EXPERIMENTAL AND THEORETICAL ANALYSIS OF ENERGY USE AND THERMAL DYNAMICS OF AN EXISTING BUILDING

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ABSTRACT

Aim of this research is to apply to an occupied residential building the experimental and data analysis techniques, previously used by the author in an instrumented test room (Calì et al., 1979). A three-story multifamily building, located near Torino, Italy, was instrumented and monitored over a five-month period during the heating season. The following quantities were continuously recorded: indoor air temperature and relative humidity in three sample rooms; outdoor air temperature and relative humidity, horizontal solar radiation, oil consumption of the boiler and heat delivered by the boiler to the water. Data on electric energy and gas consumption were also collected periodically.

The experimental results have been used in order to investigate the occupants' behavior with respect to temperature setpoints, airing habits, etc.; to analyze the dynamic behavior of the building structure under night temperature setbacks; to validate a number of simplified models for the prediction of energy consumption for building heating; and to verify the applicability of black-box regressive models to the identification and simulation of the dynamic thermal response of the building.

INTRODUCTION

The problem of energy monitoring of buildings has recently raised a wide interest in the energy research community (Fracastoro and Lyberg, 1983; Day, 1983). When facing this problem one of the first alternatives is the choice between an "intensive" and "extensive" approach. The intensive approach focuses attention on a small experimental sample with a relatively high number of accurate sensors. The extensive approach, on the other hand, requires large samples and rather simple monitoring levels. The choice depends, first of all, on the aim of the experiment. If the aim is to validate models estimating energy consumption in buildings, the extensive approach is statistically more reliable. The size of the sample offsets the scarce knowledge of the single energy terms and of the occupants' behavior in each building. However, this approach will not provide a real insight of what is happening inside the building. Alternatively, the intensive approach may be preferred whenever the aim is to achieve a deeper knowledge of the behavior of the occupants, the heating system, or of the building structure under transient conditions. This was the case for the experiment described in this paper, which followed a more conventional evaluation of the results, discussed in a 1985 study by Fracastoro.

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This paper will describe the preliminary results of elaborations aimed at the use of relative humidity as an indicator of the occupants' behavior; a simplified approach to night temperature setback analysis; the comparison with results of simplified predictive models; and the identification technique applied to simulate the dynamic behavior of the building.

EXPERIMENTAL METHODOLOGY AND SETUP

The experimental object was a three-story, six-flat, multifamily building of 1615 m3 net volume, located in the town of Pino Torinese, on the hills southeast of Torino, Italy, 500 m above sea level. The winter design temperature in Pino Torinese is -10 °C, the standard number of degree-days base 19 °C is 3030, and the regular heating season begins on October 15 and ends on April 15. The building is about 20 years old and is very representative of the "small multifamily" category of the Italian building stock from the '60s: flat roof, reinforced concrete bearing structure, masonry walls with air gap and no insulation, and single-glazed steel windows with roller blinds. The heating plant is also typical, using water as the heating medium, oil-fired one-stage burner, and radiators as terminals. A four-way valve adjusts the feed water temperature according to the outdoor air temperature, without feedback from indoor air temperature. In conformity with the existing laws, the heating system was shut off for at least 10 hours a day (generally from 9 p.m. to 7 a.m.), but the boiler was kept "in temperature" during the night.

The original design of the experiment provided for an automatic data acquisition system, which should have centrally collected the data from all the sensors used in the experiment. However, the system was not ready in due time and an "emergency" set of both mechanical and electrical instruments was installed during the month of October 1983. The main features of these instruments (type, accuracy, cost, type of readout and installation site) are summarized in Table 1. They all shared ruggedness and durability, but some of them proved to be inaccurate, compared to the importance of the measured quantity. The three instruments with electrical output (solarimeter, oil volume flow rate, and heat counter) were connected to and monitored on chart recorders, while temperature and humidity meters were autorecording mechanical instruments. Electric energy and gas volume consumed were read periodically on the utility counter.

The experimental campaign lasted 152 days, starting on November 16, 1983, and ending on April 15, 1984. Because of the collaborative mood of the occupants the campaign did not suffer serious setbacks. However, the imperfect transmission/conversion of the electrical pulses from the heat and oil counters into an analog voltage signal to the chart recorder resulted in the loss of a certain number of data. Some disturbance was also produced at the beginning of April by the internal furbishing works within two of the six flats.

The results of the campaign have not been completely analyzed due to the lengthy process of manual data reading and digitalization. In addition, direct visualization and handling of data suggests a number of ideas and ways of interpretation that look promising, but have to be tested before they are accepted or discarded. Our opinion is that, although time consuming, this stage of the experiment is very important; in fact, predetermined elaboration of on-line automatically digitalized data does not allow, in some cases, drawing from the experiment all the information it can provide.

THE USE OF RELATIVE HUMIDITY AS AN INDICATOR OF THE OCCUPANTS BEHAVIOR

A typical daily record of indoor relative humidity is shown in Figure 1. This record provides immediate information about some habits of the occupants, such as airing or cooking activity. Sudden increases of air humidity indicate cooking, bathing, or washing times; sudden decreases of air humidity indicate window openings. Window opening may also be revealed by temperature decrease, but this has proved to be less recognizable than relative humidity decrease.

