv} : volumetric concentration of moisture flow in the control volume ($J.s^{-1}.m^{-3}$)
q_{cv} : volumetric concentration of heat flow rate in the control volume ($J.s^{-1}.m^{-3}$)
t_{in} : inside temperature at the location of the controller's temperature sensor (°C)
t_{out} : outside temperature (°C)
v_{cv} : volumetric concentration of fresh air flow rate in the control volume ($m^3.s^{-1}.m^{-3}$)
w_{in} : humidity ratio of inside moist air at the location of the controller's temperature sensor (kg(water).kg^{-1}(air))
w_{out} : humidity ratio of outside moist air (kg(water).kg^{-1}(dry air))
t : time (s).

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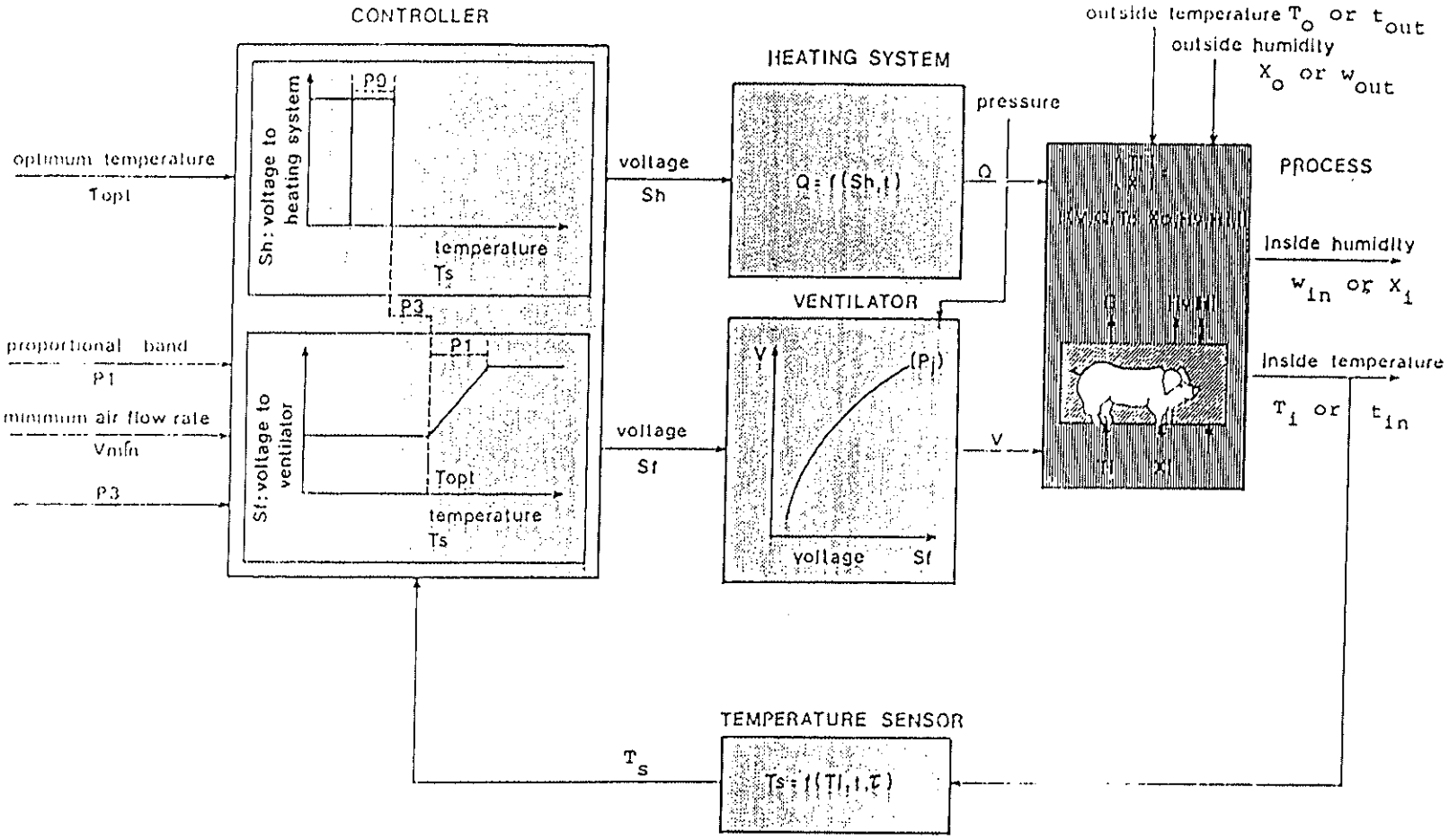

