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## TECHNICAL FIELD OF THE INVENTION

The technical field of the invention is that of building heating systems. The present invention relates to a method for determining the load-shedding capacity of a building as well as a method for load-shedding a building. The present invention also relates to a heating system implementing a method for determining the load-shedding capacity of a building or a method for load-shedding a building according to the invention.

## TECHNOLOGICAL BACKGROUND OF THE INVENTION

In general, heating of a building is ensured by a heating system including a heating device connected to a heating circuit in which a heat transfer-fluid flows, and which comprises piping elements and emitters (for example radiators). The heat input is provided by the heating device which is generally in the form of a boiler, a heat pump or a connection to a heating network. Next, unless stated otherwise, the powers are expressed in Watts, the energies in Joules and the temperatures in degrees Celsius.

An example of a heating system of a building is illustrated in Figure 1. The heating system comprises a heating device CH (for example a gas boiler), a heating circuit CC in which a heat-transfer fluid flows, and a regulation device REGUL. The heating circuit CC in which the heat-transfer fluid flows comprises a temperature sensor MT measuring the temperature  $T_c$  of the fluid at the outlet of the heating device CH (in other words, at the inlet of the heating circuit) flowing in the heating circuit CC, the temperature thus measured being sent to the regulation device REGUL. The heating system further comprises an external temperature sensor MT2, the measured temperature being converted into a temperature setpoint  $T^*_c$  by a conversion means CONV which is sent to the regulation device REGUL. The control device REGUL then sends a command value to the actuator in charge of modulating the power  $P_{ch}$  of the heating device as a function of the temperature  $T_c$  measured at the inlet of the heating circuit CC and the setpoint temperature  $T^*_c$  established by the conversion means CONV as a function of the external temperature  $T_{ext}$ .

In the previous example, the regulation of the heating system is performed by the controller. However, the latter could also be achieved through terminal regulators which regulate the power exchanged at each emitter as a function of a comfort temperature in the room in which it is located, and possibly a combination of the previous two regulation

methods. The power  $P_{ch}$  thus regulated allows maintaining in the building a temperature  $T_{int}$  as close as possible to a setpoint temperature  $T^*_{int}$ . The power  $P_{ch}$  required by the heating system to maintain the air in the building at a temperature in compliance with the setpoint temperature  $T^*_{int}$  varies as a function of different parameters, for example the weather conditions, the structure of the building (insulation, heat capacity in particular), the habits of the occupants (residential or office building in particular), etc.

Hence, over time, the power required by said heating system features significant variations, which is not without causing problems. In particular, in the case of a heating system connected to a heating network, these variations have direct impacts on the heating network, which might lead to strong consumption peaks. To address these consumption peaks, heating network operators must size the installations so as to be able to supply the required maximum power, which represents heavy investments. In addition, the generators used during peak periods are generally generators operating on fossil fuels, which are more expensive and large emitters of greenhouse gases. Drawbacks of the same kind arise for any heating system for which the energy prices are variable over time, because the price peaks generally occur at the same time as the consumption peaks.

In order to limit these consumption peaks, a new regulation mode has been developed. The latter involves a controlled reduction in the power  $P_{ch}$  supplied to the heating system, said reduction being commonly referred to as load-shedding. In this case, the power actually supplied  $P_{ch}$  is lower than the power  $P_{ch}$  necessary for the heating system to maintain a temperature  $T_{int}$  in the building as close as possible to the setpoint temperature  $T^*_{int}$ . When this regulation mode is applied in a coordinated manner to many buildings, it allows reducing and possibly suppressing consumption peaks. Yet, this translates into a drop in the temperatures  $T_{int}$  inside the buildings during the load-shedding periods.

For example, the patent EP 2021696 (A method for optimising the power usage in a district heating system) describes a method that allows taking advantage of a drop in temperature in order to reduce consumption peaks while guaranteeing consumer comfort, i.e. a moderate drop in the internal temperature  $T_{int}$ . The limitation of the temperature drop is estimated using a time constant depending on the inertia of the building determined a priori, and verified with temperature sensors placed inside the buildings. Other methods have also been developed, but they have in common the need to install temperature sensors inside each building in order to be able to assess their load-

shedding capacity  $K$ , or in other words, what load-shedding it is possible to apply to a building without the internal temperature  $T_{\text{int}}$  of the considered building falling below a minimum temperature  $T_{\text{int}}^{\text{lim}}$ . Mention may be made of the document of Bacher et al. "Identifying suitable models for the heat dynamics of building", Energy and buildings, vol. 43, No. 7.

Hence, there is a need for a method allowing determining the load-shedding capacity  $K$  of a building without it being necessary to proceed with the installation of temperature sensors in the common parts and/or the private parts of said building.

## 10 SUMMARY OF THE INVENTION

The invention offers a solution to the aforementioned problem, by allowing determining the load-shedding capacity of a building from the response of said building to a disturbance of the heating system, this determination requiring no measurements of the internal temperature and therefore the installation of temperature sensors inside said building, whether in the common parts or the private parts.

For this purpose, a first aspect of the invention relates to a method for determining the load-shedding capacity  $K$  of a building according to claim 1.

Besides the features that have just been mentioned in the previous paragraph, the method according to a first aspect of the invention may have one or more complementary features among the following ones, considered individually or according to any technically-feasible combination.

Advantageously, the model determined during the step of determining an initial operation model of the building takes into account the power consumed for the production of domestic hot water.

Thus, the influence of the power consumed for the production of domestic hot water does not distort the load-shedding capacity  $K$  determined by means of the method according to a first aspect of the invention.

Advantageously, the method comprises a step of updating the physical model, the step of disturbing the supply power  $P_{\text{ch}}$  of the heating system, the step of measuring the response of said building to a disturbance, the step of determining the parameters of said initial model and the step of determining the load-shedding capacity  $K$  of the building being implemented again during this update.

Thus, when the building model is updated, the load-shedding capacity  $K$  of said building is recalculated.

A second aspect of the invention relates to a method for load-shedding a building, said building comprising a heating system powered by a power  $P_{ch}$ . The method according to a second aspect of the invention comprises:

- a step of implementing a method for determining the load-shedding capacity  $K$  of said building according to a first aspect of the invention;
- a step of determining the optimal load-shedding setpoints from the determined load-shedding capacity;
- a step of implementing said load-shedding setpoints by the heating system.

Besides the features that have just been mentioned in the previous paragraph, the method according to a second aspect of the invention may have one or more complementary features among the following ones, considered individually or according to any technically-feasible combination.

Advantageously, the method comprises, upon completion of the second step of determining the optimal load-shedding setpoints, a step of verifying the load-shedding setpoints determined during the step of determining the load-shedding setpoints.

Advantageously, the step of verifying the load-shedding setpoints comprises:

- a first sub-step of simulating the response of the building from said setpoints and the model of the building;
- a second sub-step of verifying the compliance of the obtained response of the building;
- when the response is not compliant, a third sub-step of correcting said setpoints.

Thus, it is ensured that the load-shedding setpoints actually meet the desired criteria and in particular that the internal temperature in the building does not fall below a predetermined threshold value.

A third aspect of the invention relates to a heating system powered by a power  $P_{ch}$ . The system further comprises means for implementing a method for determining the load-shedding capacity  $K$  of a building according to a first aspect of the invention or a method for load-shedding a building according to a second aspect of the invention.

A fourth aspect of the invention relates to a computer program product comprising instructions which cause the system according to a third aspect of the invention to

execute the steps of the method according to a first aspect of the invention or a second aspect of the invention.

A fifth aspect of the invention relates to a computer-readable medium, on which the computer program according to a fourth aspect of the invention is recorded.

5 The invention and its different applications will be better understood upon reading the following description and upon examining the appended figures.

#### **BRIEF DESCRIPTION OF THE FIGURES**

The figures are presented for indication purposes and do not limit the invention.

10 - Figure 1 shows a schematic representation of a heating system according to the prior art.

- Figure 2 shows a flowchart of a method for determining the load-shedding capacity  $K$  of a building according to a first embodiment of a first aspect of the invention.

15 - Figure 3 shows a schematic representation of a building whose load-shedding capacity can be determined using a method according to a first aspect of the invention.

- Figure 4 shows a flowchart of a method for determining the load-shedding capacity  $K$  of a building according to a second embodiment of a first aspect of the invention.

20 - Figure 5 shows an evolution of the different parameters of a heating system when no disturbance is applied.

- Figure 6 shows an evolution of the different parameters of a heating system when a slight disturbance is applied.

- Figure 7 shows an evolution of the different parameters of a heating system when a strong disturbance is applied.

25 - Figure 8 shows a flowchart of a method for load-shedding a building according to an embodiment of a second aspect of the invention.

- Figure 9 shows a heating system according to a first embodiment of a third aspect of the invention.

30 - Figure 10 shows a heating system according to a second embodiment of a third aspect of the invention.

- Figure 11 shows a heating system according to a third embodiment of a third aspect of the invention.

**DETAILED DESCRIPTION OF AT LEAST ONE EMBODIMENT OF THE INVENTION**

Unless specified otherwise, the same element appearing in different figures has a unique reference.

A first embodiment illustrated in Figure 2 relates to a method for determining the load-shedding capacity  $K$  of a building according to a first aspect of the invention. An example of a building whose load-shedding capacity  $K$  could be determined by means of a method according to a first aspect of the invention is illustrated in Figure 3. In this example, the building comprises a heating system  $SYC$  including a heating circuit  $CC$ . In general, said heating circuit  $CC$  is crossed by a heat-transfer fluid and covers the entire building 1 in order to enable heating of the latter. The heating system  $SYC$  is powered by a power  $P_{ch}$ . The heating circuit  $CC$  ensures heating of the building 1 through thermal emitters 8, for example radiators, said thermal emitters 8 being themselves crossed by the fluid flowing in the heating circuit  $CC$ . The temperature of the fluid flowing in the heating circuit at the inlet of said circuit is measured using a temperature sensor  $MT$ . The measured temperature  $T_c$  is transmitted to a control means 3 of the heating system  $SYC$  which regulates the power supplied by the heating system  $SYC$  by means of a regulating device 5. In one embodiment, each thermal emitter 8 is further connected to a thermostatic valve  $VTH$  modulating the flow rate of the heat-transfer fluid crossing said emitter as a function of a local internal temperature setpoint.

