ENERGY MEASUREMENTS AND BUILDING PARAMETERS FOR AN AUDITING AND ENERGY MANAGEMENT SYSTEM

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ABSTRACT

After ten years of energy saving, we are now approaching the situation where the "worst" buildings have been retrofitted. It has been possible to use simple auditing procedures to identify the energy saving potential, but in the future, one should use more sophisticated criteria combined with continuous in-situ measurements of energy use to assess the thermal characteristics of buildings.

We have developed a system that can be used to supervise the energy consumption and the thermal performance of buildings. The system can be incorporated into an energy management system and supply the building operator and the building manager with relevant information in a simple manner. It can also monitor a building for a short period of time to supplement the instantaneous measurements performed during an audit with data on the dynamic thermal performance of a building. The system is now being tested on apartment buildings, office buildings, and industrial buildings.

The system can disaggregate the energy use in a building to identify where energy losses occur and give, for example, indications on the thermal performance of the building envelope and ventilation losses. Indicators of the thermal performance are calculated using a lumped parameter model of the building.

INTRODUCTION

After ten years of energy saving in the building sector, we are approaching the situation where the "worst" buildings have been retrofitted. To identify these buildings, it was sufficient to use a simple indicator, such as energy consumption divided by floor area. It was possible to use relatively simple auditing procedures to decide what retrofit(s) to carry out. There are several reasons why energy conservation during the next ten years ought to be based on more sophisticated criteria in combination with simple, but continuously performed, measurements to assess the building energy status. It has become more difficult to identify buildings where a retrofit could be cost- effective, as the cost- effectiveness of various measures is not the same as before.

Experience has shown that even if much energy can be saved during the first years after a retrofit, this is not a lasting effect if the energy consumption is not checked at regular intervals and malfunctions corrected. This is not common practice today. Only a few consulting firms and building managers regard a retrofit as the first step in a continuous process of building energy management. In cases where the energy consumption is continuously monitored, one often detects that one is "drowning in data." Nor does one have the routines to make use of the knowledge and experience on the energy systems of a building possessed by those involved in the daily maintenance of the building.

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It is now a generally accepted idea that energy-saving retrofits are most efficiently implemented in connection with other building retrofits required by the ordinary maintenance of a building. It has, therefore, become more common for building managers to have a long-term plan for what buildings to retrofit and when. However, the data serving as a basis for such planning have so far rarely been collected in a consistent way. For cost and other reasons, it is often desirable to restrict surveillance and inspections at site. This can be achieved using an automatic survey system.

Measuring instruments, based on microprocessors, are now available at reasonable prices, making available their utilization for energy monitoring in buildings. Software in the form of calculation and plotter programs to handle energy-related data has been developed.

The building operator should make frequent use of systems that help to maintain an acceptable indoor climate at minimal cost and supervise the energy consumption and the energy systems of buildings. Such systems should supply the building operator, as well as the building manager, with relevant information in a simple and illustrative way. The output from the system should be more than just a calculation of the total energy consumption or the average indoor temperature and a printout in the form of a table. To save the building operator and the building manager from extra work, the system should analyze all data collected and give an indication on the performance of the building's energy systems and the energy status of the building. The data collection should be automatic to minimize work on reading of meters.

Automatic control and survey systems for buildings have often not lived up to the expectations prior to implementation. This may have been because:

1. The building operators did not take part in the development of the system,
2. The consultant has insufficient knowledge of or experience with systems of this kind,
3. The hardware and the software have not been maintained,
4. The supplier of the system has lost the knowledge of how the system works because it is no longer marketed,
5. The documentation to the users is lacking or insufficient,
6. The building operators have not been given the appropriate training, or the training has not been repeated at regular intervals,
7. The system is more computer oriented than user oriented, or
8. The installation cost was larger than foreseen.

Some of the items above are associated with the fact that the expected lifetime of the systems discussed here, 10 to 15 years, is shorter than for many other building components. An important point is that if the building operators are not motivated to make full use of the capabilities of the system, energy savings are less likely to occur.

THE DEVELOPMENT OF THE SYSTEM

The Energy Conservation Division of SIB has performed and/or participated in several research projects on energy consumption and energy status of buildings. During this work we have initiated the development of sensors and instruments appropriate for energy studies in buildings.

