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(54) Title: METHOD AND SYSTEM FOR EFFICIENT REAL TIME THERMAL MANAGEMENT OF A DATA CENTER

(57) Abstract:

METHOD AND SYSTEM FOR EFFICIENT REAL TIME THERMAL MANAGEMENT OF A DATA CENTER

FIELD OF THE INVENTION

The present invention relates to thermal management of data centers. Particularly the invention provides a method and system for efficient real time thermal management of a data center using a fast thermal model and an optimizer.

The present application is an improvement of the application described and claimed in an earlier Indian Patent Application no. **465/MUM/2012**.

BACKGROUND OF THE INVENTION

A data center usually contains a variety of electronic equipment such as servers, telecom equipment, networking equipment, switches and other electronic equipment. The heat generated by such electronic components is cooled with the help of cooling units. Typically, the cooling units are computer room air conditioners (CRAC) or computer room air handlers (CRAH) which supply cold air for cooling. With the drastic increase in energy cost, the huge energy consumption by the data center is one of the major concerns of the data center managers. Power consumed by cooling equipment contributes to a major portion of the total data center power consumption. Apart from poor design of cooling infrastructure, inefficient operation of cooling units is one of the major factors causing poor cooling efficiency of the data center. Cooling capacity of the data center is designed and typically run for maximum heat load conditions. In practice, data centers rarely operated at maximum conditions. Typically, cooling units are controlled according to heat loads in a very elementary manner e.g. return air temperature control. All these practices lead to poor cooling efficiency.

Reliability of computing equipment by ensuring proper thermal management is another concern for data center managers in addition to poor cooling efficiency. Prolonged exposure of such equipment to conditions beyond their recommended and allowable range of environmental conditions, especially approaching the extremes of the allowable operating environment like temperature, may result in decreased equipment reliability and longevity. Exposure of operating equipment to conditions outside its allowable operating environment risks catastrophic equipment failure. Various reasons like hot air recirculation, CRAC failure etc may lead to higher temperatures i.e. hot spots. Due to lack of distributed sensing and continuous monitoring of environmental parameters in the data center, these thermal problems go unobserved leading to thermal failures. This issue is typically circumvented by data center managers by over provisioning of cooling capacity, which in turn, reduces cooling efficiency.

Hence, a data center manager faces dual challenge: is to ensure safety of electronic equipment by ensuring appropriate temperatures and at the same time achieving optimum cooling efficiency of the data center. Typically data centers are not equipped with large number of sensors which can give a reasonable understanding of thermal management in the data center. Moreover, the data center managers do not have analysis tools which can pinpoint the reasons behind the thermal problems or cooling inefficiencies and provide appropriate recommendations for mitigation of these thermal problems and improvement in cooling efficiency in real time. Also a data center manager can alter only operational parameters of CRAC in real time for quick and easy mitigation of thermal problems and increasing cooling efficiency. Hence, optimizing operational parameters of CRAC is typical and easy way for real time cooling optimization of data center.

There is a need for a method and system for real time efficient thermal management of a data center which ensures proper thermal management and optimizes cooling efficiency in real time. Hence, there is a definite need for a method and system which could pinpoint the reasons behind thermal problems and cooling inefficiencies by continuous monitoring and analyzing the temperature profile in the data center and provide precise and optimal recommendations regarding operational parameters of CRAC for mitigation of these thermal problems and improvement in cooling efficiency in real time. There is also a need for a method and system which should be able to perform equally well in data centers with large number of sensors and data centers with fewer numbers of sensors. Some of the existing method and systems known to us are as follows:

US7031870 to Sharma et al. describes a method for controlling CRAC based on air-recirculation index. This air-recirculation index is quantified using sensed temperatures at various locations in the data center. This method ensures appropriate temperatures at inlets of racks by controlling cooling but does not attempt to fully optimize the cooling parameters. Thus it fails to ensure optimum cooling efficiency. This invention does not pinpoint the reasons behind thermal problems. Further, the scope of this invention is limited to the data centers which are equipped with large number of sensors at required locations.