Figure 1 : Diagram of the global model.

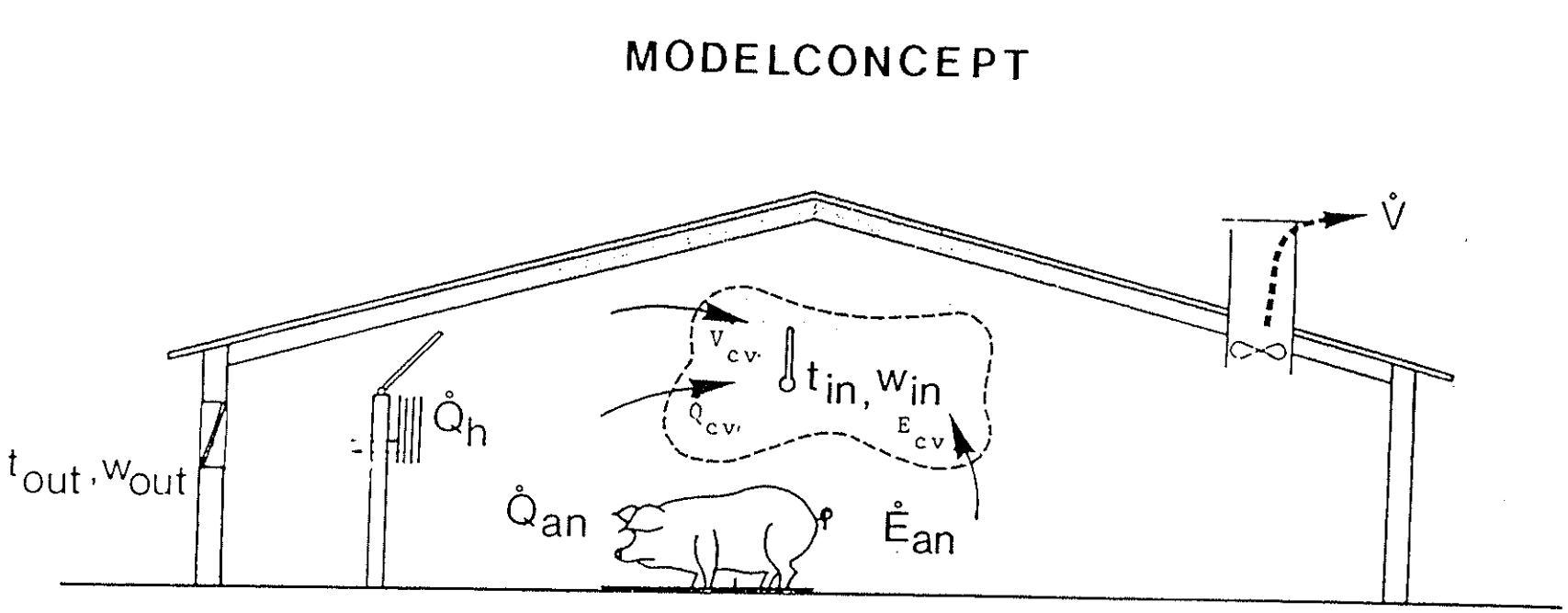

Figure 2 : Concept of the model based on physical laws.