More quantitative information may be drawn from such records, once moisture content has been derived from relative humidity and temperature records, using the equation of conservation of mass. Assuming perfect mixing, and neglecting the water vapor migration across the walls, this equation, written for water vapor contained within the inhabited space, yields

$$\dot{V}(xe - x) + v.\dot{m}v = V.dx/dt \qquad (1)$$

where

$\dot{V}$ = air volume flow rate, m3/h

V = air volume, m3

v = specific volume of the air, m3/kg

xe = outdoor air moisture content, kg/kg

x = indoor air moisture content, kg/kg

$\dot{m}v$ = mass flow rate of water vapor produced indoors, kg/h

t = time, h.

In case of a sudden moisture content decrease, generally due to window opening, the air flow rate, $\dot{V}$, may be derived from the rate of decrease, dx/dt, neglecting the term v.$\dot{m}$v:

$$\dot{V} = V.dx/dt/(xe - x). \qquad (2)$$

If moisture content keeps constant and the air exchange rate is known, the water vapor production may be derived from Equation 1, which becomes

$$\dot{m}v = \dot{V}(xe - x)/v. \qquad (3)$$

Conversely, Equation 3 may yield the air exchange rate if the water vapor production is known.

After a sudden increase of water vapor concentration, spontaneously produced, e.g., by cooking, or artificially induced by the experimenter, one may observe an exponential-like concentration decrease. Actually, assuming $\dot{m}$v, xe, and $\dot{V}$ to be constant, Equation 1 becomes the typical exponential decay equation from which $\dot{V}$ may be derived:

$$x - xe - \dot{m}v*v/\dot{V} = (xo - xe - \dot{m}v*v/\dot{V})*\ \exp\ (-V/\dot{V}*t) \qquad (4)$$

where

xo = initial value of indoor air moisture content

Equations 3 and 4 may be used simultaneously or alternatively to find the water vapor production and the air infiltration rate. In the first case one has to assume that the air infiltration rate and the vapor production are constant during the two stages to which Equations 3 and 4 apply (constant moisture content and decaying moisture content). This is true if the wind velocity (occasionally collected from a nearby meteorological station) is constantly below 1.0 m/s, and the other natural cause of infiltration, the temperature difference, does not show relevant oscillations (thermal excursion below 5 °C). When there is no vapor-producing activity, and the only water vapor source is the occupants themselves, the water vapor production may also be assumed to be constant. This approach did not yield satisfactory results, however, as both the water vapor production and the infiltration rate calculated values turned out to be too high. An alternative procedure was adopted in which the water vapor production was assigned a value derived from standard water production values of human beings. In this case the results (a number of air changes per hour oscillating from 0.25 to 0.5) were more encouraging, but there was no real evidence of accuracy, as no other reliable technique was conjunctly adopted.

Everyone may recognize the resemblance of Equations 1 through 4 with those adopted for tracer gas techniques (Kronvall,1980; Sandberg and Fracastoro, 1984). With respect to the tracer gas technique, advantages of the "humidity technique" include an inexpensive experimental apparatus (a thermohygrometer costs about 1/50 of an infrared gas analyzer), as well as a more confident attitude of the occupant towards the experiment. A major drawback is the imprecision of this technique, due to the fact that water vapor is present in outdoor air, that its emission cannot be controlled at will under normal occupation conditions, and that part of the water vapor produced may "disappear" because of condensation above cold surfaces, adsorption, etc. On the other hand, neglecting water vapor migration across the walls does not seem to be a major cause of inaccuracy, being the moisture flow across the walls about 20 to 30 times smaller than moisture carried by the air. A more precise evaluation of the accuracy of this procedure should be derived from laboratory experiments.

NIGHT TEMPERATURE SETBACK ANALYSIS: A SIMPLIFIED APPROACH

Another phenomenon that was analyzed was the dynamic behavior of the building under intermittent heating. Transient heat transfer in buildings and building components has been studied previously, both in theory and in laboratory or field experiments (e.g., Mitalas, 1972; Sonderegger, 1977). There is, however, a certain feeling that the enormous development of numerical (digital) solutions to the complex equations describing the thermodynamic equilibrium of all building components has not favored the development of simple mathematical descriptions of the physical phenomenon - descriptions that could be used, for instance, in the implementation of simplified models for predicting building heat requirements.

Results from the present experiment cannot be generalized, but may support the following "common sense" convictions.

1. In the first period after shutting off the system, the indoor temperature is influenced by the thermal capacity of the terminals; the thermal capacity of the building exerts its influence only in a second stage.
2. The temperature decrease in each room is influenced by the heat loss coefficient of the room; peripheral rooms will cool down more rapidly than internal rooms.
3. The energy-saving effect of night temperature setback or intermittence may be evaluated, assuming the heat losses are proportional to the difference between the actual average indoor and outdoor temperatures (neglecting unsteady-state effects).

A simplified two-capacity model has been used to simulate the temperature decrease when the heating system was shut off. Considering as three lumped systems the air (zero thermal capacity), the radiator, and the building, the equations of thermal equilibrium yield respectively:

$$q1*(T1 - T2) = q2*(T2 - T3) \quad (5)$$

$$q1*(T1 - T2) = - C1*dT1/dt \quad (6)$$

$$q3*(T3 - To) - q2*(T2 - T3) = - C3*dT3/dt \quad (7)$$

where

q1 = heat loss per unit temperature difference between air and radiator, W/K

q2 = heat loss per unit temperature difference between air and building, W/K

$q3$ = heat loss per unit temperature difference between building and external environment, W/K

$T1$ = temperature of the radiator, °C

$T2$ = temperature of the air, °C

$T3$ = temperature of the building structure, °C

To = outdoor temperature, supposed to be constant, °C

$C1$ = heat capacity of the radiator, J/K

$C3$ = heat capacity of the building, J/K

t = time, s.