In order to determine the load-shedding capacity  $K$  of the building, the method comprises a step  $E1$  of determining an initial operation model of the building characterising the equilibrium state of said building and comprising parameters related to the inertia of the building.

In one embodiment, the building is considered as a physical system where an average temperature  $T_{int}$  prevails. For this system, an instantaneous power balance is written:

$$I_{building} \frac{\partial T_{int}}{\partial t} = P_{rad} + P_{ai} - P_{loss} \quad (1)$$

where  $I_{building}$  is the inertia of the building (in Joule per Kelvin),  $P_{rad}$  is the power emitted by the radiators,  $P_{ai}$  is the power by internal input and  $P_{loss}$  is the power lost by the building. In other words, the variation over time of the internal temperature  $T_{int}$  of the building is a function of the power emitted by the radiators  $P_{rad}$ , of the internal power  $P_{ai}$ , i.e. the power provided by the presence of occupants or by the operation of household

appliances, and of the power lost by the building  $P_{\text{loss}}$ . The proportionality coefficient  $I_{\text{building}}$  between these different powers and the variation over time of the internal temperature  $T_{\text{int}}$  is called the inertia of the building.

In general, the power lost by a building  $P_{\text{loss}}$  is related to the difference between the internal temperature  $T_{\text{int}}$  and the external temperature of the building  $T_{\text{ext}}$ . In order to model this power lost by the building, in one embodiment, the following model is adopted:

$$P_{\text{loss}} = UA \cdot (T_{\text{int}} - T_{\text{ext}}) \quad (2)$$

where  $UA$  is the generalised loss coefficient of the building.

In turn, the power by internal input  $P_{\text{ai}}$  (presence of people, operation of household appliances, etc.) could be treated as a Gaussian white noise with a zero average and a low variance compared to the emitted power  $P_{\text{rad}}$  and the lost power  $P_{\text{loss}}$ .

In order to determine the power emitted by the radiators  $P_{\text{rad}}$  of the heating circuit, it is necessary to focus on the physical system formed by the heating circuit. The heating circuit is powered by a heating power  $P_{\text{ch}}$  in order to deliver the power emitted by the radiators  $P_{\text{rad}}$  in the building. More particularly, the power of the radiators  $P_{\text{rad}}$  originates from the circulation of a fluid which at the heating circuit inlet has a temperature  $T_c$ . Like with the internal temperature  $T_{\text{int}}$  of the building, it is possible to relate this temperature  $T_c$  to the aforementioned two powers by means of the following equation:

$$I_c \frac{\partial T_c}{\partial t} = P_{\text{ch}} - P_{\text{rad}} \quad (3)$$

where  $I_c$  is the inertia coefficient of the heating system (circuit and radiators). In this embodiment, the model does not take into account the distribution losses or the pumping power. However, in another embodiment, these two parameters could also be integrated into the model.

In general, the heating power  $P_{\text{ch}}$  is regulated in order to impose a temperature setpoint of the fluid at the inlet of the heating circuit  $T^*_c$ . This regulation could be modelled by the following equation:

$$P_{\text{ch}} = P_{\text{ch-nom}} \frac{T_c - T_c^*}{\delta T} \quad (4) \quad \text{with} \quad \delta T \ll 1$$

where  $P_{\text{ch-nom}}$  is the rated power of the heating system and  $T$  a numerical parameter corresponding to a temperature deviation,  $\delta T$  being for example equal to  $0.1^\circ\text{C}$ . By "rated

power”, it should be understood the characteristic power, related to the sizing of the heating system to enable it to supply the estimated heating power of a building in extreme cold situations (in general, sizing is done for an external temperature of -11 °C in France), In another embodiment, this model may be modified by taking into account a bounding  
 5 between a technical minimum of the heating system and a maximum value which could be obtained from measurements defining the energy state of the heating network and available on the heating network. In one embodiment, the technical minimum is equal to the minimum power to be supplied to avoid a degradation of the installations (for example to avoid an untimely shutdown of a boiler) and the maximum value is equal to  
 10 the maximum power that could be supplied by a heating network, depending on the current temperature of the network at the substation.

Like with the heating power  $P_{ch}$ , it is possible to take into account the regulation of the power emitted by the radiators  $P_{rad}$ . This regulation allows linking the heating power  $P_{ch}$  and the power emitted by the radiators  $P_{rad}$  through the following equation:

$$P_{rad} = P_{ch-nom} \cdot f(T_c) \frac{\delta(T_c - T_c^{min})}{\delta T} \quad (5) \text{ with } \delta T \ll 1$$

where  $g$  is a bounding function whose value varies between 0 and  $\delta T$  so as to guarantee a value of the power emitted by the radiators  $P_{rad}$  comprised between 0 and  $P_{ch-nom}$ , and  $f(T_c)$  is a linear modulation term allowing limiting the power emitted by the radiators  $P_{rad}$  when the temperature of the heating circuit is too low. In general, this  
 20 modulation is in the following form:

$$f(T_c) = \frac{T_c - T_c^{min}}{T_c^{max} - T_c^{min}} \quad (6)$$

where  $T_c^{min}$  is the minimum value for the start temperature of the heating circuit and  $T_c^{max}$  is the maximum value for the start temperature of the heating circuit.

All of the previous considerations are just an illustration through a particular  
 25 example of the step of determining an initial operation model of the building. The equations may vary depending on the considered building and/or assumptions. However, such a modelling falls within the daily practice of a person skilled in the art and is only illustrated herein in order to allow for a better understanding of the different steps of the method according to a first aspect of the invention. The model obtained in the previous  
 30 detailed example could be synthesised in the form of two equations.

$$I_{\text{building}} \frac{\partial T_{\text{int}}}{\partial t} = \frac{P_{\text{ch-nom}}}{\delta T} \cdot f(T_c) \cdot g(T_{\text{int}}^* - T_{\text{int}}) - UA(T_{\text{int}} - T_{\text{ext}}) \quad (7)$$

$$I_c \frac{\partial T_c}{\partial t} = \frac{P_{\text{ch-nom}}}{\delta T} \{ (T_c^* - T_c) - f(T_c) \cdot g(T_{\text{int}}^* - T_{\text{int}}) \} \quad (8)$$

These two equations allow taking up the three main parameters of the problem which are the inertia of the building  $I_{\text{building}}$ , the inertia of the heating circuit  $I_c$  and the generalised loss coefficient of the building  $UA$ .

5 Figure 5 illustrates the evolution of the external temperature  $T_{\text{ext}}$ , of the power of the boiler room  $P_{\text{ch}}$  as well as the variation of the temperature of the fluid at the outlet of the exchanger  $\frac{\partial T_c}{\partial t}$  during a rated operation period. In rated operation, the temperature of the heating circuit  $T_c$  and the internal temperature of the building  $T_{\text{int}}$  vary only very slightly or, in other words,  $\frac{\partial T_{\text{int}}}{\partial t} \ll 1$  and  $\frac{\partial T_c}{\partial t} \ll 1$ . As a result, from the measurements available  
 10 to the heating system, only some parameters of the model could be determined. The day/night cycles appear clearly on the curve representing the external temperature  $T_{\text{ext}}$  over time in the form of oscillations. It is also important to note that the variation in the temperature of the fluid at the outlet of the exchanger  $\frac{\partial T_c}{\partial t}$  remains low. In other words, although the external temperature  $T_{\text{ext}}$  changes, the regulation system causes the heating  
 15 power  $P_{\text{ch}}$  to change so that the temperature of the fluid at the outlet of the exchanger  $T_c$  remains constant and as close as possible to the setpoint temperature  $T_c^*$ .

In order to be able to determine all of the parameters of the model, the method according to a first aspect of the invention also comprises a step E2 of disturbing the supply power  $P_{\text{ch}}$  of the heating system of said building. The response of the building  
 20 to said disturbance is further measured during a step E3 of measuring the response of said building to said disturbance, said measuring step not comprising a measurement of the internal temperature  $T_{\text{int}}$  of the building. In other words, the measurements performed during this step do not include a measurement of the internal temperature  $T_{\text{int}}$  of the building whose load-shedding capacity  $K$  is to be determined. From these measurements,  
 25 the parameters of the model are determined during a step E4 of determining the parameters of the initial operation model of the building from the measurement of the response of said building, said determination being a function of the initial operation model of the building. Finally, the method comprises a step E5 of determining the load-

shedding capacity  $K$  of the building from the parameters of the initial model, said determination being a function of the initial operation model of the building.

In a non-claimed embodiment, the disturbance is inherent to the normal operation of the heating system of the building whose load-shedding capacity is to be determined.

5 In one embodiment, this disturbance is induced by the night setback, the latter for example systematically lowering the temperature between midnight and 5 am.

In an alternative or complementary embodiment illustrated in Figure 4, step E2 of disturbing the supply power  $P_{ch}$  of the heating system of said building comprises:

- a first sub-step E21 of reducing a temperature setpoint  $T^*_c$  over a first period;
- 10 - a second sub-step E22 of reducing the temperature setpoint  $T^*_c$  over a second period.

In addition, the reduction performed during the first reduction sub-step E21 is lower, for example twice lower, than the reduction performed during the second reduction sub-step, step E3 of measuring the response of the building to a disturbance of the supply power  $P_{ch}$  being repeated for each of these sub-steps.

