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ENERGY DIAGNOSTIC SYSTEM

SYSTÈME DE DIAGNOSTIC ENERGÉTIQUE

ENERGIE DIAGNOSTIK SYSTEM

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Summary

The Energy Diagnostic System (EDS) automatically reviews the energy condition of a building and performs some simple diagnostics. The system contains a thermal model of the building that has been determined earlier in a learning period of approximately 90 days after the installation of the system. This model calculates the reference energy consumption. The energy condition is determined by comparing the measured energy consumption with this calculated energy consumption. Based on the results and with the additional knowledge of the condition of the heating installation, some simple diagnostics can be performed: whether the increased energy consumption is caused by the installation or due to situations in the building itself.

Résumé

Le Système de Diagnostic Energétique (SDE) estime la condition energétique d'un bâtiment et effectue des actions simples de diagnostic. Le système contient un modèle du bâtiment qui a été déterminé au début du processus pendant une période d'apprentissage d'environ 90 jours, après l'installation du système. Ce modèle est utilisé pour calculer une consommation énergétique de référence. La différence entre cette consommation et la consommation énergétique mesurée détermine la condition énergétique du bâtiment. En enregistrant continuement la condition de l'installation de chauffage, le système est capable d'effectuer des diagnostics simples tels que déterminer si l'augmentation de la consommation d'énergie est dûe à l'installation de chauffage ou à des problèmes dans le bâtiment lui-même.

Zusammenfassung

Das Energie Diagnostik System (EDS) bewacht automatisch die Energiekondition eines Gebäudes und führt einige einfache diagnostische Aktionen aus. Das System enthält ein Modell des Gebäudes, das vorher in eine Lehrperiode von etwa 90 Tage identifiziert wurde. Hiermit wird den Referenz-Energieverbrauch bestimmt. Die Differenz zwischen den gemessen Energieverbrauch und den bestimmten Referenz-Energieverbrauch bestimmt die Energiekondition des Gebäudes. Durch kontinuierlich die Kondition von der Heizungsanlage zu beobachten, ist das System imstande einige einfache Diagnostiken aus zu führen: ob das zugenommene Energieverbrauch verursacht ist durch die Heizungsanlage oder durch Ursachen im Gebäude.

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INTRODUCTION

The cost for space heating (energy and maintenance) consumes a substantial part of the available operating budget of a building. A system that gives the building manager insight in the energy use of the building and shows the deviations from the normal pattern at a glance is very attractive. But unfortunately the tools to supply this information are very clumsy or laborious.

The Energy Diagnostic System offers him this tool. Furthermore, because of the clear and simple presentation, a larger audience, such as for instance the inhabitants of the building, is reached.

THE CONCEPT OF THE ENERGY DIAGNOSTIC SYSTEM

What is the Energy Diagnostic System ?

The Energy Diagnose System (EDS) is a system that automatically reviews the "Energy Condition" of a building, signals the deviations from the reference energy consumption and states obvious causes [1]. The Energy Condition (EC) is defined as:

$$EC = \frac{\sum_{j=1}^{N_d} V_{gas,mes}(j) - \sum_{j=1}^{N_d} V_{gas,ref}(j)}{\sum_{j=1}^{N_d} V_{gas,ref}(j)} * 100\%$$

EC	The Energy Condition
$V_{gas,mes}(j)$	The measured energy consumption till day N_d
$V_{gas,ref}(j)$	The reference energy consumption till day N_d
N_d	Number of days from the start of the heating season

and is shown very conveniently as an increasing or decreasing bar, see figure 1.

Components of the EDS

The system consists of a data acquisition network (a low cost weather station, measuring instruments and sensors), a single-board computer for calculations and data storage, a display, a key-board and optionally a modem for communication with a central computer.

How does the EDS operate ?