Obtaining T2 in terms of T1 and T3 from Equation 5 and substituting this expression in Equations 6 and 7 gives a pair of linear differential equations. Now we obtain T3 in terms of T1 and dT1/dt, and substituting this expression into Equation 7 gives the following second-order equation for T1:

$$d^2T1/dt + a1*dT1/dt + a2*T1 = a2*To \tag{8}$$

with

$$a1 = A/C1 + A/C3 + q3/C3$$

$$a2 = (A/C1)*(q3/C3)$$

and

$$A = (q1*q2)/(q1 + q2).$$

The general solution of the homogeneous equation, in nondimensional form, is

$$\vartheta 1/\vartheta 10 = \alpha 1* \exp(m1*t) + \alpha 2* \exp(m2*t) \tag{9}$$

where

$$\vartheta 1 = T1 - To$$

$$\vartheta 10 = T1(0) - To.$$

m1 and m2 are the two solutions of the quadratic equation in m:

$$m^2 + a1*m + a2 = 0$$

and the two constants $\alpha 1$ and $\alpha 2$ are derived from the initial conditions

$$\left\{\begin{array}{l} T1(0)=T10 \text{ (function of the outdoor temperature)} \\ (dT1/dt)_{t=0} = -q1/C1*(T10 - T20) \end{array}\right. \tag{10}$$

with T20 = T2(0). The expressions for constants $\alpha 1$ and $\alpha 2$ are

$$\left\{\begin{array}{l} \alpha 1 = (q1/C1 - q1/C1*\vartheta 20/\vartheta 10 + m2)/(m2 - m1) \\ \alpha 2 = 1 - \alpha 1 \end{array}\right. \tag{11}$$

with $\vartheta 10$ = T10 - To and $\vartheta 20$ = T20 - To. Equation 6 will finally provide an expression for the nondimensional indoor-outdoor air temperature difference $\vartheta 2/\vartheta 20$:

$$\vartheta 2/\vartheta 20 = \vartheta 10/\vartheta 20 * [\alpha 1 * (1+C1*m1/q1) * \exp(m1*t) + \alpha 2 * (1+C1*m2/q1) * \exp(m2*t)] . \quad (12)$$

As an example, this method was applied to the third-floor room where one of the thermographs had been placed. The values of the constants were

$$a1 = 0.341 \qquad a2 = 0.0063\ h-2$$

$$m1 = -0.0196 \qquad m2 = -0.3214\ h-1$$

$$\alpha 1 = 0.338 \qquad \alpha 2 = 0.662$$

yielding

$$\vartheta 2/\vartheta 20 = 0.954 * \exp(-0.0196t) + 0.046 * \exp(-0.3214t).$$

Table 2 shows the comparison between measured values and the values calculated adopting Equation 12 and the simple lumped parameters system hypothesis (with a time constant C3/q3 = 50 h, valid for the considered room). The results seem to confirm the validity of the two time constants model adopted in this paper.

VALIDATION OF SIMPLIFIED PREDICTIVE MODELS

The results of the measurement campaign, in terms of energy requirements, were compared with those provided by two different procedures. In the first procedure the model served to make a simple disaggregation of the building energy balance, based on a first principle analysis, into its components:

$$Eu = Ed + Ev - (Es + Ei) + \Delta U \quad (13)$$

where

Eu = heat provided by the heating system to the building (useful energy)

Ed = transmission losses

Ev = ventilation losses

Es = solar energy entering through the glazed surfaces and absorbed by opaque walls

Ei = heating contribution of energy use indoors

ΔU = variation of internal energy.

Of these quantities, only Eu is entirely determined by direct measurements (through feed water flow rate and temperature difference). As for the other energy terms, only the intensive components are determined experimentally (i.e., the indoor-outdoor temperature difference in Ed and Ev, the impinging solar radiance in Es), while the remaining components are determined analytically (U-values, surface areas, etc.) or on a statistical basis (metabolic heat, air exchange rates, etc.).

Referring to Fracastoro (1985) for further details, the final form of Equation 13 may be written as

$$Eu = c1*\Delta T*t + (c2*\Delta x+c3*\Delta T)*t - t*\sum_{j=1} c4j*Ij - c5*Ee - c6*Eg - c7*t+ c8*(Ti(t)-Ti(0)) \quad (14)$$

where

ΔT = indoor-outdoor temperature difference, °C

Ti = indoor temperature, °C

Δx = indoor-outdoor moisture content difference, kg/kg

Ij = solar radiation on the different orientations, W/m^2

Ee = electric energy, Wh

Eg = energy from gas consumption, Wh

t = time, h.