In one embodiment, the first sub-step E21 consists of a slight reduction in the setpoint temperature of the temperature of the heating circuit  $T^*_c$ , and that being so over a first determined time interval. Such a disturbance will result in two periods of variation of the heating power  $P_{ch}$ , the first period corresponding to the adjustment of the temperature of the heating circuit  $T_c$  to reach the new setpoint temperature of the heating circuit  $T^*_c$ , the second period corresponding to the adjustment of the temperature of the heating circuit  $T_c$  to reach the normal operating setpoint at the end of the disturbance. These variations will be measured during a first iteration of step E3 of measuring the response of the building. An example of such a disturbance is illustrated in Figure 6 which represents the evolution of the heating power  $P_{ch}$ , of the variation of the temperature at the inlet of the heating circuit  $\frac{\partial T_c}{\partial t}$  and of the temperature at the inlet of the heating circuit  $T_c$  over time. In this example, the temperature setpoint at the inlet of the heating circuit  $T^*_c$  is lowered by 20°C from 90°C to 70°C and this modification is maintained for six hours.

30 In one embodiment, the second sub-step E22 consists, in turn, of a sharp reduction in the setpoint temperature of the temperature of the heating circuit  $T^*_c$ , and that being so over a second determined time interval. Such a disturbance will result in two periods of variation of the heating power  $P_{ch}$ , the first period corresponding to the adjustment of

the temperature of the heating circuit  $T_c$  to reach the setpoint temperature of the heating circuit  $T_c^*$  but also to a ceiling of the power emitted by the radiators at a constant level, the second period corresponding to the adjustment of the temperature of the heating circuit  $T_c$  to reach the normal operating setpoint at the end of the disturbance. An example of such a disturbance is illustrated in Figure 7 which represents the evolution of the heating power  $P_{ch}$ , of the variation of the temperature at the inlet of the heating circuit  $\frac{\partial T_c}{\partial t}$  and of the temperature at the inlet of the heating circuit  $T_c$  over time. In this example, the temperature setpoint at the inlet of the heating circuit  $T_c^*$  is lowered by 40°C from 90°C to 50°C and this modification is maintained for six hours.

10 In one embodiment, the step E4 of determining the parameters of the initial model is performed based on the measurements carried out during the different iterations of step E3 of measuring the response of said building to said disturbance.

In one embodiment, the step of determining the parameters of the initial model firstly takes into account the response of the building before the disturbance as illustrated in Figure 4, i.e. when the heating system is in the rated operation. From these measurements, the generalised loss coefficient of the building  $UA$  could be determined. Indeed, given the small variation of the temperature of the heating circuit  $T_c$  and of the internal temperature of the building  $T_{int}$ , the power supplied to the heating system may be written in the following form (using the equations (1), (2) and (3)):

$$P_{ch} = -UA(T_{int} - T_{ext}) \quad (9)$$

20 Knowing also that the internal temperature  $T_{int}$  is equal to the setpoint temperature  $T_{int}^*$  which could in turn be assumed to be equal to 20°C (the heating system being in the rated mode), it is possible to determine the generalised loss coefficient of the building  $UA$  which, in this embodiment, amounts to 26,000 W/K (Watt per Kelvin). As explained before, the measurement of the internal temperature  $T_{int}$  is not necessary, only the knowledge of the internal temperature setpoint  $T_{int}^*$  being required.

In one embodiment, the external temperature  $T_{ext}$  is extracted from weather forecasts. In this case, the heating system includes means for interrogating, for example via the Internet, a database comprising meteorological data relating to the geographical area corresponding to the building. In an alternative or complementary embodiment, the external temperature is obtained by one or more temperature sensors proximate to the

building. In this case, the heating system includes means for interrogating, for example via a wireless connection, said temperature sensor(s).

In one embodiment, the step of determining the parameters of the initial model also takes into account the response of the building to the disturbance induced during the first sub-step E21 of reducing a temperature setpoint  $T^*_c$  over a first period. Moreover, it should be noted that during this disturbance, the internal temperature  $T_{int}$  remains equal to the setpoint internal temperature  $T^*_{int}$  and therefore that  $\frac{\partial T_{int}}{\partial t} \cong 0$ , once the temperature  $T_c$  has stabilised, the power  $P_{ch}$  continuing to vary by following the external temperature variations  $T_{ext}$  and not reaching the limits of the heating system. This assumption allows considering, by combining equation (1) and equation (2), that the power emitted by the radiators  $P_{rad}$  is given by  $P_{rad} = UA \cdot (T^*_{int} - T_{ext})$ . From this equation, it is possible to reformulate equation (3) as follows.

$$I_c \frac{\partial T_c}{\partial t} = P_{ch} - UA \cdot (T^*_{int} - T_{ext})$$

Afterwards, the inertia of the heating system  $I_c$  is determined, for example by integrating the previous equation (obtained from equation (8) and while taking into account the previously-described assumption) over the periods during which the temperature  $T_c$  varies. In the example illustrated in Figure 6 and by integrating the previous equation over the periods during which the temperature  $T_c$  varies, for example between 30h and 31h, an energy of  $1.66e^8$  Joules is obtained, and the value of the inertia of the heating system  $I_c$  could therefore be estimated as being equal to  $8.36e^6$  J/K (Joules per Kelvin). Once again, measurement of the internal temperature  $T_{int}$  is not necessary, only the knowledge of the internal temperature setpoint  $T^*_{int}$  is required.

In one embodiment, the step of determining the parameters of the initial model also takes into account the response of the building to the disturbance induced during the second sub-step E22 of reducing a temperature setpoint  $T^*_c$  over a second period. During this disturbance, the internal temperature  $T_{int}$  drops until it reaches a threshold temperature at which the maximum power emitted by the radiators enables it to be maintained. More particularly, this threshold temperature could be derived from equation (7) while taking into account the fact that, in this embodiment,  $\frac{g(T^*_{int} - T_{int})}{\delta T} = 1$  and that  $\frac{\partial T_{int}}{\partial T} \cong 0$  so as to obtain the following relationship.

$$T_{int}^{TH} = T_{ext} - \frac{f(T_c)P_{ch-nom}}{UA}$$

Hence, it is considered that the threshold temperature  $T_{int}^{TH}$  is reached during the disturbance. In other words, the duration and the amplitude of the disturbance should be enough for said threshold temperature  $T_{int}^{TH}$  to be reached. This condition being met, the inertia of the building  $I_{building}$  is determined by integrating the energy variation, in other words by integrating the heating power  $P_{ch}$  over the second period of variation of this same power and while considering that the energy thus obtained is the energy needed to restore the internal temperature  $T_{int}$  of the building so that  $T_{int} = T_{int}^*$ . This energy is by definition equal to  $I_{building}(T_{int}^* - T_{int}^{TH})$ . For this purpose, the value of the internal temperature is firstly determined, i.e. the value of the threshold internal temperature  $T_{int}^{TH}$ . As this variable depends on the external temperature  $T_{ext}$ , it is preferable to determine the threshold temperature value when the external temperature  $T_{ext}$  varies little, for example at daybreak. In the embodiment illustrated in Figure 7, it is considered that the threshold temperature  $T_{int}^{TH}$  is reached before 30h and the power  $P_{ch}$  is integrated over the variation period comprised between 30h and 31h. The energy difference obtained by integration is equal to  $7.46e^8$  Joules, which corresponds to an inertia of the building  $I_{building}$  equal to  $1.254e^8$  J/K (Joules per Kelvin). Like before, the measurement of the internal temperature  $T_{int}$  is not necessary.

Upon completion of this step E4 of determining the parameters of the model, all of the parameters of the model have been obtained, and that being so, from the measurement of the response of the building to a disturbance induced by the heating system including no measurement of the internal temperature  $T_{int}$ .

The method also comprises a step E5 of determining the load-shedding capacity of the building from the previously-determined parameters of the model as well as from the initial model. In one embodiment, this load-shedding capacity can be expressed using the following expression.

$$K = I_{building} (T_{int} - T_{int}^{lim})$$

Where  $T_{int}^{lim}$  is the low temperature limit that one wishes to have during load-shedding. In the previous embodiment and when setting  $T_{int}^{lim}$  equal to  $18^\circ\text{C}$ , a load-shedding capacity of  $1.881e^8$  Joules, or 52.25 kWh, is obtained. In one embodiment, the

considered internal temperature  $T_{int}$  is a usual setpoint temperature, typically 20°C. In a non-claimed alternative embodiment, the internal temperature  $T_{int}$  is calculated using the model whose parameters have been determined during this step E4 of determining the parameters of the model, which allows in particular taking the load-shedding actions already performed into account.

Thus, upon completion of the method according to a first aspect of the invention and by measuring the response of a building to a disturbance, the load-shedding capacity of the building is determined.

In one embodiment, the model takes into account the power consumed for the production of domestic hot water. This consumed power is introduced into the model mentioned before by means of the power of the inner inputs  $P_{ai}$ , the latter then being able to be formulated as follows.

$$P_{ai} = \beta \cdot \overline{P_{SST-ECS}}$$

where  $\overline{P_{SST-ECS}}$  is the average power profile required for the production of hot water and  $\beta$  is a proportionality coefficient depending on the used hot water production system.

In one embodiment, the model takes into account the presence of at least one heating slab. This aspect is integrated into the model by modifying the expression of the linear modulation coefficient in the power emitted by the radiators as follows.

$$f(T_e) = \frac{T_c(t - \tau_{slab}) - T_c^{min}}{T_c^{max} - T_c^{min}}$$

where  $\tau_{slab}$  is a delay time associated with the slab. Thus, it is possible to take into account the presence of a heating slab in the determination of the load-shedding capacity  $K$  of a building.

In one embodiment, the method according to a first aspect of the invention comprises a step of updating the physical model, the step E2 of disturbing the supply power  $P_{ch}$  of the heating system, the step E3 of measuring the response of said building to a disturbance, the step E4 of determining the parameters of the initial model and the step E5 of determining the load-shedding capacity  $K$  of the building being implemented again during this update. Thus, a modification of the model results in a new calculation of the load-shedding capacity of the building.