The EDS operates as a Stand Alone System or as local sub-system in a Building Energy Management System. As a Stand Alone System, due to the limited storage capacity available, old data will be overwritten by new data. As local sub-system it can make use of the background storage capacity of the Building Energy Management System.
Figure 2 is a schematic drawing of the EDS while figure 3 explains schematically its operation. Continuously the sampled data from the data acquisition network are stored in the single-board computer and processed into hourly and daily means and totals. At the end of a day (24.00 h) the reference energy consumption is calculated and the energy condition of the building determined. This is represented by an in- or decreasing bar. When the energy condition is bad, a LED light with a number on it begins to

blink. By pressing the key with this number on the key-board, a message appears on the screen, informing the building manager about the probably cause (heating installation or building). Optionally (as local sub-system) this message is also send to the central computer, where experts will analyze these data carefully. When necessary they can advice the building manager. It is left to him to undertake the necessary steps based on this advice.
At regular intervals, while in the Stand Alone version the old data are overwritten by new data, the local sub-system sends this information to the central computer where they are administered and stored in the background storage.

The building model

The kernel of the system is determined by the building model. The building model describes the relation between on the one side the outdoor climate, properties of the building, heating installation and human behaviour of the inhabitants of the building (a priori knowledge) and on the other side the energy consumption [1].
These relations are expressed in mathematical equations. The local conditions however can not be expressed in equations and are accounted for in a "learning period" of a certain length to correct the model with the coefficients F_1 , F_2 , F_3. An other model is the blackbox model, where no a priori knowledge is involved and the energy consumption is directly related to the outdoor climate and indoor temperature by the identified parameters. Figure 4 shows the procedure to adapt the parameters of the building model.

The diagnostics

The diagnostics is performed stepwise. When an increase in the energy consumption is detected, the condition of the heating installation is first checked. This includes checking the thermostat setting, water temperature and the ON/OFF periods of the installation. When the condition of the heating installation is satisfactory, it can be concluded, that the increased energy consumption is an effect of a condition within the building.

Now the diagnostics enters the second step. This step concerns the condition of the building. With the data, that has been stored in the background storage a new model of the building will be identified. Because it is assumed, that the input variables are all independent from each other, it is expected, that from the change of the parameters of the old and the new model, one is able to obtain more information about the cause of increased energy consumption. This diagnostics is only possible with the physical model, where the coefficients are related to physical properties. With the blackbox model, this cannot be concluded, because the parameters have no physical meaning at all. With the blackbox model more sophisticated methods must be used. It can be said, the more information we obtain from the measurements, the easier it is to perform a diagnostics.

REALIZATION OF THE EDS DESIGN

The simulator

To investigate, whether this design works, a simulator, that is available at the TU Delft has been used [2]. Originally the simulator is used to test control systems [3,4], but after some modifications it can be used for this project. The simulator consists of a building module with several building models [5], a climate module with real measured weather data of several Dutch stations and a control system [6]. The results of the simulator are assumed to be the measured data from a real building and are used for the identification procedure. As reference heating season (October, 1st - April, 30th) is used the heating season of 1964/1965 [7]. For the analysis is used the mathematical packet PC-MATLAB [8].

RESULTS

The Building Model

In the first instance the corrected building model as is given in figure 4 has been used. Mathematically this is given by :

$$V_{gas,ref} = -\frac{(F_1 \cdot (Q_{sun} + Q_{intern}) - F_2 \cdot Q_{trans} - F_3 \cdot Q_{vent})}{3,6 \cdot \eta \cdot HS \cdot 10^6}$$

$V_{gas,ref}$ = reference energy consumption [m^3 per day]
Q_{sun} = transmitted solar energy [kWh per day]
Q_{intern} = internal heat [kWh per day]
Q_{vent} = ventilation losses [kWh per day]
Q_{trans} = transmission losses [kWh per day]
η = boiler efficiency [-]
HS = heating value natural gas [$kWh.m^{-3}$]
F_1, F_2, F_3 = coefficients [-]

After the first results has been analyzed, it is concluded, that these results do not confirm to the physical reality: the influence of the solar radiation is not correct. Instead of reducing the energy consumption when there is much sunshine, the model calculates an increased energy consumption. The reason for this is probably caused by the fact that the input variables are not more independent from each other through the use of a priori knowledge in the building model (for instance the same ΔT is used in the calculation of the transmission and the ventilation losses).