The description of parameters c1...c8, their means of evaluation, and their values are listed in Table 3. The time-dependent quantities (Ti, ΔT, Ij, Ee) were introduced in Equation 14 and the resulting value of useful energy (Eu) was compared with the measured value (see Figure 1). The slight overestimate of the calculated Eu with respect to the measured value may be due to the underevaluation of the internal or solar heat gains, or, more probably, to the number of air changes per hour (0.5) adopted in the absence of reliable experimental data. A successive analysis performed using the tracer gas technique (N_2O decay) with ΔT = 10 K and v = 0 m/s, led to a value of 0.35 air changes per hour, which was probably closer to the true average value. Dispersion of results seems to be mainly related to bad tracking of dynamic effects, as dispersion reduces with increasing time step.

In a second phase, a simplified model called BILTE, based on the so-called method of the "free heat utilization coefficient" (Agnoletto et al.,1980), was used to calculate the energy requirement (Eu). In this case only the experimental values of the outdoor quantities (To, Ij) were introduced in the model, because the model assumed default values for the quantities depending on the occupant behavior and attitudes (Ti, Ee, Eg). The results, on a monthly basis, are shown in Table 4. There is a rather good agreement between the measured and calculated values; the sharp underestimate in April was probably due to furbishing (with higher than usual ventilation rates, lower internal heat gains, etc.) performed in two of the flats during that month.

THE IDENTIFICATION TECHNIQUE

The procedure applied for the dynamic regressive analysis of the experimental data is the so called "black-box identification", which has already been described by Calì et al. (1982), where it had been applied to a single testroom. The system input-output quantities are introduced in the algorithm SIMIDE, which identifies a model, the complexity (i.e., order) of which is chosen by the analyst. An interesting feature of the algorithm is that it does not require any information about the structure of the system itself.

SIMIDE has been developed by Menga and Greco, 1979, and belongs to the family of standard or extended least squares. The identified model is of the ARMA type and, when there is no identification of the error, is represented by the following discrete expression:

$$\begin{aligned}\hat{y}(t) = {} & a_1*y(t-1) + \dots + a_n*y(t-n) + \\ & + b_{o,1}*u_1(t) + \dots + b_{n,1}*u_1(t-n) + \\ & \dots\dots\dots\dots\dots\dots \\ & + b_{o,m}*u_m(t) + \dots + b_{n,m}*u_m(t-n) \qquad (15)\end{aligned}$$

where

y = output vector ($\hat{y}$ = estimated output)

uj = j-th input vector

a,b = parameter vectors

n = model order

m = number of inputs

The data were available in continuous form, and it was possible to choose among different sets of physical quantities. Data set A, to which SIMIDE was first applied, had

$$y = Eu$$

$$u1 = Ti$$

$$u2 = To$$

$$u3 = Ih$$

$$u4 = Ee$$

$$n = 1 - 2$$

time step = 1 day

data set length = 152 days.

In some analyses input u4 (Ee) was neglected and inputs u1 (Ti) and u2 (To) were lumped together (u1 = Ti - To).

In the other case SIMIDE was applied using data set B:

$$y = Ti$$

$$u1 = To$$

$$u2 = Ih$$

$$u3 = Eu$$

$$n = 1 - 3$$

time step = 2 - 8 hours

data set length = 192 hours.

In both cases SIMIDE identifies a model, i.e., a set of transfer function coefficients, at each step. Once these sets of parameters are known, two different types of simulations may be performed.. In the first case a single set of parameters is used to simulate the output, starting from the measured values of the inputs (this type of comparison simulates the behavior of a control system using a predetermined set of parameters and a larger than usual number of inputs). In the second case one may use at each time step the set of parameters identified at the previous step (adaptive control, requiring the use of an on-line computer).

Another type of comparison may be performed analyzing the parameters directly. In fact, the transfer function poles are related to the time constants of the model, which may, in turn, be compared to the time constants of the system. The determination of the time constant of the system is particularly easy when the analysis is confined only to one time constant. In this case, the main time constant of the system, represented by the classical storage/loss ratio (Davies, 1984), may be compared with the first order model time constant, given by

$$t1 = -\Delta t/\ln(a1) \tag{16}$$

where

t1 = first time constant of the model

Δt = time step

a1 = coefficient of the output at the previous step (see Equation 15).

A comparison of real and simulated outputs of data set A is shown in Figures 4a and 4b. Figure 4a shows the results of the simulation obtained adopting the second order model identified at the 50th day, and Figure 2b shows those results identified at the 140th day. As expected, although the parameters do not differ greatly, the simulated output in the second case matches the real output slightly better, especially in the last period of the campaign. The analysis of the parameters of the first order model gave a1 = 0.4656, leading to a time constant of 31 hours, in fair agreement with the storage/loss time determined analytically from the ratio c8/(c1 + c3) = 27 hrs.

Different time steps were used in analyzing data set B, but apparently it was not possible to achieve model convergence for time steps lower than two hours, probably because of the long series of zero values in the Ih and Eu data sets. Furthermore, in order to accelerate convergence of the model simulation results, the average value of indoor temperature was suppressed. The results shown in Figure 3 referred to a time step of two hours and a second order model identified at the 80th step. Higher model orders did not lead to significant improvements of the simulation, while the first order model showed promising results. Calculation of model time constant in this case lead to a value of 24 hours, which is in good agreement with the value found using the one-day time step (data set A) and with the storage/loss ratio found analytically.