Once the load-shedding capacity  $K$  of a building has been determined, it becomes possible to proceed with the load-shedding of said building in an optimised manner. For this purpose, a second aspect of the invention illustrated in Figure 8 relates to a method for load-shedding a building, said building comprising a heating system supplied by a power  $P_{ch}$ .

The method comprises a step F1 of implementing a method for determining the load-shedding capacity  $K$  of said building according to a first aspect of the invention. As we have just detailed, upon completion of this step, the load-shedding capacity  $K$  of the building is known.

The method also comprises a step F2 of determining the optimal load-shedding setpoints from the determined load-shedding capacity. For example, setpoints may be determined in order to minimise greenhouse gas emissions. Knowing that the production of energy associated with a high level of greenhouse gas emissions corresponds to the production having a higher financial cost, the optimisation is then done according to the cost associated with energy. Thus, the load-shedding setpoints are calculated so as to maximise the energy shed over the periods during which the price associated with the energy is maximum. For example, this optimisation may consist in maximising the following function.

$$\Delta = \int_0^{T_d} P(t)C(t)dt$$

where  $P(t)$  is the power shed at a time  $t$ ,  $C(t)$  is the cost of the energy at a time  $t$  and  $T_d$  is the load-shedding duration. This optimisation should be performed while ensuring that the power shed over the shedding period does not exceed the load-shedding capacities, in other words that the following relationship is met.

$$K \geq \int_0^{T_d} P(t)dt$$

Finally, the method comprises a step F3 of implementing said load-shedding setpoints by the heating system. Thus, the load-shedding of the building is performed in an optimal way, for example by minimising the carbon impact of the latter. Of course, the optimisation may be performed according to other criteria. For example, in one embodiment, each occupant of the building could indicate the desired minimum internal

temperature during load-shedding. This indication may be fixed or vary according to the time of the day and/or the day of the week. Thus, load-shedding could be carried out while meeting the comfort of each occupant.

In one embodiment, the method comprises, upon completion of step F2 of determining the optimal load-shedding setpoints, a step of verifying the load-shedding setpoints determined during step F2 of determining the load-shedding setpoints.

In one embodiment, this step of verifying the load-shedding setpoints comprises a first sub-step of simulating the response of the building from said setpoints and from the model of the building. During this first sub-step, a simulation is performed on the basis of the model determined beforehand during step E1 of determining the initial operation model of the building.

The step of verifying the load-shedding setpoints also comprises a second sub-step of verifying the compliance of the obtained response. In particular, this second sub-step allows verifying that the temperatures estimated inside the building using the simulation comply with the imposed temperature limits  $T_{int}^{lim}$ . It further allows ensuring that the assumptions retained at the time of the calculation are still valid.

Finally, the step of verifying the load-shedding setpoints comprises, when the response is not compliant, a third sub-step of correcting said setpoints. For example, this correction may be performed so as to limit the power supplied to the heating system of the building and results in the definition of a new temperature setpoint temperature  $T_c^*$  so that the supplied power complies with the corrected setpoints.

In order to implement a method according to a first aspect or a second aspect of the invention, a third aspect of the invention illustrated in Figure 9 relates to a heating system SYC including a heating circuit CC, said system SYC being supplied by a power  $P_{ch}$ . The system further comprises means for implementing a method for determining the load-shedding capacity K of a building 1 according to a first aspect of the invention or a method for load-shedding a building 1 according to a second aspect of the invention.

In one embodiment, the heating system SYC comprises a temperature sensor MT measuring the temperature  $T_c$  of the fluid at the inlet of the heating circuit CC. The heating circuit CC further receives from a heating device CH (for example a boiler) a power  $P_{ch}$  which could be regulated. In order to regulate heating within the building, the heating system SYC also comprises a control means CMD including calculation means, storage means and communication means so as to be able to communicate with the heating

device CH and the temperature sensor MT. The control means CMD is further configured to measure the power  $P_{ch}$  received by the heating circuit as well as the input temperature  $T_c$  of said heating circuit CC. The control means is also configured to determine an initial operation model of the building characterising the equilibrium state of said building. For example, this determination may be obtained by an input means enabling an operator to input, into the memory of the control means CMD, the parameters of the model. Alternatively or complementarily, the control means CMD is configured to connect to a network, for example the Internet, and receive the parameters of the model from a remote computer.

In addition, the control means CMD is also configured to disturb the supply power  $P_{ch}$  of the heating system of said building and, when the building undergoes a disturbance in the supply power  $P_{ch}$  of the heating system, to measure the response of said building. This measurement may be made by measuring the heating power  $P_{ch}$  supplied to the heating circuit and the input temperature  $T_c$  of the heating circuit during said disturbance.

The control means CMD is also configured to determine the parameters of the initial operation model of the building from the measurement of the response of said building, said determination being a function of the initial operation model of the building and to determine the load-shedding capacity  $K$  of the building from the measurement of the response of said building, said determination being a function of the initial operation model of the building.

In an embodiment illustrated in Figure 10, the heating system SYC is connected to a heating network via a primary circuit CP and receives from said heating network a power  $P_{ch}$  that could be modulated using a valve V. In order to measure the power  $P_{ch}$  supplied by the heating network, the heating system SYC also comprises an energy meter CMPT.

In addition, the control means CMD comprises a controller CTRL, a first regulator PID1 and a second regulator PID2. The controller CTRL includes calculation means, storage means and communication means so as to be able to communicate with the energy meter CMPT, with the temperature sensor MT and the valve V of the primary circuit as well as with the first regulator PID1 and the second regulator PID2. More particularly, the energy meter CMPT supplies the controller CTRL and the second regulator PID2 with the power  $P_{ch}$  supplied by the heating network RC to the heating circuit CC. The controller CTRL deduces from this supplied power  $P_{ch}$  a setpoint power  $P^*_{ch}$  and communicates the latter to the second regulator PID2 which determines, from this power setpoint  $P^*_{ch}$ , a

temperature setpoint  $T^*_c$  of the fluid at the outlet of the exchanger of the heating circuit. This setpoint is sent by the second regulator PID2 to the first regulator PID1 which, according to this setpoint, controls the valve V, thus controlling the heating power  $P_{ch}$  supplied by the heating network to the heating circuit CC.

5 In addition, the controller CTRL in collaboration with the first regulator PID1 and the second regulator PID2 is configured to implement a method for determining the load-shedding capacity according to a first aspect of the invention. Hence, the heating system SYC thus obtained includes the means for implementing a method for determining the load-shedding capacity of a building according to a first aspect of the invention.

10 In one embodiment, in order to implement the disturbance step E2 of the method according to a first aspect of the invention, the controller CTRL, in collaboration with the first regulator PID1 and the second regulator PID2, is configured to reduce a first time the temperature setpoint  $T^*_c$  over a first period of time and reduce a second time the temperature setpoint  $T^*_c$  over a second period while ensuring that the reduction  
15 performed during the first period is less than the reduction performed during the second period. In addition, the controller CTRL, in collaboration with the first regulator PID1 and the second regulator PID2, is configured to measure the response of the building to a disturbance of the power  $P_{ch}$  over each of these periods. As explained before, this measurement may be made in particular using the power meter CMTP and the  
20 temperature sensor MT'

In one embodiment, the controller CTRL of the heating system is also configured to determine optimal load-shedding setpoints from the previously-determined load-shedding capacity and to implement said load-shedding setpoints. In particular, the determination of the optimal load-shedding setpoints may be performed by the  
25 calculation means of the controller CTRL.

Of course, this is just an exemplary embodiment of a heating system including the means for implementing a method for determining the load-shedding capacity of a building according to a first aspect of the invention or a load-shedding method according to a second aspect of the invention. Indeed, it is possible to consider other configurations  
30 for the heating system.

In an embodiment illustrated in Figure 11, the heating system also comprises an exchanger ECH allowing exchanging heat between the primary circuit CP and the heating circuit CC. The heating system further comprises a means for measuring the flow rate MD,

measuring the flow rate circulating in the primary circuit CP. In addition, the system also comprises a first means for measuring the input temperature MT1 of the primary circuit CP and a second means for measuring the output temperature MT2 of the primary circuit CP. Furthermore, the first input temperature measuring means MT1, the second output  
5 temperature measuring means MT2 and the flow rate measuring means MD are connected to the meter CMPT. Thus, the meter CMPT can determine the power  $P_{ch}$  supplied by the heating network to the heating circuit CC.