The purpose of the project described here was to test and develop a system for supervising energy systems in buildings. This system does not at present have the capacity for feed-back control of building energy systems, but it can control on-off switches. The system furnishes the building operator with relevant information for the daily supervision and maintenance of the building's energy systems. The building manager receives an analysis of the energy status of the building, serving as a basis for decisions regarding maintenance and implementation of energy-conservation measures. Energy management should be integrated into already existing routines for building maintenance.

We have cooperated with building operators and managers in the development of the system. During 1985 the system was tested in ten apartment and office buildings. After the test period the system will undergo further development based on the experiences of ourselves and the building operators and managers taking part in the test. In 1986 the system will be used by a number of building management companies in apartment buildings and will also be tested in buildings of other kinds.

DESCRIPTION OF THE HARDWARE

The system uses data transmission by the public telephone network to allow a quick processing of data. The public network is also used for the communication between sensors and microprocessors inside a building. The system is self-configurating. The micro-processors are equipped with built-in modems. The signal input to the processors can originate from temperature sensors (analogue signals), flow-meters (pulsed signals), or from running-time meters (the time of on-off signals is recorded). This covers most measurements needed in energy surveillance of buildings.

The tested system (see Figure 1) contains sensors for the measurement of (1) indoor temperature, (2) outdoor temperature, (3) solar radiation through windows, (4) energy consumption (flow rate, feed, and return temperature), (5) hot water consumption (flow rate and temperarure), (6) cold water consumption (flow rate and temperature), (7) household electricity consumption, (8) temperature in air ducts, and (9) running time of burner, fans, heat pumps, etc.

The extent, level, and frequency of the measurements depend on the kind of building and building useage. All sensors listed above normally will not be present in one building. However, there are, in principle, no limits to the number of sensors. For an apartment building, 5 to 10 sensors should suffice. The topology of the data collection system may vary, depending on the requirements of the building manager.

Data are collected by and stored in microprocessors (see Figure 2) in the building. Sensors are read every minute, and averages for a preset time varying from one minute to 24 hours are stored in the processor. Each microprocessor handles from four to eight sensors. Data are transfered by the public network to a central processing unit. In the test buildings data are averaged over six hours, and the data transfer takes place every second night. Data are processed and results are available at any time. The microprocessors are run either on the electric power of the public telephone network or the power is supplied by the electric network. In either case the processors are equipped with a battery back-up.

DESCRIPTION OF THE SOFTWARE

A variety of sophisticated systems for the supervision and control of building energy systems are on the market today. However, such systems are, in general, too expensive for use in small to medium-sized apartment buildings, office buildings, and schools. The system described here is not intended to be a duplicate of already existing systems but rather to be a simpler and cheaper alternative. As a consequence, it does not contain some options present in other systems. The specific properties of this system are:

- -- The use of a data base containing information on experiences and results collected in studies of energy conservation measures,
- -- An analytical program constructed with knowledge of how to describe the energy consumption of a building in an efficient way , and
- -- Preparation for the installation of control systems at a later stage. At present the only control capacity is control of on-off switches.

The system can be used to:

1. Supervise energy consumption and building energy systems,
2. Compare the actual energy consumption of a building to the expected consumtion,
3. Indicate energy conservation opportunities,
4. Compile statistics on energy consumption,
5. Monitor effects of energy-conservation measures, and
6. Provide a basis for decisions regarding the maintenance of building energy systems and conservation measures.

When the user logs in, all measured variables that have exceeded preset limits are automatically displayed on the screen. The upper and lower limits are set by the user of the system. The system automatically gives an indication on the performance of building energy systems, for example, if any subsystem starts consuming energy at a rate above the normal one, or if preset temperature levels are exceeded.

The user can choose from a menu (see Figure 1) the topic for study. The system gives information on the total energy consumption, disaggregated into energy for heating, hot tap water, household electricity, ventilation, and air conditioning. It also furnishes data on temperatures and flow rates in the heating system and on the indoor and outdoor air temperature. The system also provides information on the temperature distribution of the building, and the degree of adjustment of the heat distribution system.

The individual energy consumptions can be obtained in the form of a diagram of the energy balance of the building (see Figure 3). Information can also be obtained in the form of a time-series (see Figure 4), or in the form of a scatter diagram containing either a curve characteristic of the studied building component or a theoretically calculated curve (see Figure 5). To facilitate comparisons it is possible to display in a diagram two different variables either (1) from two different periods for the same building, or (2) from the same period for two different buildings.