CONCLUSION

This paper presents a second-phase analysis of the results of an experimental campaign carried on during the 1983-1984 heating season. A number of different elaborations, aimed at a detailed and sometimes unconventional evaluation of the experimental data, are presented.

The "humidity technique" may represent a simple and unexpensive way to monitor the habits of the occupants. Under some circustances (controlled water vapor production, low moisture content in outdoor air, etc.) the humidity technique may also be used to measure the air change rate; however, its accuracy has to be tested in the laboratory and the experimental procedure has to be better defined.

The simplified bi-lump analysis of the temperature decrease during night temperature setback has provided fair results. Possible generalization should further be tested in order to apply these results to the analysis of the effect of intermittence on the energy requirements of buildings.

The simplified model for the calculation of the energy requirements of buildings tested in this work may be considered sufficiently reliable under different climatic conditions, though it should be tested using highly insulated or passive buildings, where the relative importance of dynamic effects is more relevant.

Finally, the black-box identification has proved itself to be an already mature technique, which should now be implemented for microprocessor application.

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TABLE 1

Physical Quantities and Related Transducers

Measured quantity	Instrument	Accuracy	Cost,$	Output
Outdoor temperature	Thermograph	2 C	160	Mechanical
Solar Irradiance	Solarimeter	5 %	1500	Voltage
Indoor temperature	Thermohygrograph	1 C	200	Mechanical
and rel. humidity		10 %		
Oil flow rate	Rotating piston counter	2 %	170	El. Pulses
Heat from system	Heat counter composed by:	3 %	600	El. Pulses
	- water flow counter	2 %		
	- 2 Pt100 RTD's	0.2 C		
	- Integrator	0.3 %		
Electric energy	Utility counter			Mechanical
Gas volume	Utility counter			Mechanical

TABLE 2

Comparison of Measured and Calculated Nondimensional Temperature Decay

time (h)	0	1	2	3	4	5	6	7	8	9
measured 02/020	1.000	.975	.950	.927	.895	.875	.850	.833	.820	.810
calc.(1 time const.)	1.000	.980	.961	.942	.923	.905	.887	.870	.853	.836
calc.(2 time const.)	1.000	.968	.941	.917	.895	.874	.855	.836	.819	.802

TABLE 3

Description of parameters c1...c8 in Equation 12

Param.	Description	Value	Unit	Evaluation
c1	Transmission loss per unit ΔT	1549	W/K	A
c2	Ventilation loss per unit Δx (1) (2)	6.4E5	W	A/S
c3	Ventilation loss per unit ΔT (1)	257	W/K	A/S
c41	Equivalent glazed area on WSW orient.	6.8	m2	A
c42	Equivalent glazed area on NNW orient.	21.4	m2	A
c43	Equivalent glazed area on ENE orient.	10.4	m2	A
c44	Equivalent glazed area on SSE orient.	21.2	m2	A
c45	Equivalent glazed horizontal area	13.2	m2	A
c5	Utilization coeff. of electric energy	0.56	-	A/S
c6	Utilization coeff. of gas (3)	0.90	-	A/S
c7	Metabolic heat	1332	W	A/S
c8	Building thermal capacity	0.18	GJ/K	A

A = determined analytically

S = determined on a statistical basis

(1) these parameters were calculated assuming an average air change rate of 0.5 vol/h

(2) due to the little importance of this term, the average x=.0035 kg/kg was lumped together with c2 and considered constant (c2*x=2240 W)

(3) due to the irregularity of gas consumption records, the average gas power ($\dot{E}_g$ = 884 W) was lumped with parameter c6 (c6*$\dot{E}_g$=800 W)

TABLE 4

Comparison of Measured and Calculated Energy Requirements

Month	Measured Energy Requirements (kWh)	Calculated Energy Requirements (kWh)	Difference (%)
November	8673	7662	– 12
December	17479	19949	+ 14
January	18394	19929	+ 8
February	17789	18043	+ 1
March	12452	13219	+ 6
April	5063	4245	– 16
Total	79850	83047	+ 4