## Patentkrav

1. Fremgangsmåde til bestemmelse af en bygnings aflastningskapacitet  $K$ , hvilken bygning omfatter et varmesystem, der forsynes af en effekt  $P_{ch}$  og omfatter et varmekredsløb, idet varmesystemet er udformet til at modulere den energi, der

5 overføres til bygningens indre som funktion af en tilsigtet indre temperatur

$$T_{int}^*$$

idet aflastningskapaciteten  $K$  er reduktionen af forsyningseffekten  $P_{ch}$  i et bestemt tidsrum, som det er muligt at anvende på en bygning, uden at den pågældende bygnings indre temperatur  $T_{int}$  falder under en fastsat minimumstemperatur

10  $T_{int}^{lim}$ , idet fremgangsmåden omfatter et trin (E1) til bestemmelse af en oprindelig driftsmodel for bygningen, som karakteriserer bygningens ligevægtstilstand, og som tager hensyn til bygningens inertti  $I_{bat}$ ; idet fremgangsmåden er **kendetegnet ved, at** den omfatter:

- et trin (E2) til forstyrrelse af varmesystemets forsyningseffekt  $P_{ch}$  i

15 bygningen, idet forstyrrelsen fremkaldes ved en ændring af den tilsigtede temperatur

$$T_c^*$$

i varmekredsløbet, der omfatter:

• et første deltrin (E21) til nedsættelse af den tilsigtede temperatur

20  $T_c^*$

i et første tidsrum;

• et andet deltrin (E22) til nedsættelse af den tilsigtede temperatur

$$T_c^*$$

25 i et andet tidsrum, i hvilket den indre temperatur  $T_{int}$  når en temperaturtærskel

$$T_{int}^{seuil}$$

givet ved:

$$T_{int}^{seuil} = T_{ext} - \frac{f(T_c)P_{ch-nom}}{UA}$$

30 hvor  $T_{ext}$  er den ydre temperatur,  $P_{ch-nom}$  er varmesystemets nominelle effekt,  $f(T_c)$  er givet ved følgende ligning:

$$f(T_c) = \frac{T_c - T_c^{\min}}{T_c^{\max} - T_c^{\min}} \quad (6)$$

hvor  $T_c$  er varmekredsløbets temperatur,

$T_c^{\min}$

er minimalværdien for varmekredsløbets udgangstemperatur, og

$T_c^{\max}$

5

er maksimalværdien for varmekredsløbets udgangstemperatur, og  $UA$  er bygningens generaliserede tabskoefficient bestemt ved hjælp af følgende ligning:

$$P_{ch} = -UA(T_{int} - T_{ext})$$

10

idet det tages i betragtning, at den indre temperatur  $T_{int}$  er lig med den tilsigtede indre temperatur

$T_{int}^*$

under varmesystemets nominelle drift, ved hvilken varmeeffekten  $P_{ch}$

udvikler sig således, at varmekredsløbets temperatur  $T_c$  er konstant og i det

15

væsentlige lig med varmesystemets tilsigtede temperatur

$T_c^*$

medens den ydre temperatur  $T_{ext}$  ændres;

den reduktion, der udføres under det første reduktionsdeltrin (E21) er

mindre end den reduktion, der udføres under det andet reduktionsdeltrin

20

(E22);

- for hvert af reduktionsdeltrinnene (E21, E22) i forstyrrelsestrinnet (E2), et

trin (E3) til måling af bygningens reaktion på forstyrrelsen omfattende

måling af varmesystemets forsyningseffekt  $P_{ch}$  under forstyrrelsen;

- et trin (E4) til bestemmelse af parametrene for den oprindelige driftsmodel

25

for bygningen ud fra målingen af bygningens reaktion, idet bestemmelsen

er en funktion af den oprindelige driftsmodel for bygningen og omfatter

bestemmelse af bygningens termiske inertie  $I_{bat}$  ved integrering af

varmeeffekten  $P_{ch}$  under det andet reduktionsdeltrin (E22) taget i

betragtning, at den således beregnede energi er lig med

30

$$I_{bat}(T_{int}^* - T_{int}^{seuil}),$$

- et trin (E5) til bestemmelse af aflastningskapaciteten  $K$  for bygningen ved hjælp af ligningen

$$K = I_{\text{bat}}(T_{\text{int}} - T_{\text{int}}^{\text{lim}})$$

idet det antages, at den indre temperatur  $T_{\text{int}}$  er lig med den forudbestemte tilsigtede temperatur

5

$$T_{\text{int}}^*$$

**2.** Fremgangsmåde ifølge det foregående krav, **kendetegnet ved, at** den under trinnet til bestemmelse af en oprindelig driftsmodel for bygningen bestemte model tager hensyn til den fremstilling af varmt brugsvand forbrugte effekt.

10

**3.** Fremgangsmåde ifølge et af de foregående krav, **kendetegnet ved, at** omfatter et trin til ajourføring af den fysiske model, idet trinnet (E2) til forstyrrelse af varmesystemets forsyningseffekt  $P_{\text{ch}}$ , trinnet (E3) til måling af bygningens reaktion på forstyrrelsen, trinnet (E4) til bestemmelse af parametre for den oprindelige model og trinnet (E5) til bestemmelse af aflastningskapaciteten  $K$  for bygningen udføres påny under denne ajourføring.

15

**4.** Fremgangsmåde ifølge et af de foregående krav, **kendetegnet ved, at** bygningens generaliserede tabskoefficient bestemmes, idet det tages i betragtning, at den indre temperatur  $T_{\text{int}}$  er lig med den tilsigtede temperatur

20

$$T_{\text{int}}^*$$

under varmesystemets nominelle drift, ved hvilken varmekredsløbets temperatur  $T_c$  er konstant og i det væsentlige lig med varmesystemets tilsigtede temperatur

25

$$T_c^*$$

**5.** Fremgangsmåde til aflastning en bygning, hvilken bygning omfatter et varmesystem, der forsynes af en effekt  $P_{\text{ch}}$ , hvilken fremgangsmåde er **kendetegnet ved, at** omfatter:

30

- et trin (F1) til udførelse af en fremgangsmåde til bestemmelse af bygningens aflastningskapacitet  $K$  ifølge et af de foregående krav;

- et trin (F2) til bestemmelse den optimale tilsigtede aflastning ud fra den ovenfor bestemte aflastningskapacitet;
- et trin (F3) til varmesystemets udførelse af de tilsigtede aflastninger.

- 5 **6.** Fremgangsmåde ifølge det foregående krav, **kendetegnet ved, at** fremgangsmåden i tilslutning til det andet trin til bestemmelse af den optimale tilsigtede aflastning omfatter et trin til kontrol af den under trinnet (F2) til bestemmelse af den tilsigtede aflastning bestemte tilsigtede aflastning.
- 10 **7.** Fremgangsmåde ifølge det foregående krav, **kendetegnet ved, at** trinnet til kontrol af den tilsigtede aflastning omfatter:
- et første deltrin til simulation af bygningens reaktion ud fra de tilsigtede værdier og modellen for bygningen;
  - et andet deltrin til kontrol af ensartetheden i den opnåede reaktion fra
- 15 bygningen;
- når reaktionen ikke er ensartet, et tredje deltrin til korrektion af de tilsigtede værdier.
- 8.** Varmesystem (SYC), der forsynes af en effekt  $P_{ch}$ , **kendetegnet ved, at** det
- 20 omfatter midler, der er udformede til at udføre en fremgangsmåde til bestemmelse af en bygnings aflastningskapacitet  $K$  ifølge et af kravene 1 til 4 eller en fremgangsmåde til aflastning af en bygning ifølge et af kravene 5 til 7.
- 9.** Computerprogram omfattende instruktioner, som bringer systemet ifølge det
- 25 foregående krav til at udføre trinnene i fremgangsmåden ifølge et af kravene 1 til 7.
- 10.** Computerlæsbart medium, på hvilket computerprogrammet ifølge det foregående krav er lagret.