US7493193B2 to Hyland et al. discloses a method, apparatus and computer program for monitoring and real-time heat load control based on server and environmental parameters.

In this invention, heat load control rules are used to ensure operation of electronic equipment within predefined specification. These predefined control rules are primitive and hence do not ensure optimum cooling efficiency of the data center. Further, the scope of this invention is limited to the data centers which are equipped with large number of sensors at required locations.

US2010076608A by Nakajima et al. provides a system and method for controlling cooling using correlations namely temperature sensitivity coefficients. These temperature sensitivity coefficients also have limited scope compared to influence indices which are used in present invention. They typically quantify correlation between CRAC and racks only. This invention does not give causal analysis of thermal problems.

Further, the scope of this invention is limited to the data centers which are equipped with large number of sensors at required locations.

The above mentioned prior arts fail to disclose an efficient method and system which pinpoint the reasons behind thermal problems and cooling inefficiencies by continuous monitoring and analyzing the temperature profile in the data center and provide precise and optimal recommendations regarding operating parameters of CRAC for mitigation of these thermal problems and improvement in cooling efficiency in real time. The existing prior art also failed to disclose method and system which should be able to perform equally well in data centers with large number of sensors and data centers with fewer numbers of sensors.

With the objective of overcoming the problems associated with the above mentioned prior art, it is evident that there is a need to have a method and system for efficient real time thermal management of a data center.

OBJECTIVES OF THE INVENTION

In accordance with the present invention, the primary objective is to provide a method and system for efficient real time thermal management of a data center using a fast thermal model and an optimizer.

Another objective of the invention is to provide a method and system for real time monitoring of operational parameters of data center with the help of sensor network and predicting where sensors are not present for finding potential thermal problem and cooling inefficiencies in the data center.

Another objective of the invention is to provide a method and system for generating quick and precise recommendations regarding optimum operational parameters of

CRAC for mitigation of thermal problems and improving cooling efficiency using the fast thermal model and the optimizer capable of running online in quick time.

Another objective of the invention is to provide a method and system for generating and sending SMS alerts, emails, alarms or notification recommending corrective actions needed to be taken to a user in case of thermal problems.

SUMMARY OF THE INVENTION

Before the present methods, systems, and hardware enablement are described, it is to be understood that this invention in not limited to the particular systems, and methodologies described, as there can be multiple possible embodiments of the present invention which are not expressly illustrated in the present disclosure. It is also to be understood that the terminology used in the description is for the purpose of describing the particular versions or embodiments only, and is not intended to limit the scope of the present invention.

The present invention provides a method and system for efficient real time thermal management of a data center using a fast thermal model and an optimizer.

In an embodiment of the invention a method and system is provided for real time monitoring of operational parameters of data center at various locations in the data center with the help of sensor network and predicting where sensors are not present for finding potential thermal problem in the data center and cooling inefficiencies of the data center.

In an embodiment of the invention a method and system is provided for generating quick and precise recommendations regarding optimum operational parameters of CRAC for mitigation of thermal problems and improving cooling efficiency using the fast thermal model and the optimizer capable of running online in quick time.

In an embodiment of the invention a method and system is provided for generating and sending SMS alerts, emails, alarms or notification recommending corrective actions needed to be taken to a user in case of emergency such as an equipment failure.

The above said method and system are preferably for efficient real time thermal management of a data center but also can be used for many other applications.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of preferred embodiments, are better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there is shown in the drawings exemplary constructions of the invention; however, the invention is not limited to the specific methods and system disclosed. In the drawings:

Figure 1: shows a flow diagram of the process for efficient real time thermal management of a data center.
Figure 2: shows a flow diagram of the process for generating recommendation.
Figure 3: shows a block diagram of the user interface displayed on a display device.

DETAILED DESCRIPTION OF THE INVENTION

Some embodiments of this invention, illustrating all its features, will now be discussed in detail.