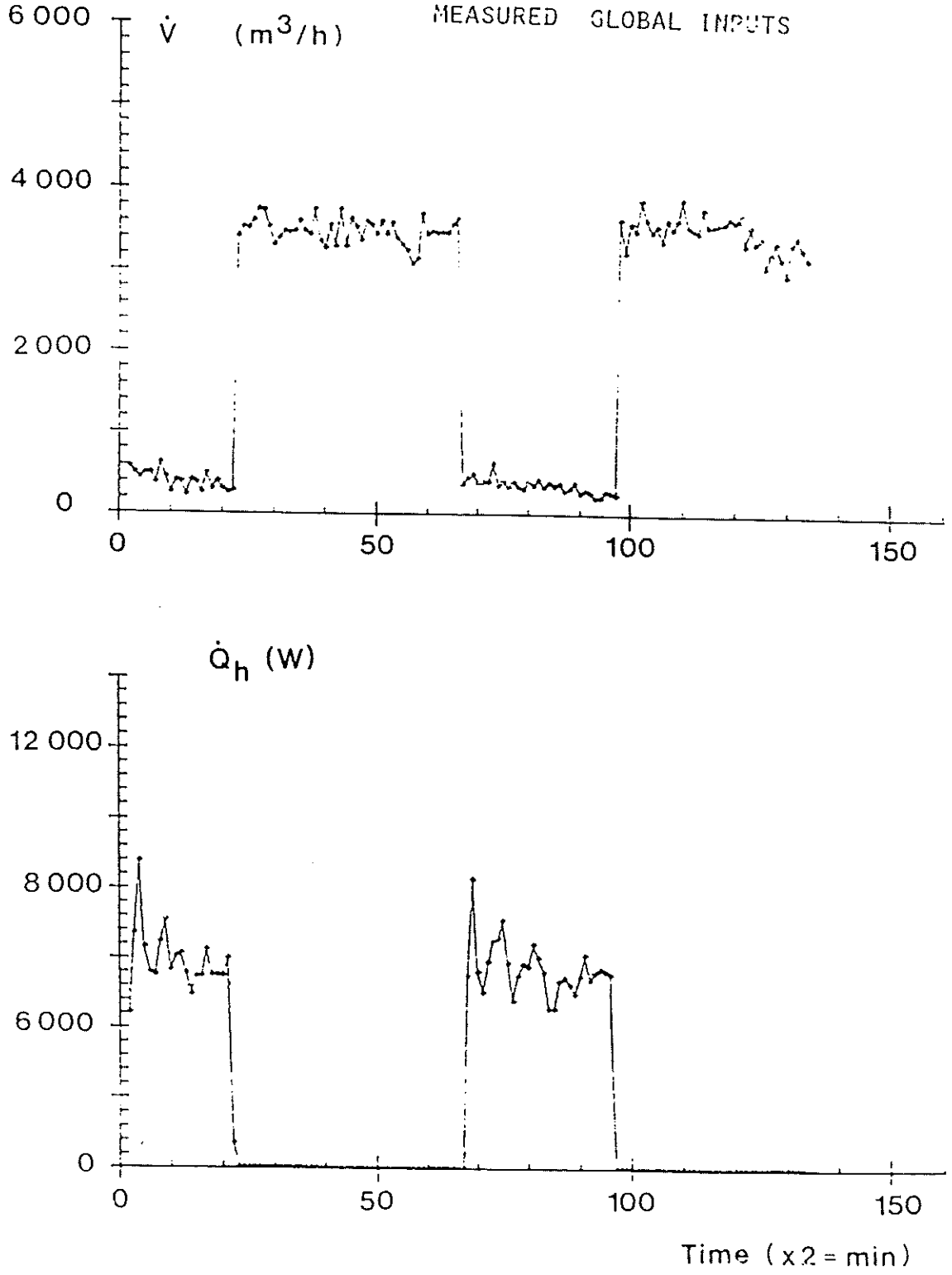

Figure 3 : Example of measured signal of the global inputs ventilating rate and heat supply.