Because of these conflicting results it was decided to leave the physical model as it was and to use the "blackbox" model. This is given by the equation:

$$V_{gas,ref} = C_1 * Q_{z,v} + C_2 * T_o + C_3 * T_i + C_4 * V_{wi}$$

$V_{gas,ref}$ = reference gas consumption [m^3 per day]
$Q_{z,v}$ = daily total measured solar radiation [$kWh.m^{-2}$ per day]
T_o = daily mean outdoor temperature [°C]
T_i = mean indoor temperature [°C]
V_{wi} = daily mean wind velocity [m/s]

The coefficients are now not dimensionless anymore, but have the dimensions:

C_1 : [m^3 per $kWh.m^{-2}$]
C_2 : [m^3 per °C]
C_3 : [m^3 per °C]
C_4 : [m^3 per $m.s^{-1}$]

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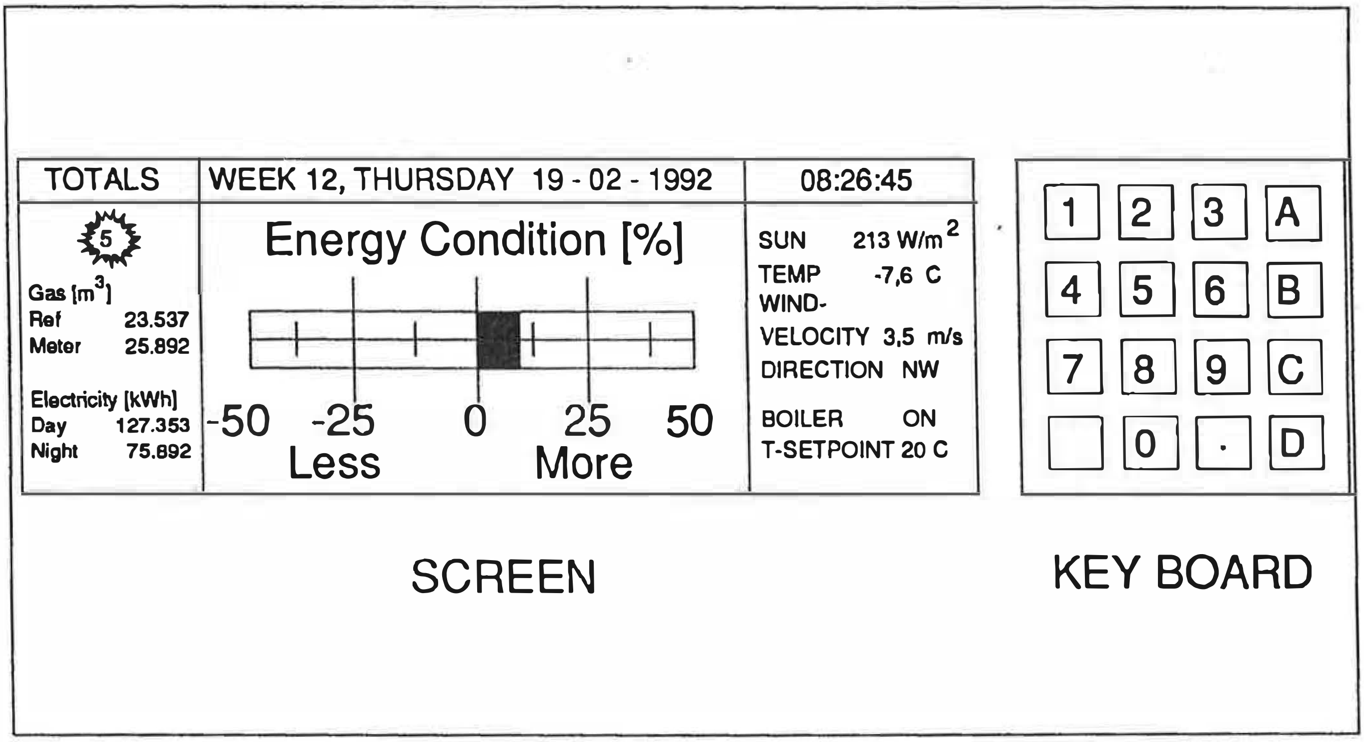