In the same manner, one can, instead of presenting data for single buildings, aggregate data for a group of buildings or for a building category. The scale of the diagrams is automatically chosen in such a way that optimal use is made of the space available on the screen. The units of all entities presented are those customary to building operators. Written compilations can be easily produced by the system.

Time series of data are used to make a more detailed analysis of the energy status of the building, including a correction for climatic conditions deviating from the normal and a comparison with reference values. The information is presented in the form of normalized energy indicators for various end uses of energy. This makes it easy to compare the energy consumption for different periods or to make comparisons between different buildings. The system can produce a forecast of the energy consumption based on the trend of the present consumption.

Energy indicators and the predicted energy consumption are calculated using lumped parameter models of components of the building envelope and the building energy systems. A number of algorithms have been developed for the calculation of variables that are not measured directly. The input to these algorithms consists of data recorded by the measuring system and data obtained from an energy audit of the building stored in a separate file.

To avoid the use of large manuals, the system has been made self-instructing. Much attention has been devoted to the instruction of building operators and the construction of training programs to furnish them with an understanding of the basic processes influencing energy consumption. The introduction of the system has been made over a rather long period to make the users familiar with it and to assure that it is functioning properly.

EXPERIENCES FROM THE TEST PERIOD

The use of the public telephone network for communication between the sensors and the microprocessor has greatly reduced the cost for wiring.

Because a full use of the capacity of the system requires long time-series of data, it is essential to make sure that no losses of collected data occur due to, for example, a breakdown of the central processing unit. Routines for data backup must be constructed, and users must be informed about the necessity of implementing these routines.

It has been found that training of the building operators must be emphasized. If a feature of the system is not understood, that feature will seldom be used. The attitudes and expectations may vary enormously between building operators. Those who get a negative impression when making their first acquaintance with the system are hard to convince about the advantage of using it. It is probably an advantage if use of the system is not forced upon the building operators. One can start by letting a few interested building operators use the system; these will then inform others about the advantages of using it.

It is an advantage if every building operator is solely responsible for a limited number of buildings. This is not always possible with the present organization of many building management companies. Building managers, at first, tend not to be interested in this aspect of the use of the system. They are likely to be interested mostly in the economic advantages. However, building managers eventually realize that an efficient use of the system may require organizational changes.

When the system has been in use for some time, some instructions by the computer tend to become boring for the users. At this stage it has been found that the software for the communication between the user and the computer may have to be revised.

The full advantage of the system does not show up during the first year it is used because of the lack of earlier data. Before the introduction of the system, data in general consisted of monthly data on energy for heating and electricity and data on outdoor temperature that could be obtained from meteorological records. Thus, only a limited number of comparisons could be made with periods before the system was introduced.

The users have asked for some features that are not at present included in the system. Some examples are:

-- A manual for action in case of malfunctions of building energy systems,
-- The ability to bring notice when different maintenance operations (for example, regular inspections or replacement of components) should be performed, and
-- A capacity to calculate the expected energy savings and the cost for the implementation of common retrofits.

CONCLUSION

A system of the kind described above requires that all aspects of its use are considered before the implementation. How building operators are acquainted with the system is important. They should be introduced to its use gradually and it is probably advantageous to make separate program packages for building operators and building managers.

It is important to consider the coupling between the system and its functions, the routines for the building maintenance, and the organization of the building management. The use of the system may require modifications of the maintenance routines and organizational changes that are not easily foreseen at the design stage.

Even if the system has only been tested to a limited extent, there are indications that the payback time is only a few years.