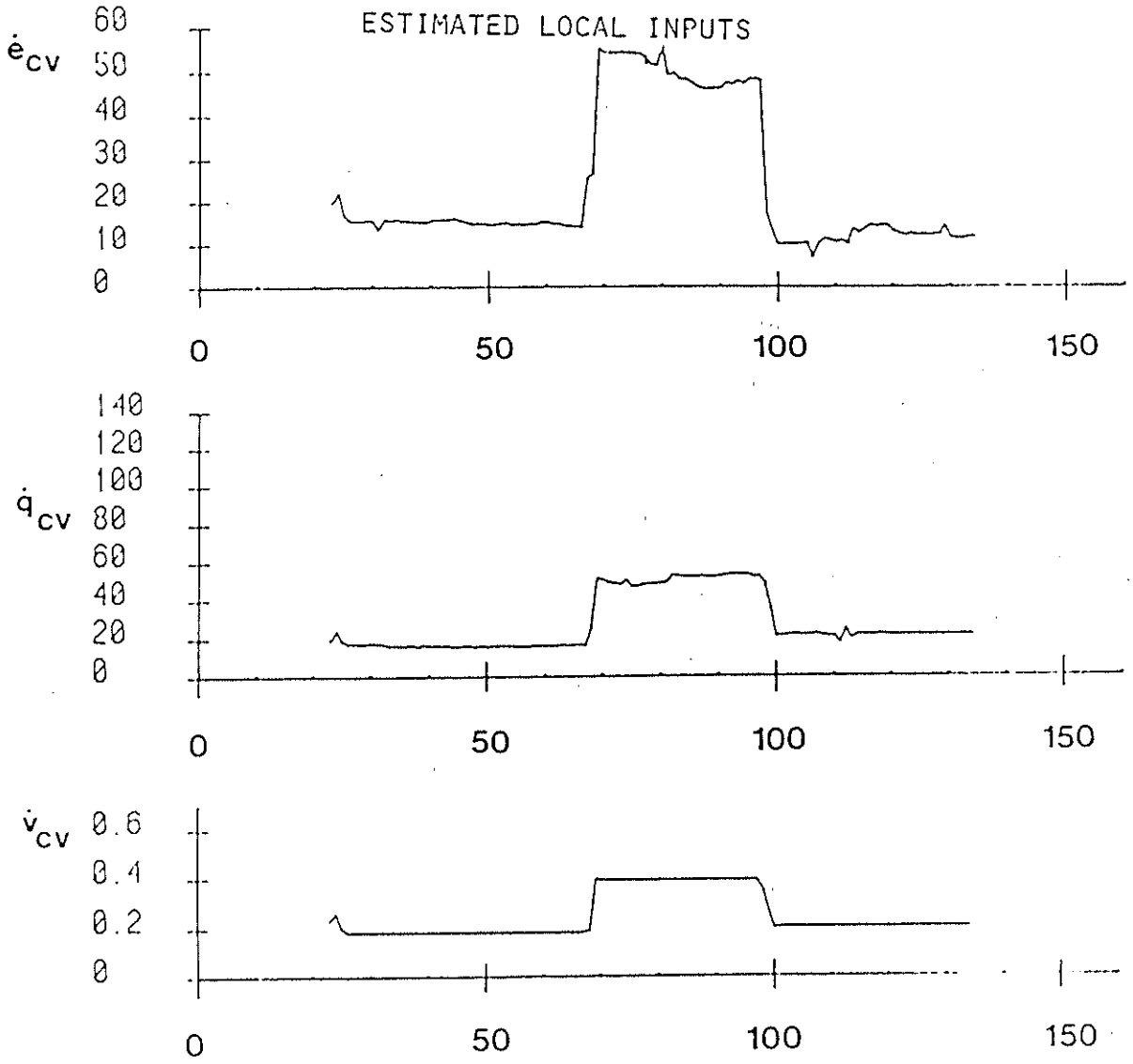

Figure 4 : Calculated local inputs.