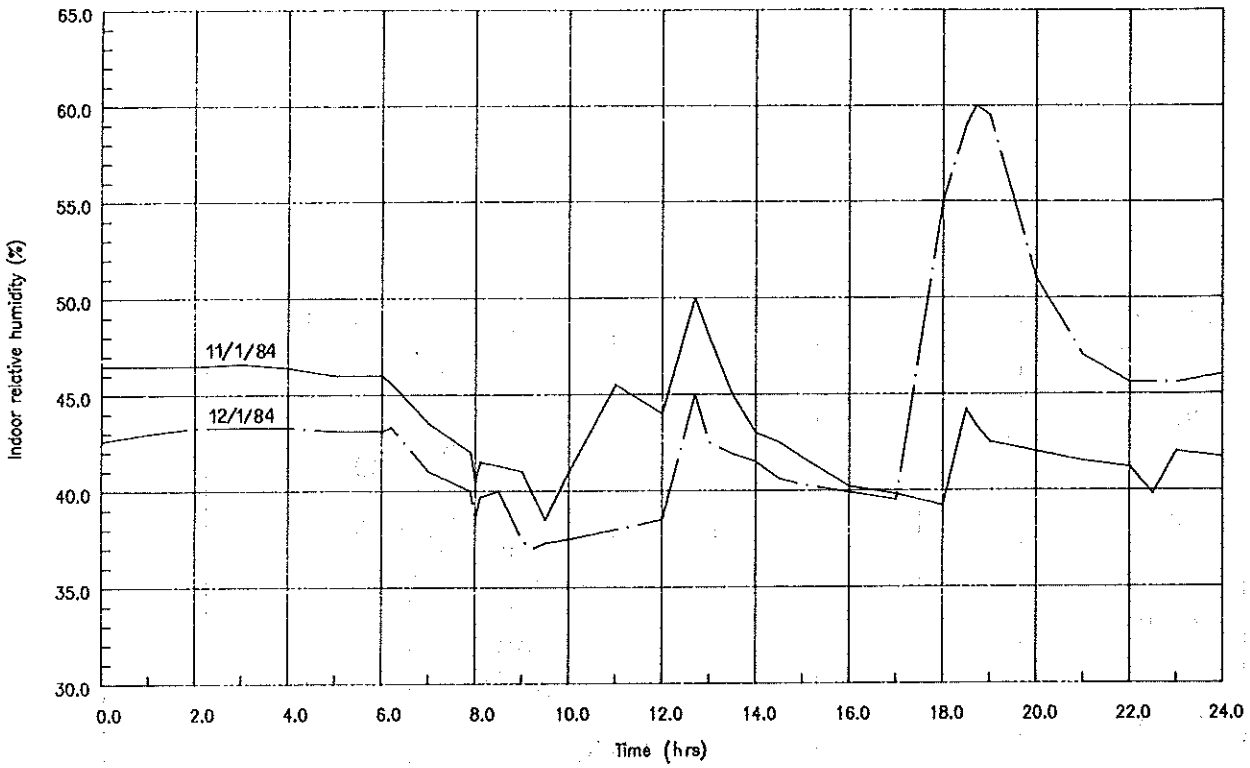

Figure 1. Two typical daily records of indoor air relative humidity

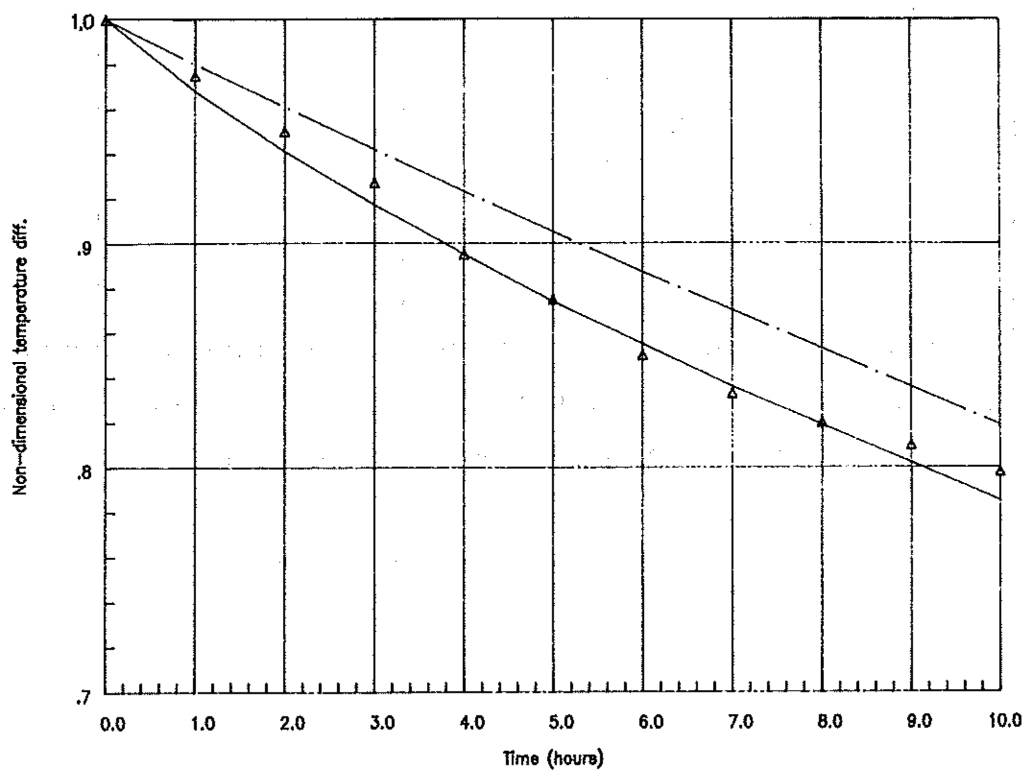

Figure 2. Nondimensional temperature difference decay with time: measured (Δ) and calculated (broken line = 1 time constant, solid line = 2 time constants) values