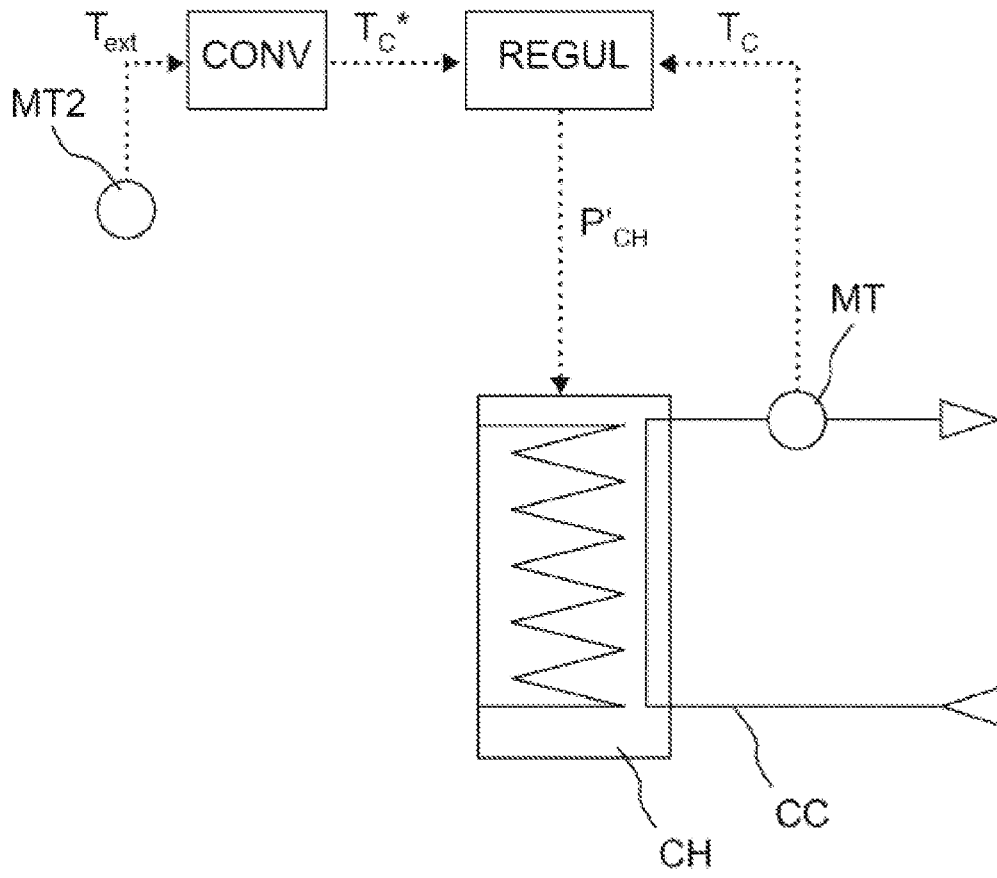


Fig. 1

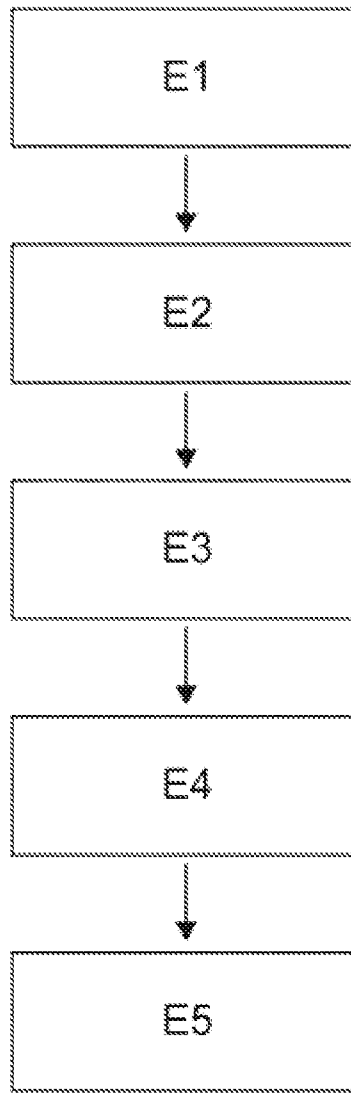


Fig. 2

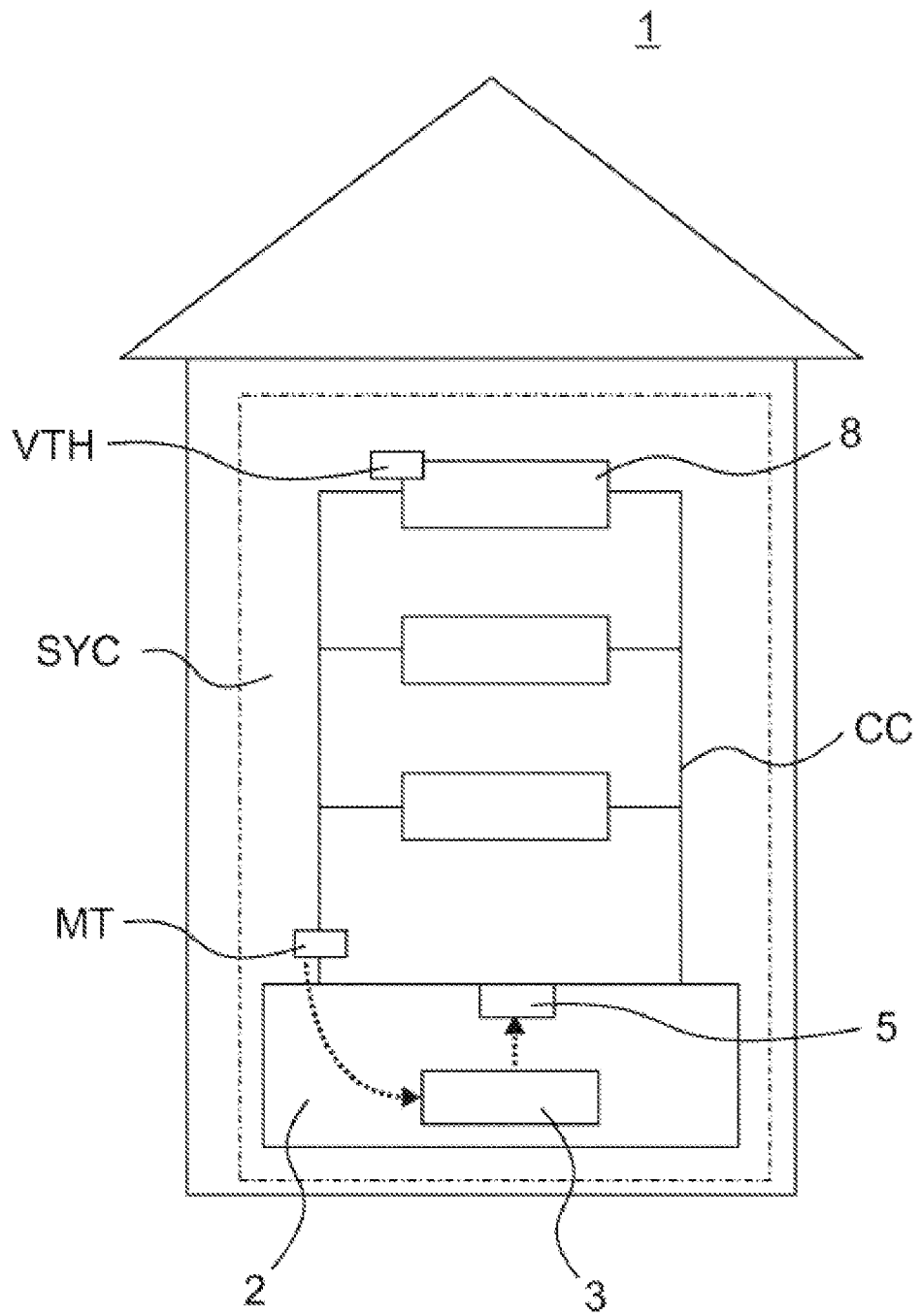


Fig. 3

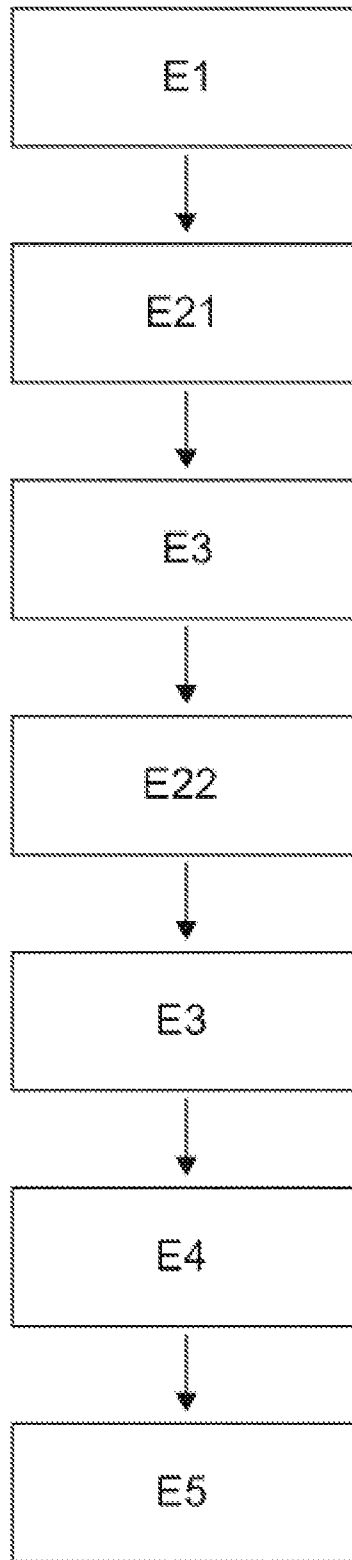