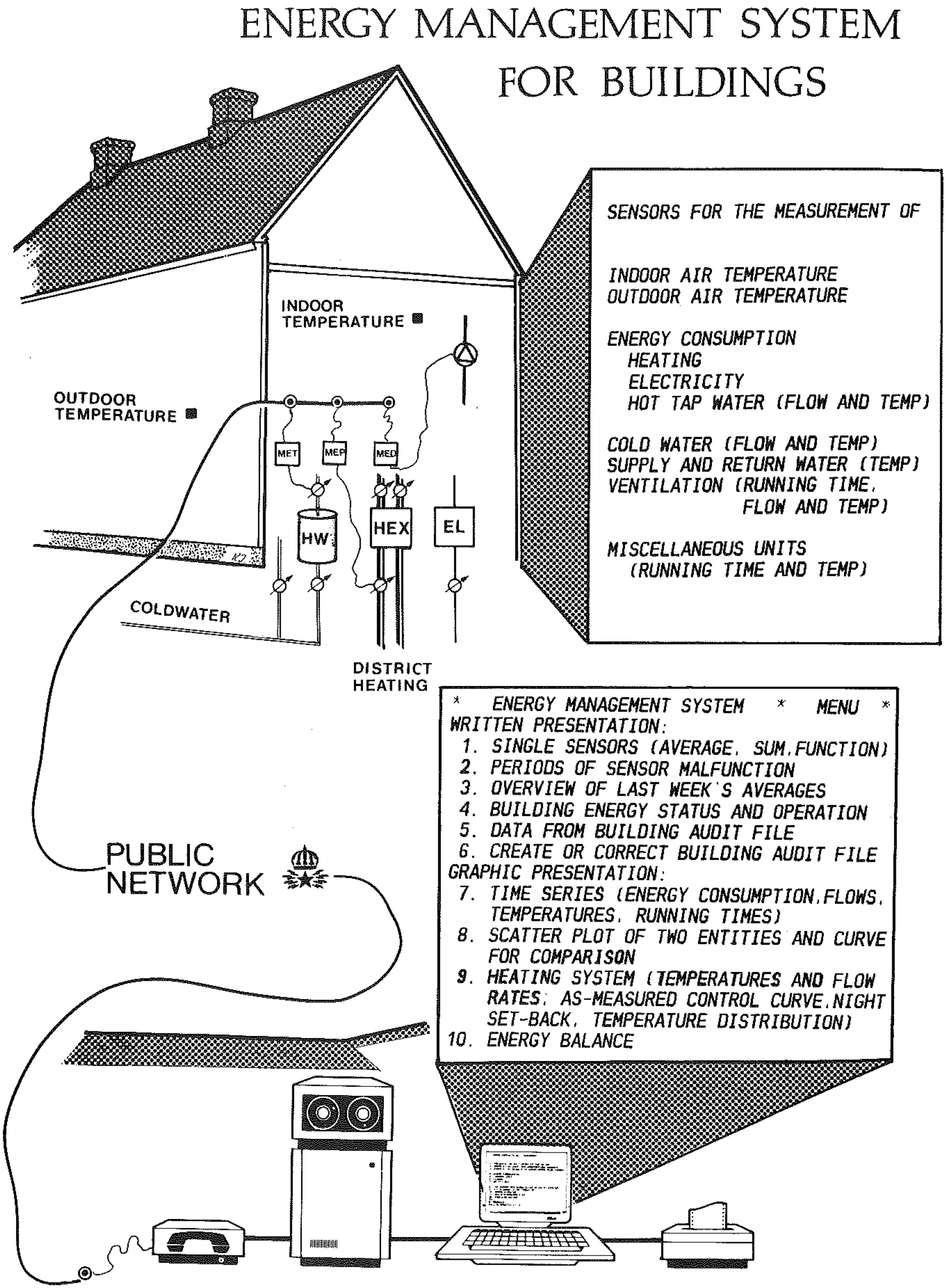

Figure 1. Data collection system

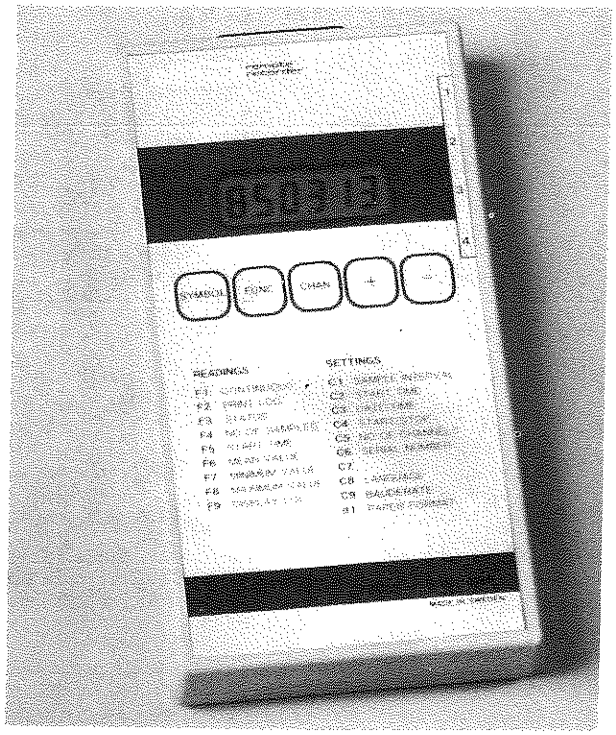

Figure 2. The microprocessor used in the buildings

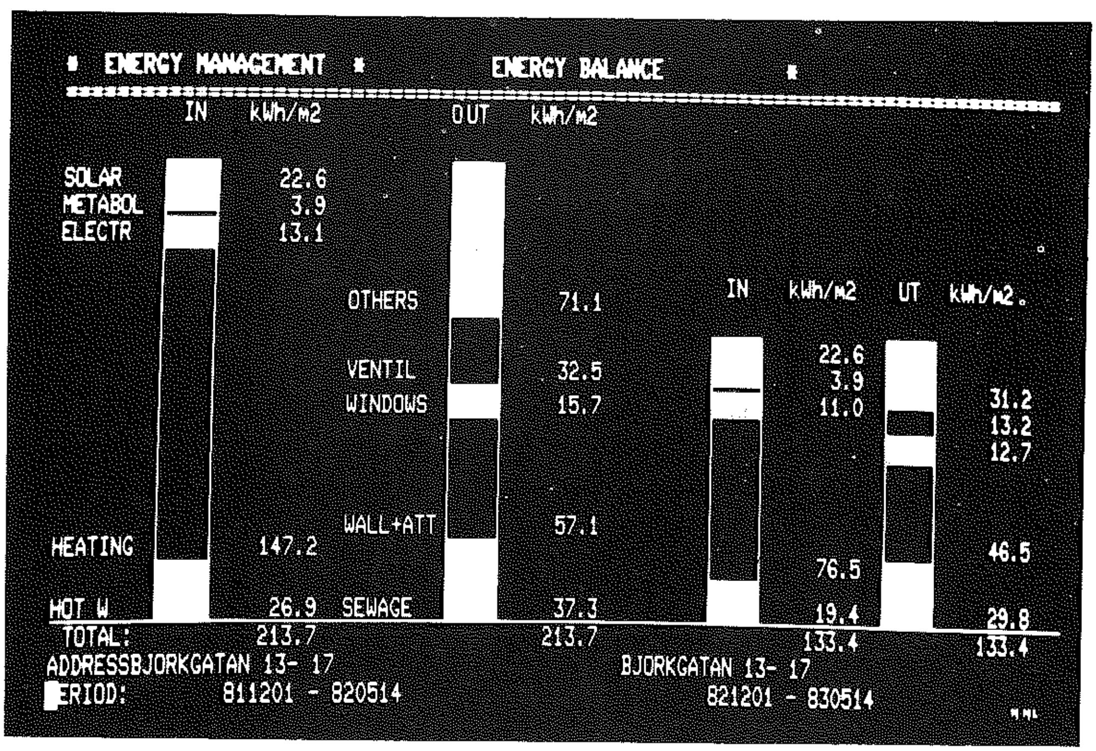