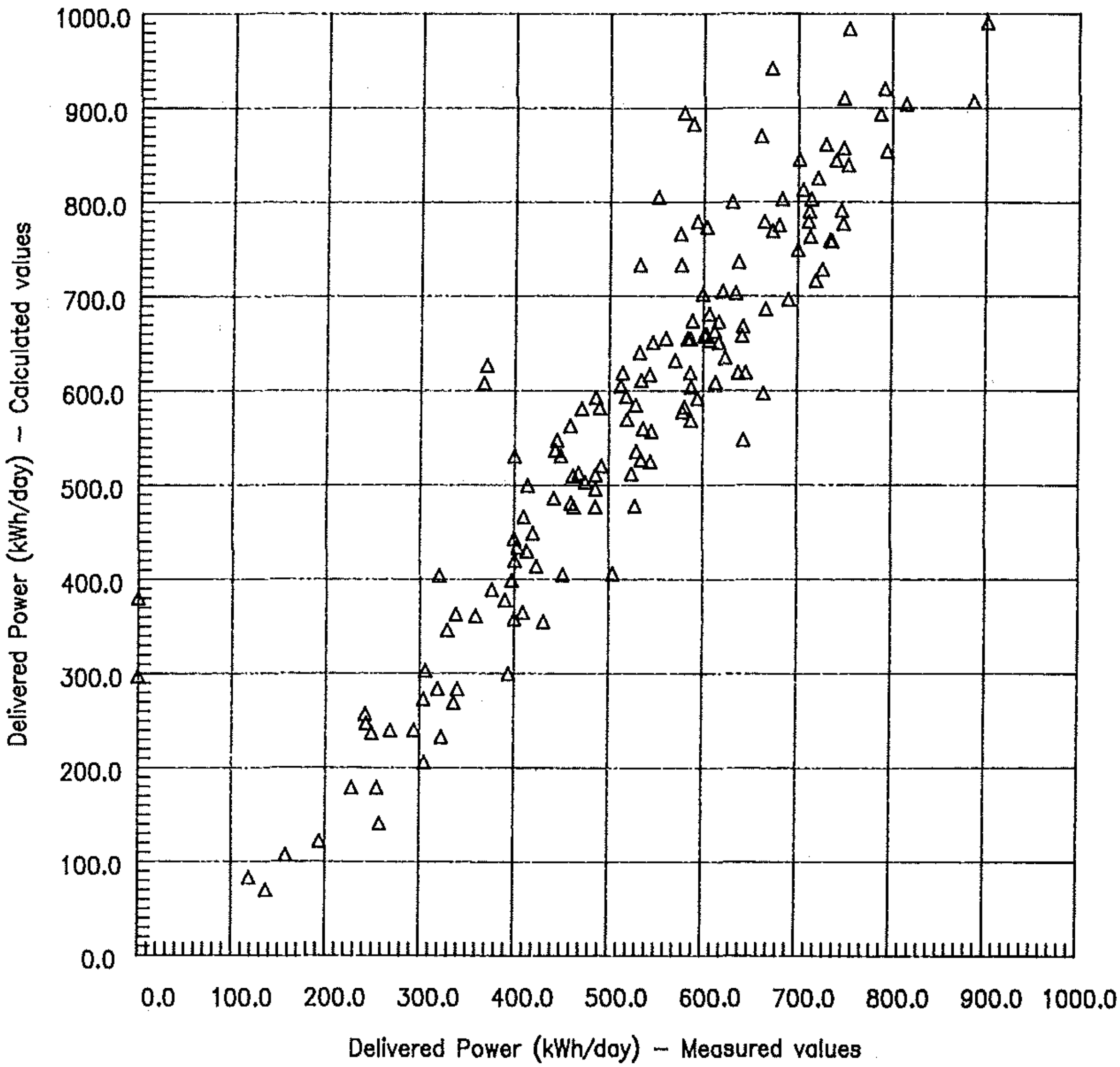

Figure 3. Delivered power for building heat: measured vs. calculated values

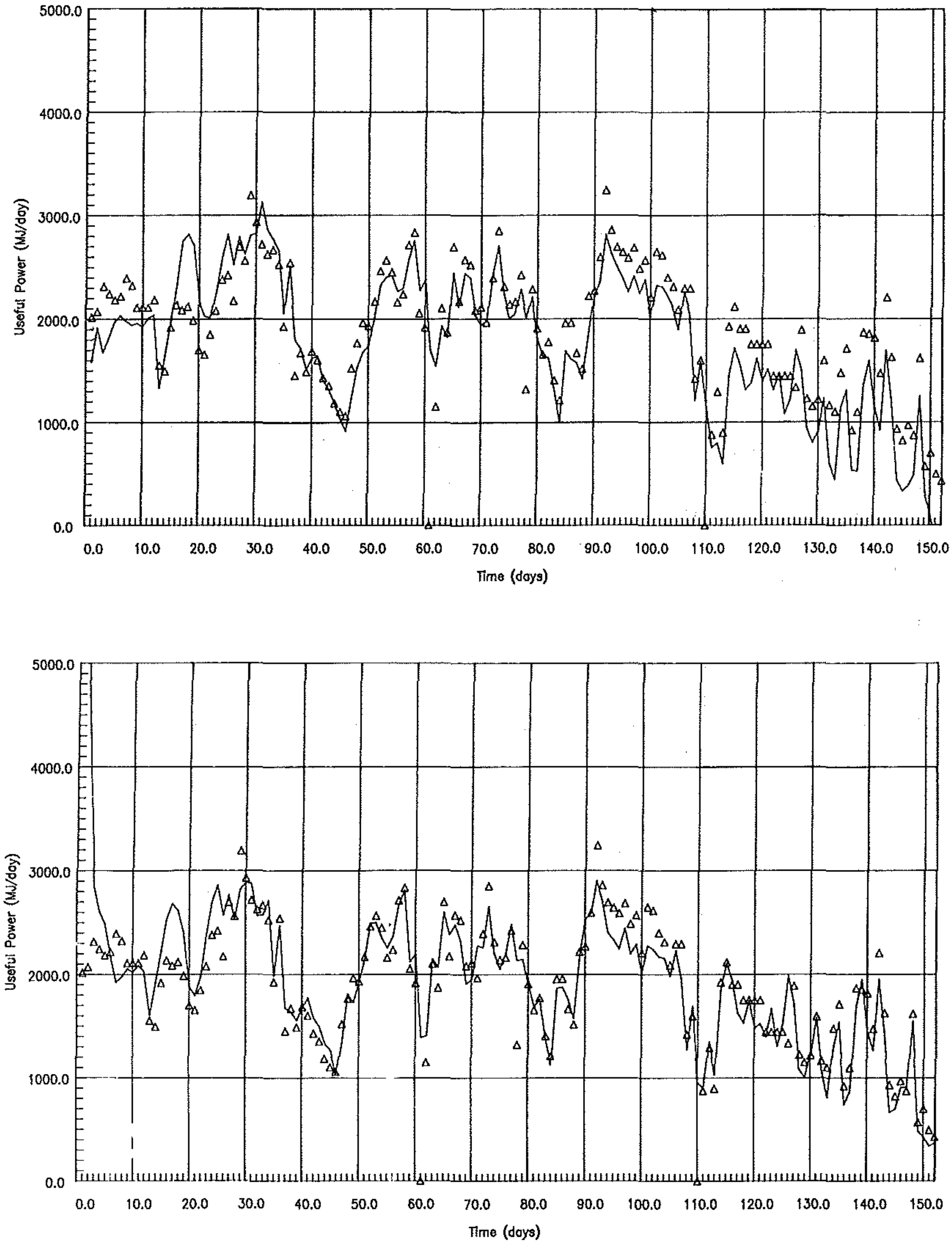

Figure 4. Time trends of useful (delivered) heating power (data set A): measured values (Δ) and simulation results (solid line) using 