Fig. 4

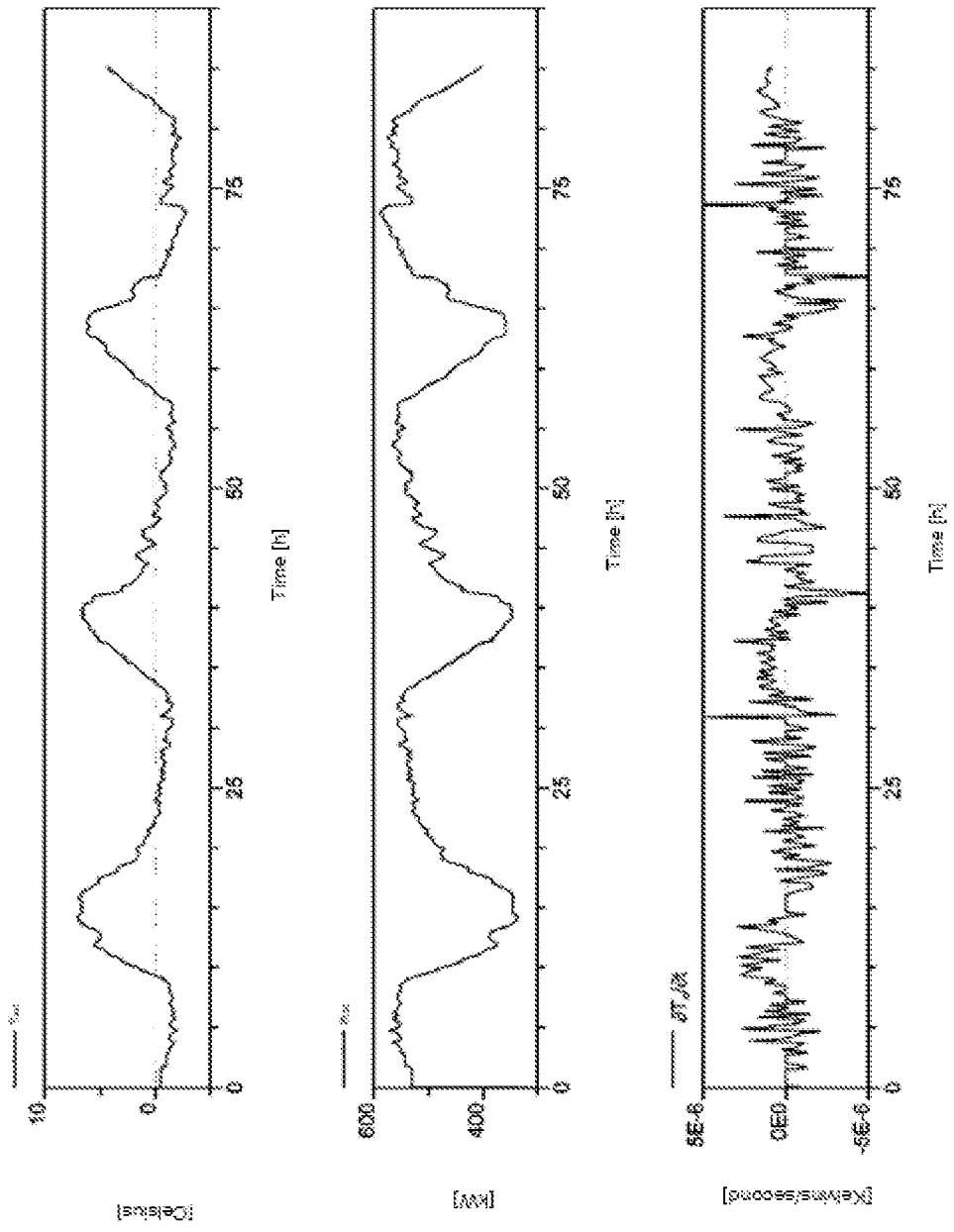


Fig.5

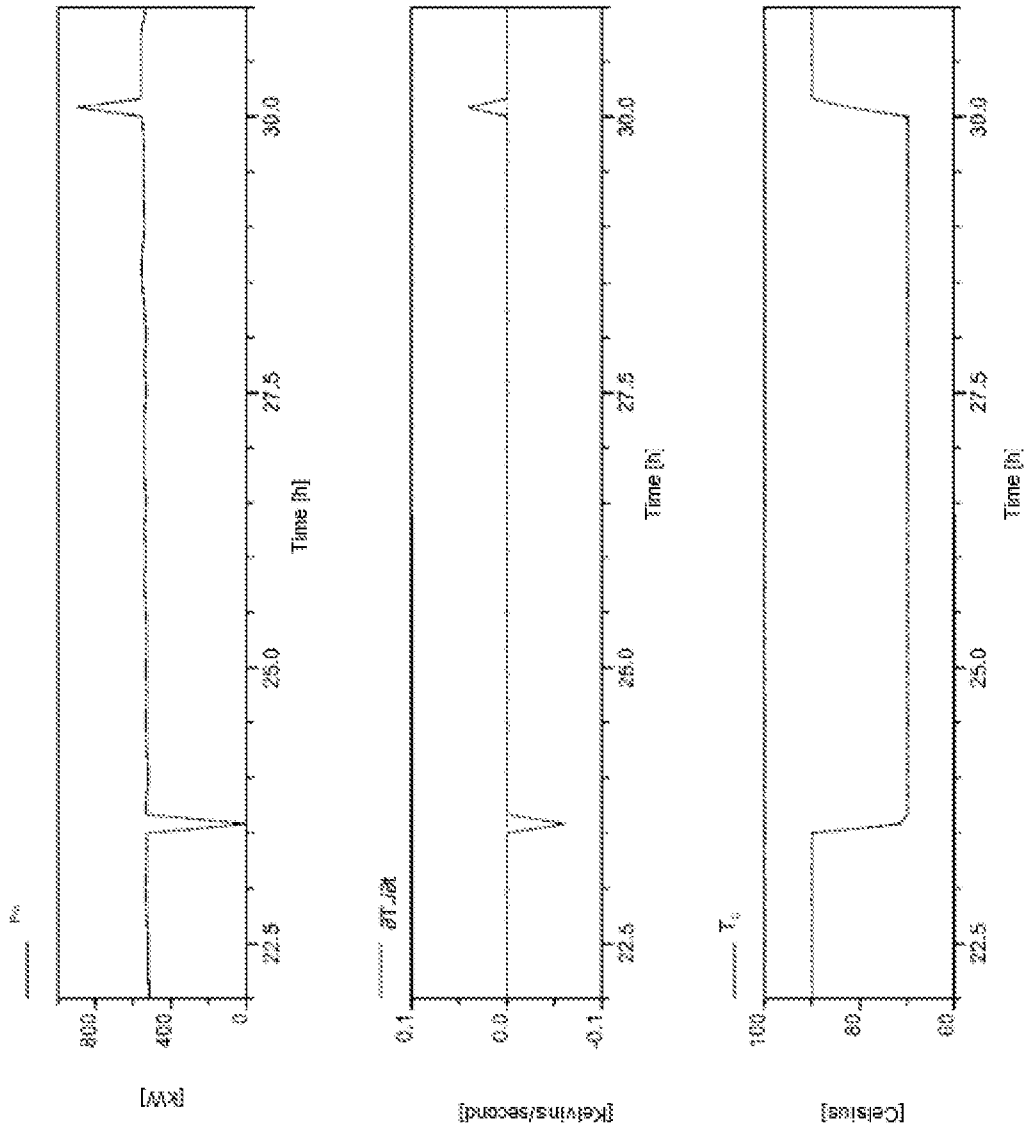


Fig.6

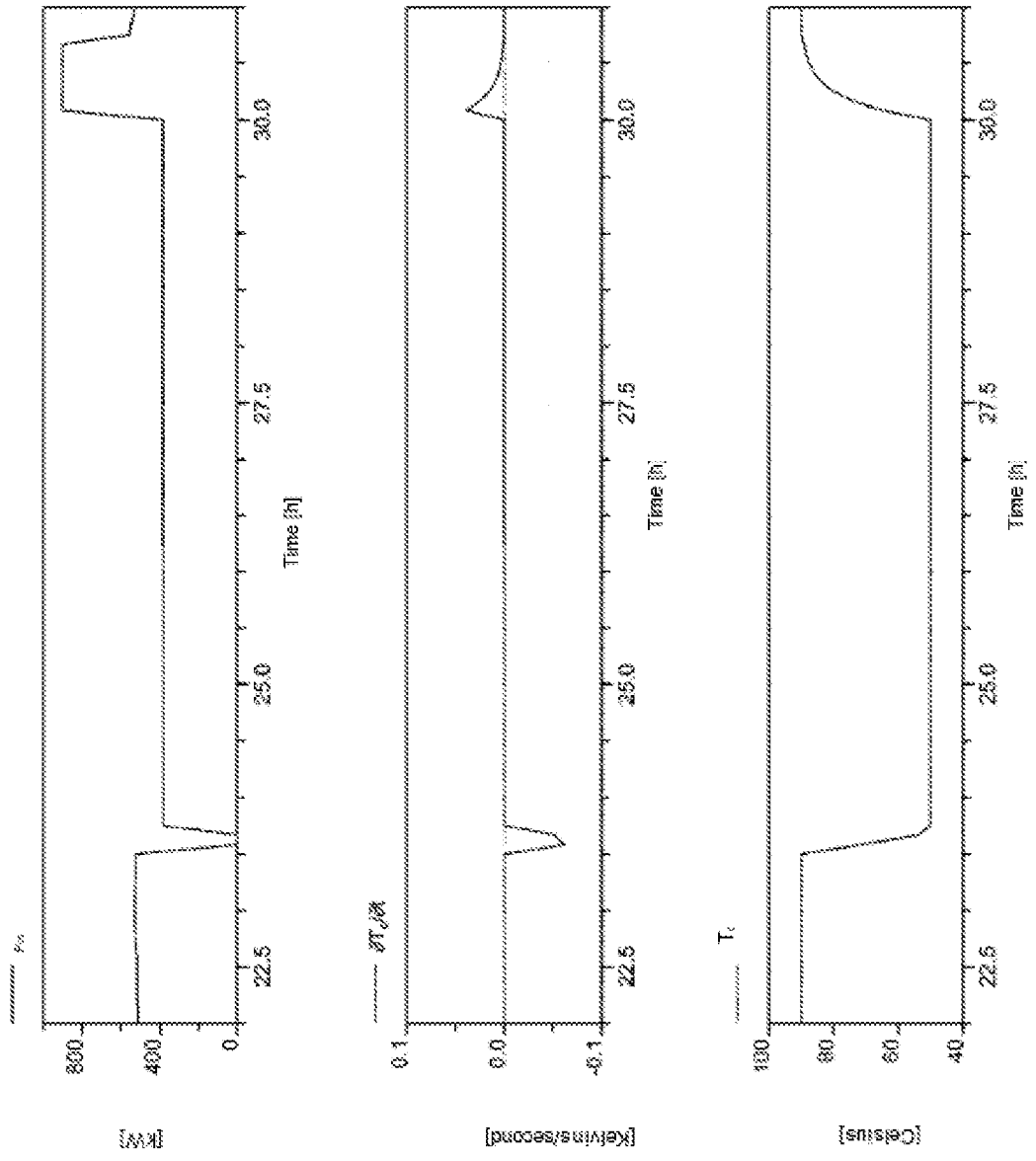


Fig. 7