Figure 1 The energy condition of the building (EC) is shown conveniently on a screen. With the pre-programmed keys on the key-board a message can be evoked in the middle screen.

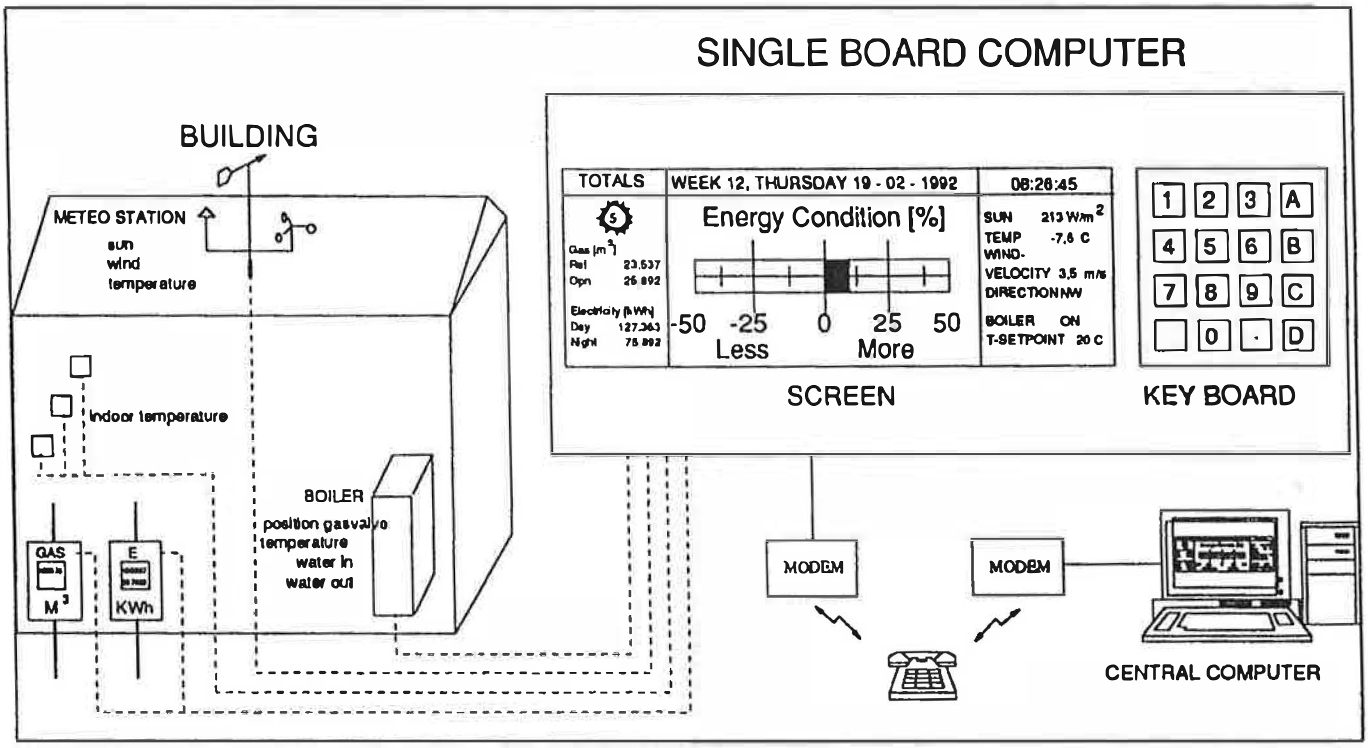

Figure 2 The Energy Diagnose System - EDS

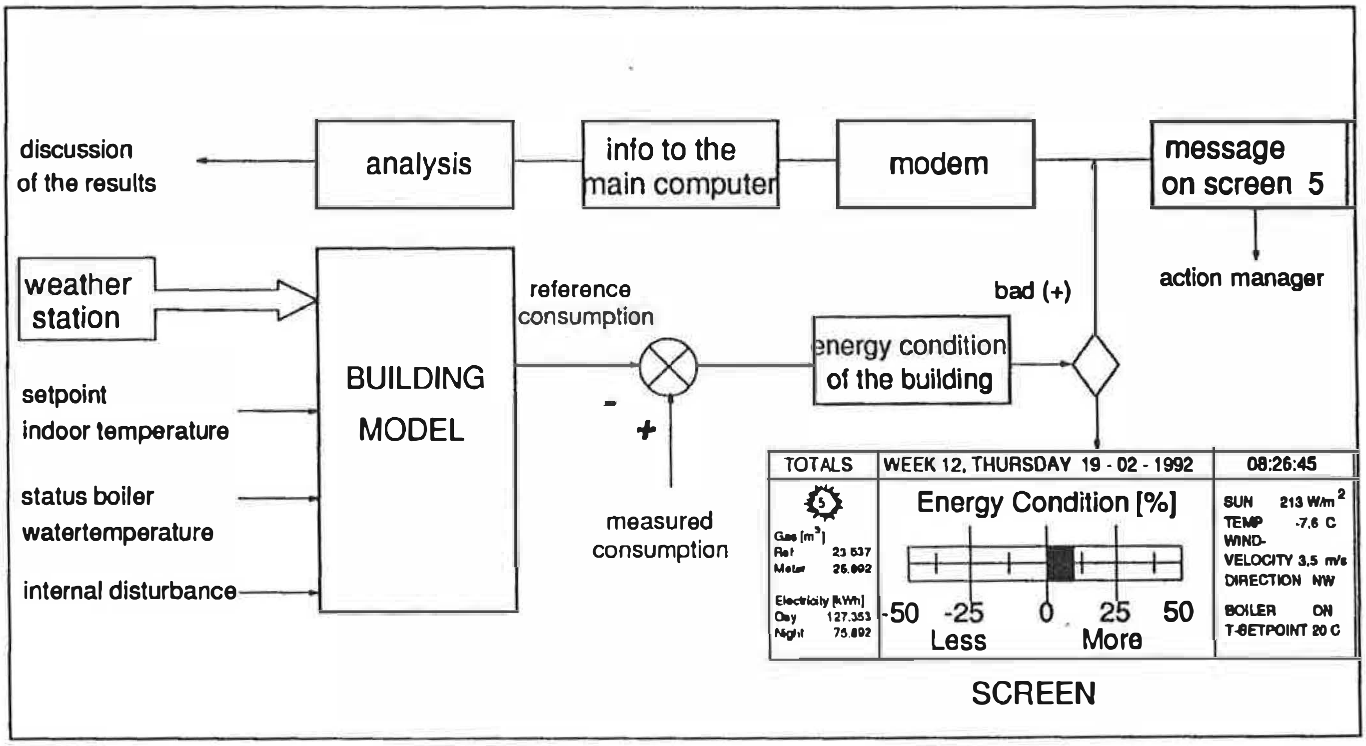