Figure 3. Presentation of energy balance of building before and after retrofit

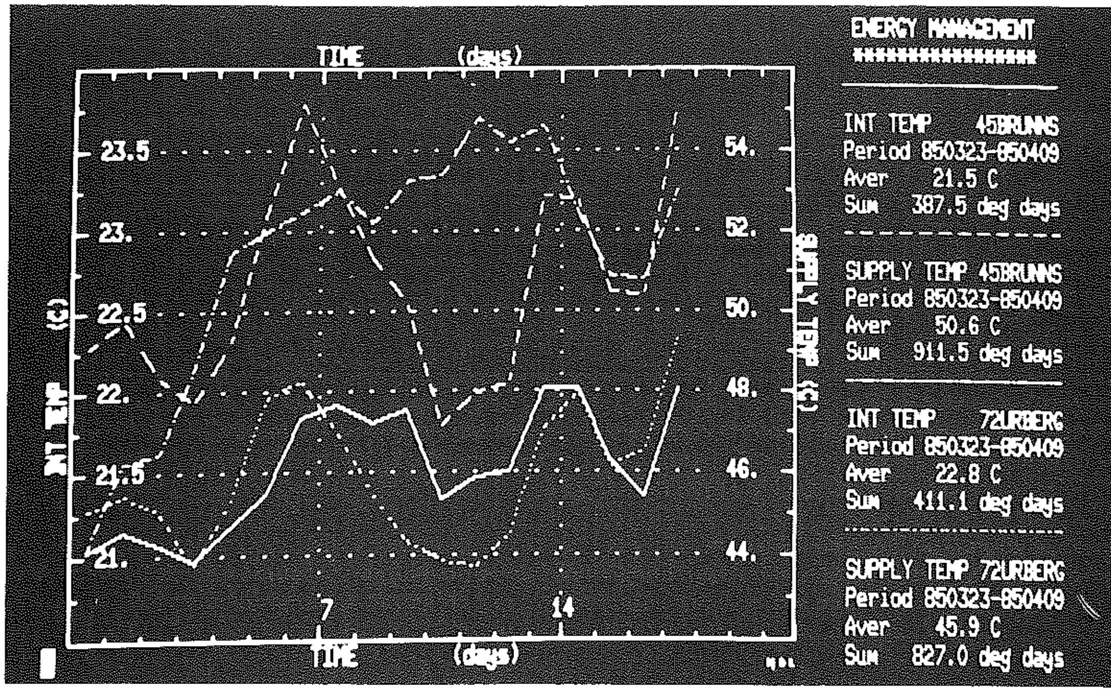

Figure 4. Example of the presentation of supply water temperature and indoor temperature for two different buildings during the same period