2nd order model identified at step 50 (top) and step 140 (bottom)

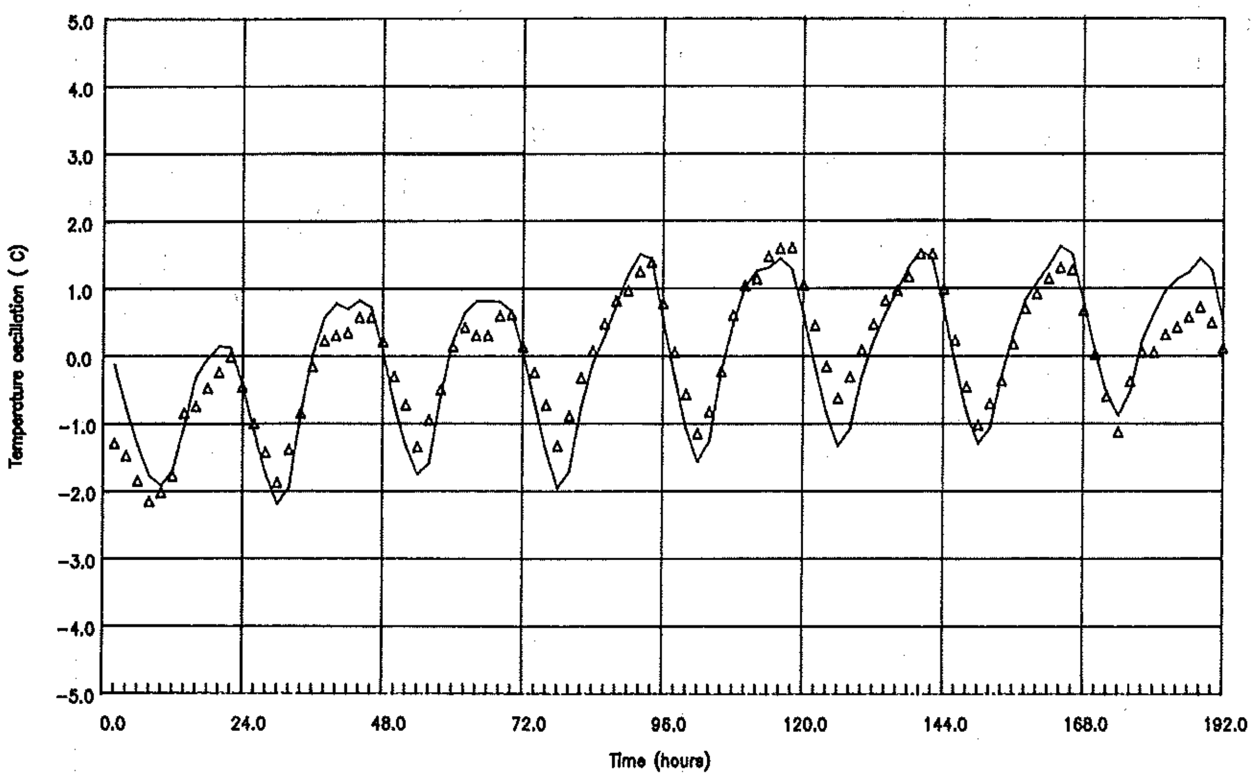

Figure 5. Indoor air temperature oscillation (data set B): measured values (Δ) and simulation results (solid line) using a 2nd order model identified at step 80. Time step = 2 hours