Figure 3 The EDS in action

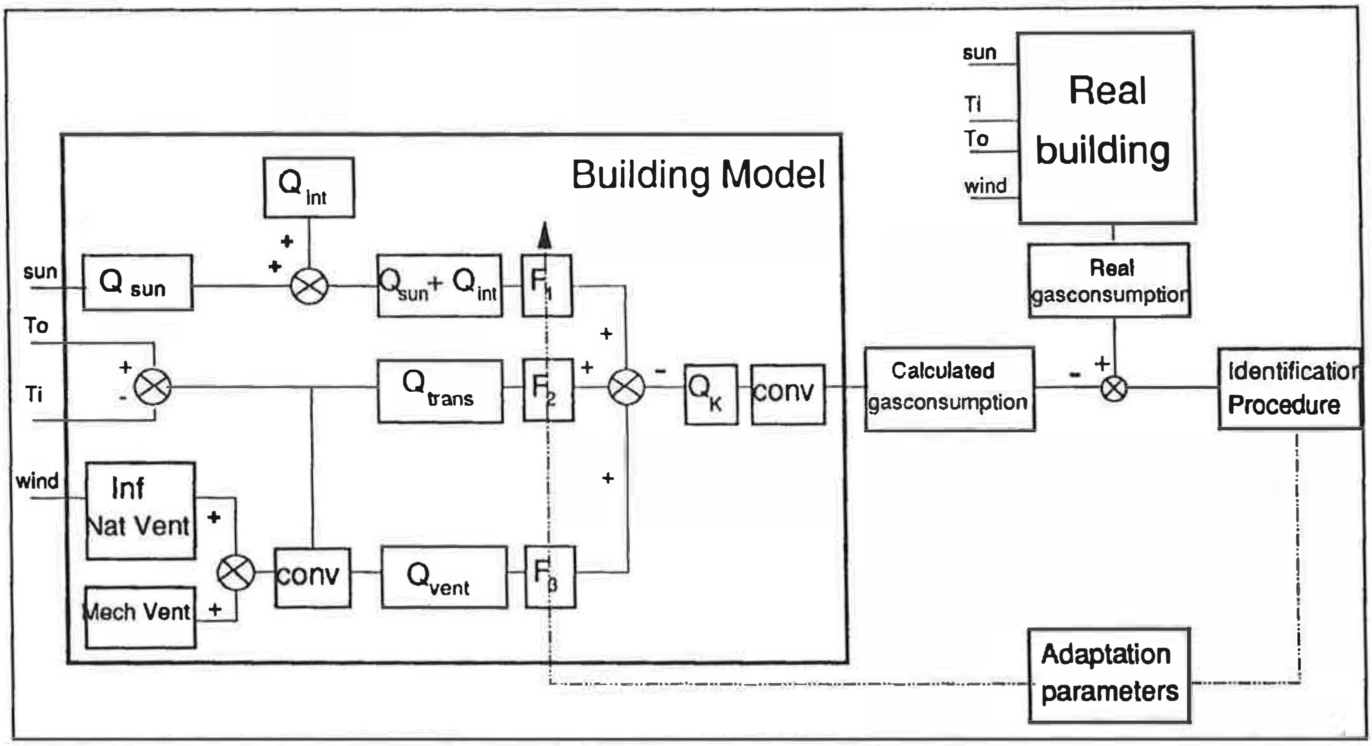

Figure 4 In the learning period the parameters of the building model are adapted to the real building