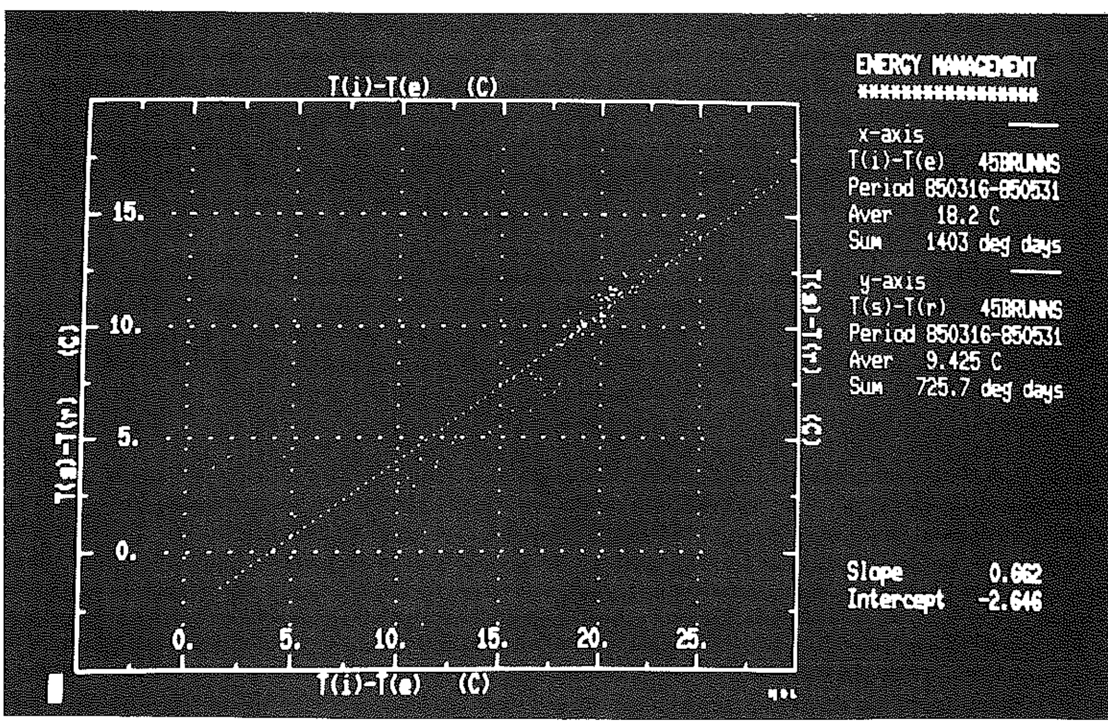

Figure 5. Example of the presentation of the measured temperature difference between supply water and the return water versus the indoor-outdoor temperature difference