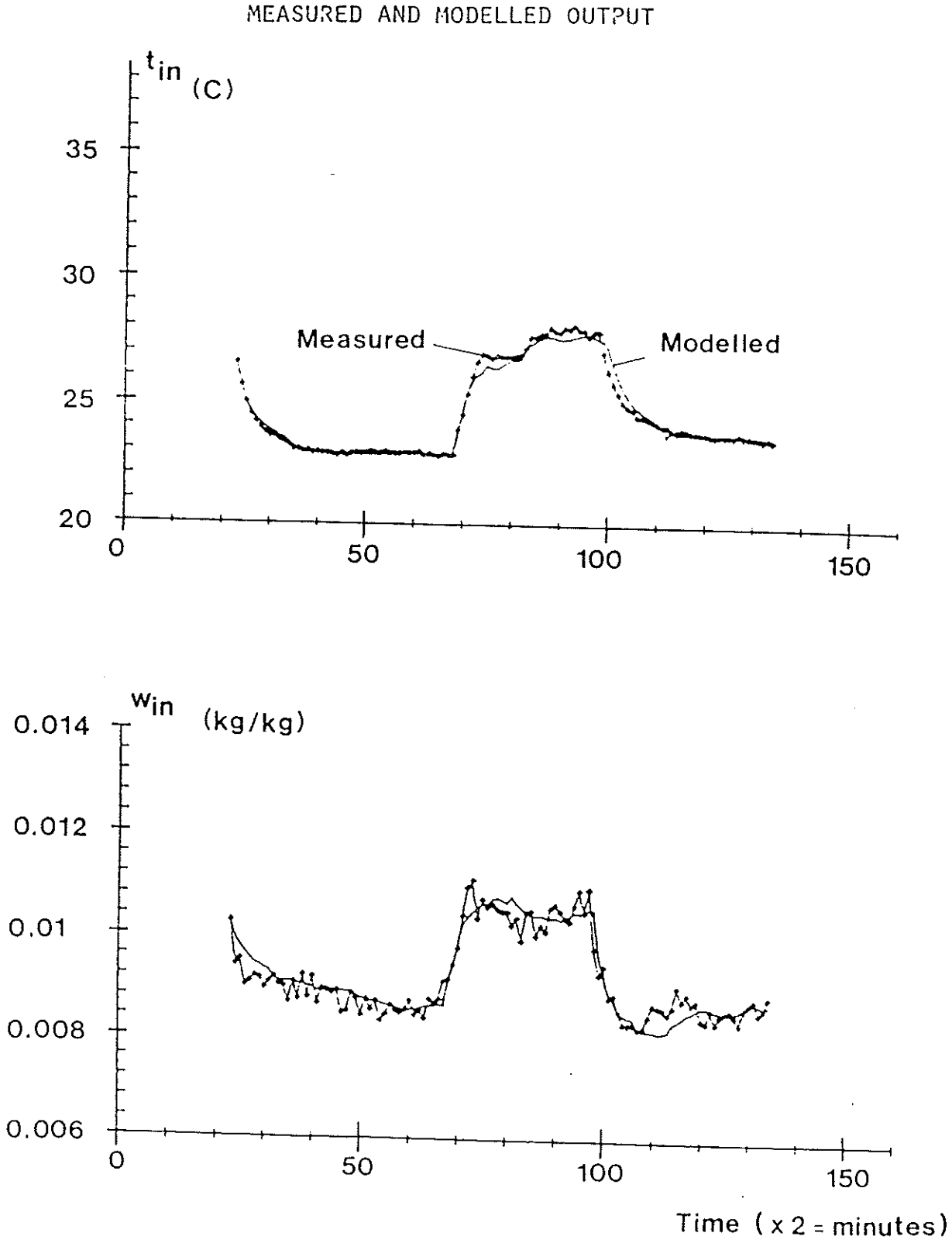

Figure 5 : Measured and modelled output of inside temperature and humidity.