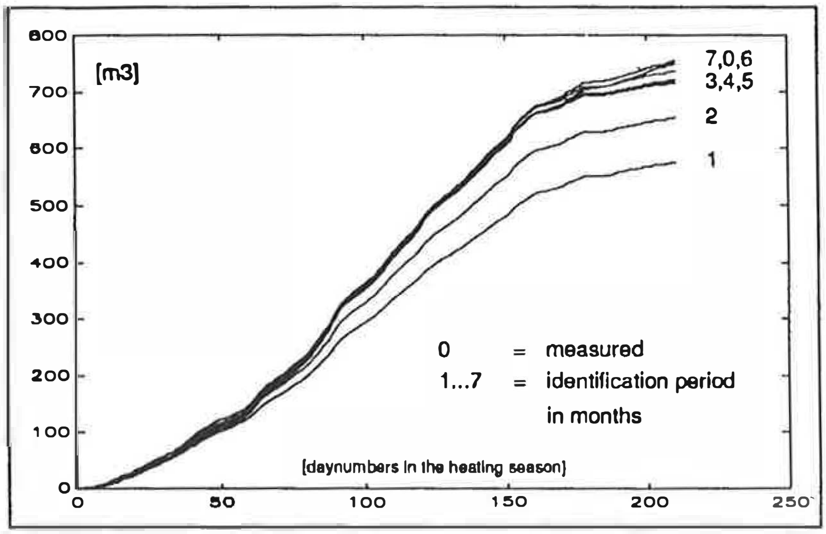

Figure 5 Influence of the length of the identification period

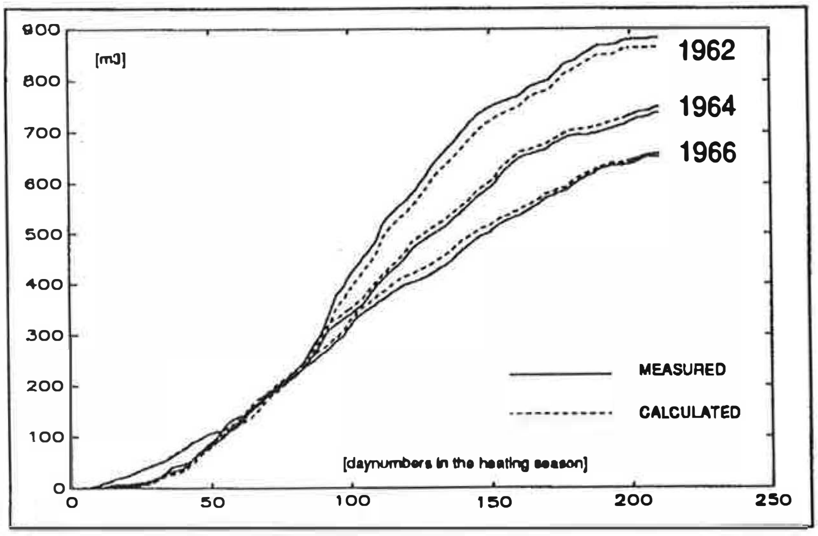

Figure 6 Measured and calculated gas consumption in several heating seasons

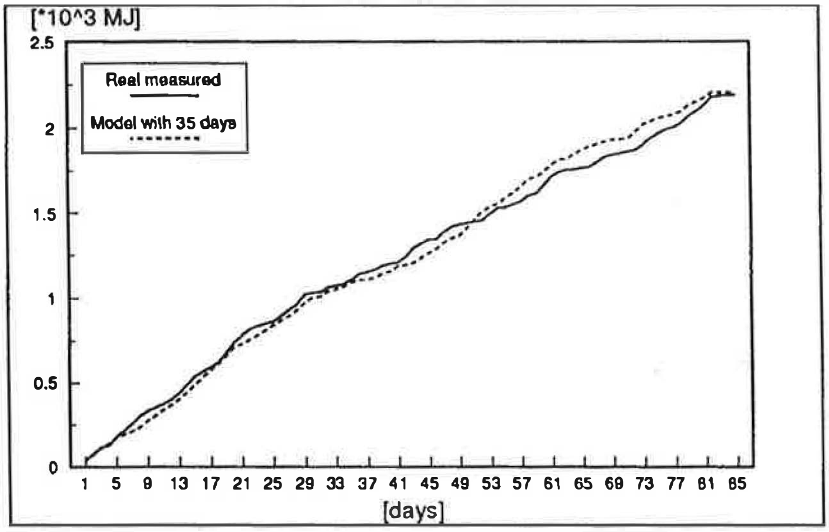

Figure 7 Result of a real test period of 85 days in the winter of 92/93; identification period: 35 days

This model qualitatively agrees with the physical reality: when there is no sun and/or when the outdoor temperature is low, more gas is consumed.
Based on this blackbox model the reference model for the system is developed.