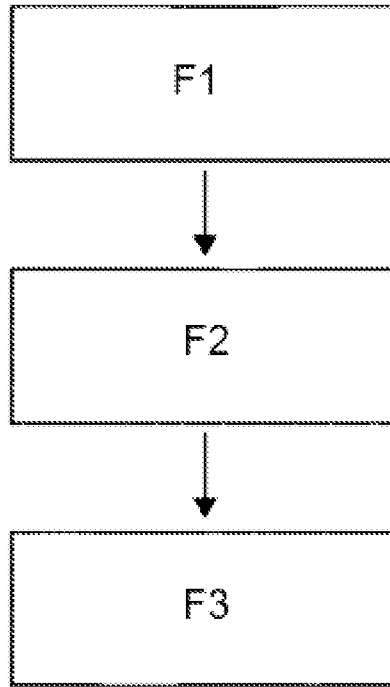


Fig.8

SYC

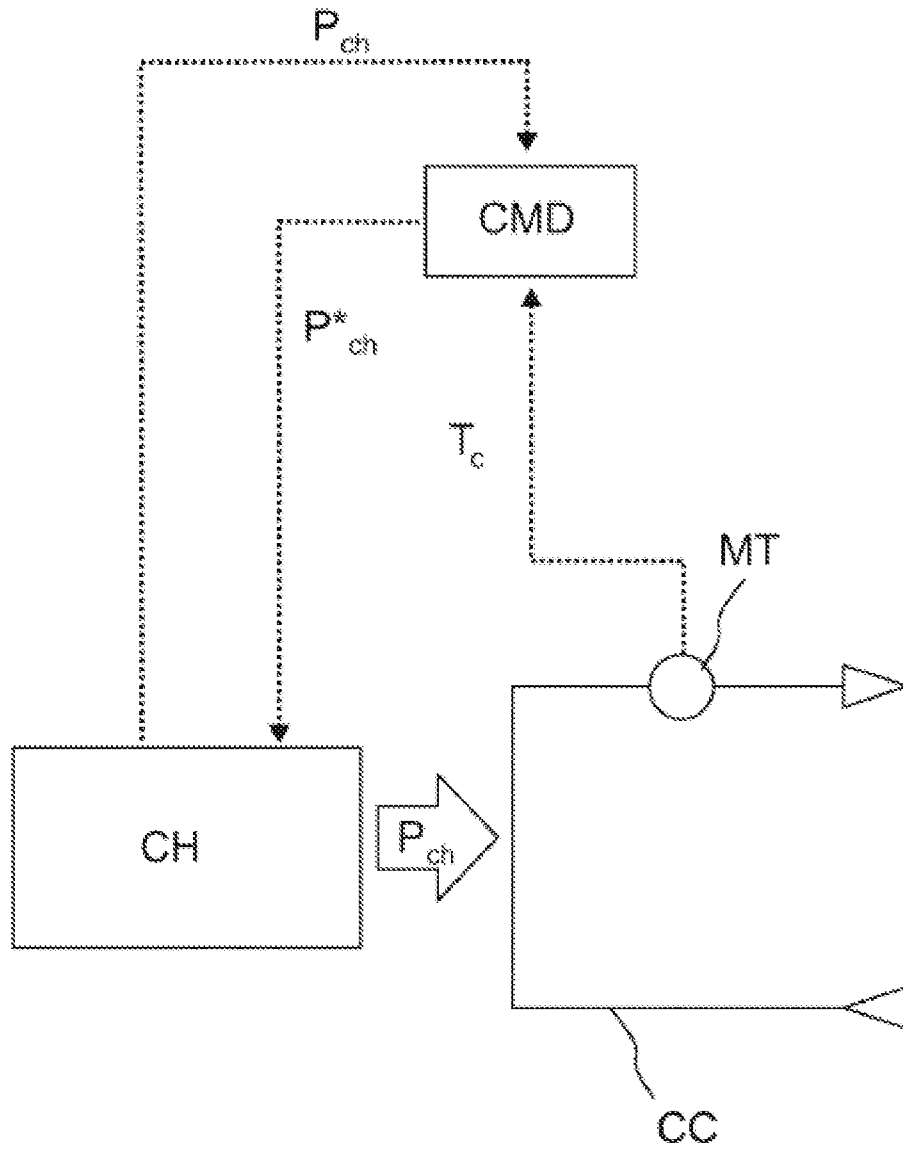


Fig. 9

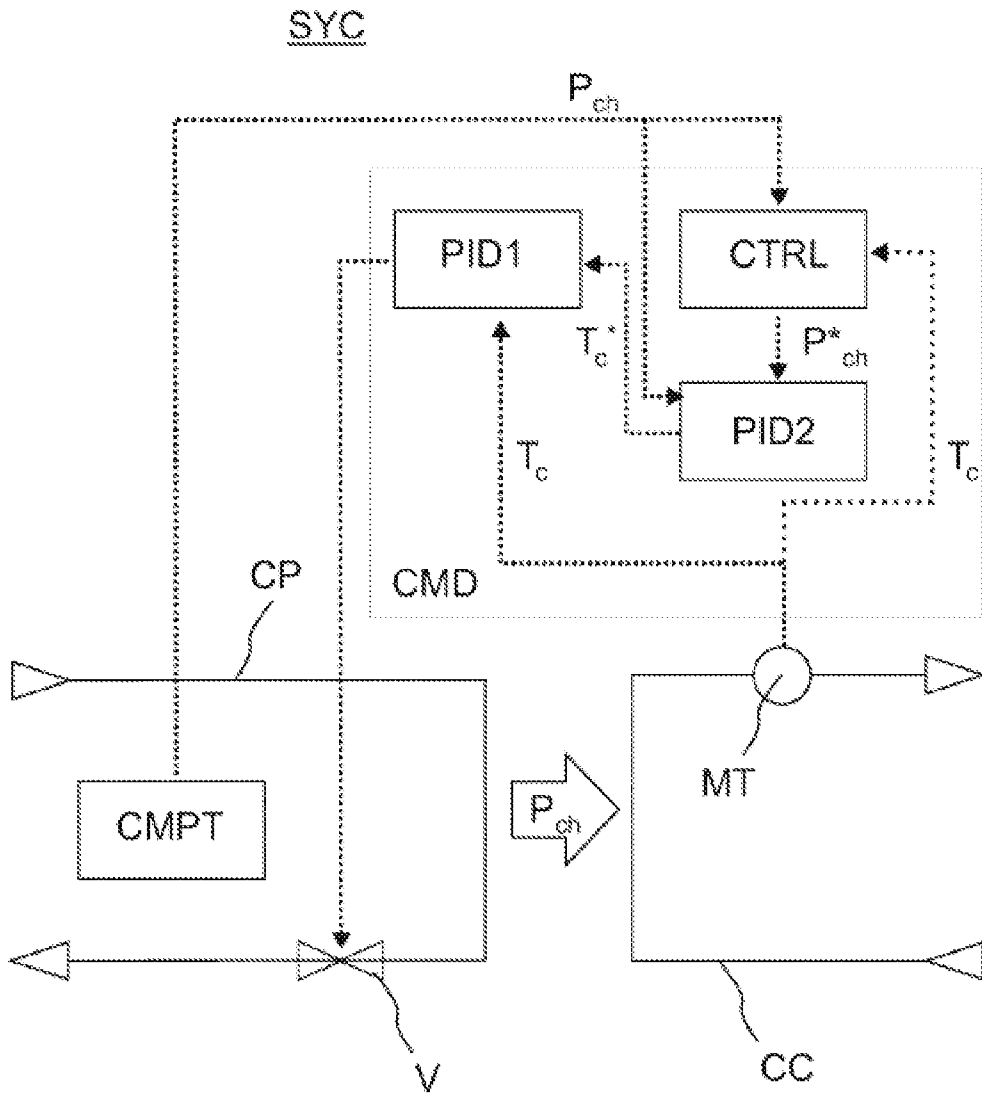


Fig. 10

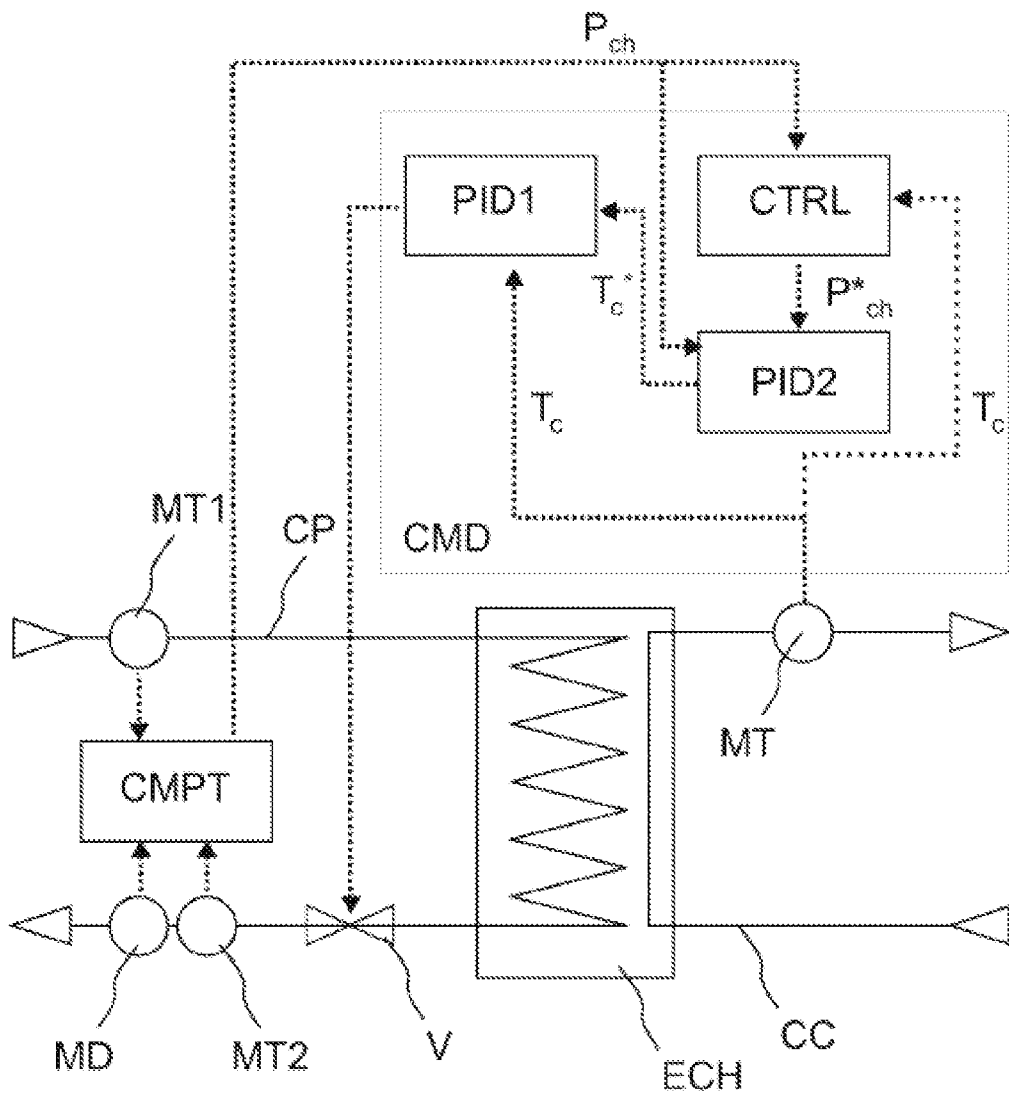


Fig. 11