DISCUSSION

Influence of the "learning period"

The first step is to take a one-month learning period. This period is analyzed [8,9] and a building model developed. By using this model as reference model the reference energy consumption for the whole season is calculated. Then the learning period is extended to two months and so on till the whole seasonal period is used as the learning period to determine the reference model. The results are given in figure 5 (for comparison the measured energy consumption "0" is also given). As can be seen from these results, a learning period of 3 months is sufficient for the system to characterize the building; longer periods do not improve the building model much more.

Night and weekend reduction

Up till now the heating is continuously on. Because the results are very promising, a more realistic situation is chosen: after working time (18.00) and in the weekends the heating is reduced. The thermostat is lowered to 10 °C and the capacity of the heating system is reduced with 50% (it is assumed that there are two boilers available).

With these new data a new building model is created. But unlike the above mentioned results, no agreement can be found between the model and the measurements. It seems, that the weekend reduction confuses the identification procedure. This problem has been solved by discarding not only the weekends, but also the Monday (due to the extensive cooling during the weekend, on Monday more heating is required to bring the building at temperature). So only the data from Tuesday to Friday has been used.
The "reduced" building model is given by:

$$V_{gas,ref} = -\ 0.2835\ .\ Q_{z,v} - 1.2721\ .\ T_o + 0.5815\ .\ T_i + 0.1901\ .\ V_{wi}$$

This new model is verified with the heating seasons of 62/63 and 66/67 and the results together with the measured consumption are plotted in figure 6. As can be seen from this figure, the calculated energy consumption agrees very good with the measured consumption in each season. From this it can be concluded, that most information are stored in the regular working days.

Energy consumption per part of the day

It is also very interesting to know, whether it is possible to determine the energy consumption for part of the day, for instance during the working hours and during night activities. For this investigation the day is divided in three time periods: day period, from 7.00 till 16.00 hours, an evening period, from 14.00 till 22.00 hours and a night period, from 22 till 7.00 hours. Analysis of these daily periods learns, that it is not possible to obtain a good model for each part of the day.

This can be explained by the fact, that through the inertia of the building, each daily period influences the next daily period. For instance, after office hours, there is still so much heat in the walls, so that in the evening period less additional heating is required. In the early morning much heating is already used to bring the building at working temperature. So actually, most of the heat requirement is paid by the users during office hours.

THE PROTOTYPE

A prototype of this system has been build. A Scorpion K4 single-board computer, equipped with a 128 K operating system, and 64 K static RAM storage and a powerful multitasking object orientated language is used. During part of the winter of 1992/1993 the system has been in operation. Although some difficulty is obtained with measuring the wind velocity, the identification procedure performs very satisfactory, even with omitting the influence of the wind velocity. With a learning period of 35 days the system can predict the energy consumption for the whole period of 85 days (see figure 7).

CONCLUSIONS AND SUGGESTIONS

1. Within a learning period of approximately 90 days the system is able to identify a model of the building.
2. Due to its clear and straightforward presentation of the energy condition of the building, a greater audience is reached, namely the inhabitants of the building it self. This motivates them to participate in energy saving operations.
3. By automatically monitoring the condition of the heating installation, the system can state whether the trouble is caused by a malfunction of the installation or as a result of conditions in the building.
4. Because of the inertia of the building it is not possible to determine the energy use for a certain daily period. Already much energy is used before working time to obtain a comfortable temperature at the start of the day, while after working hours still much heat is left in the walls, so that the activities after working hours will profit from it.
5. With components available in the market, a prototype has been build.
6. Due to its small storage capacity the possibilities of the Stand-Alone System is very limited. Operating as a local sub-system of a Building Energy Management System, its possiblitities are much more extended.
7. The results of the prototype that is tested during the winter of 1992/1993 in the laboratory is according to the expectations.
8. It is suggested to implement this system in a Building Energy Management System.

ACKNOWLEDGEMENT

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