The words "comprising," "having," "containing," and "including," and other forms thereof, are intended to be equivalent in meaning and be open ended in that an item or items following any one of these words is not meant to be an exhaustive listing of such item or items, or meant to be limited to only the listed item or items.

It must also be noted that as used herein, the singular forms "a," "an," and "the" include plural references unless the context clearly dictates otherwise. Although any systems and methods similar or equivalent to those described herein can be used in the practice or testing of embodiments of the present invention, the preferred, systems and methods are now described.

The disclosed embodiments are merely exemplary of the invention, which may be embodied in various forms.

The present application uses specific terminologies such as CRAC, rack, etc. only for simplicity. The subject matter of the present application is applicable to any type of electronic equipment like servers, networking equipment, telecommunications equipment etc. arranged in any fashion, any type of air delivery mechanism such as raised floor, overhead ducts etc, any type of air cooling infrastructure and any type of cooling units.

The data center may contain racks, housing various electronic and electric equipment and the racks are arranged in rows. Heat generated by the electronic and electric equipment is cooled by CRACs which are situated near periphery of the data center. These CRACs enable cold air to flow into the under-floor plenum. This cold air is delivered to intended places (e.g. fronts of racks) through tiles or vents. The equipment typically has fans for taking in cold air. This air picks up the heat generated and the hot air is exhausted. Some of this hot air is returned back to CRAC and some of this hot air may mix with cold air from tiles and recirculated into inlets of equipment. This recirculation of hot air may cause rising of temperature at inlets of racks above recommended temperature suggested by manufacturer of equipment. These locations of high temperatures are called hot spots. The heat generation inside racks change with time depending upon amount of workload put onto the equipment inside the racks. The CRAC have mechanism to change amount of cooling dynamically according to changing the heat load conditions in the data center. There may be emergency cases of CRAC failure causing the temperatures at some regions in the data center to overshoot.

In this way, various parameters in the data center such as temperatures at inlets of racks, heat generation by equipment inside racks and amount of cooling provided by CRAC are very dynamic. Given these dynamic conditions in the data center, continuous monitoring with alarms and notifications enables data center managers to supervise the data center effectively and reliably. Also, an analysis tool which can pinpoint reasons behind thermal problems and cooling efficiencies give data center manager valuable insights into current status of the data center. Accordingly, mitigation of thermal problems and optimization of cooling efficiency requires analysis tools to provide quick and precise recommendations regarding optimal operating parameters of CRAC so as to take in-time and correct decisions. The present invention fulfils all the above needs. It continuously monitors operational parameters of data center like power consumption of racks and temperatures at various locations, pinpoints reasons behind thermal problems and cooling inefficiencies, generates quick and precise recommendations regarding optimum operating parameters of CRAC. The invention also enables data center manager for effective thermal management by displaying the monitored parameters and recommendations on a user interface and generating alarms and notifications.

Continuous and real time monitoring and efficient thermal management of dynamic environment in data center requires continuous sensing of temperature at various locations such as the inlets and outlets of racks, and also sensing of temperature at the supply and returns of CRAC etc. But in reality, data centers are not generally equipped with enough number of sensors to completely characterize the temperature profile in the data center. Moreover, the sensors placed are not at important locations like probable hot spot locations. Data managers are even unaware of important locations. It is difficult and expensive to put enough number of sensors in legacy data centers. To solve all the above issues, present invention makes use of a fast thermal model to predict the temperatures at various locations in the data center using measured temperatures at few locations in the data center and measured or predicted power consumption of racks.
The present invention utilizes the concept of influence indices for fast prediction of temperatures and for causal analysis of thermal problems, the disclosure of which is

incorporated herein by reference of Indian patent application 652/MUM/2011 and US patent application 13/234,763.

Referring to **Figure 1** is a flow diagram of the process for efficient real time thermal management of a data center.

It should be noted that following discussion only illustrates one of the procedures to be used. These procedure may need some modification, some parts may be added, removed or the process may be used iteratively while actual use. Some of the steps may involve offline work to be carried out. For example, calculation of influence indices using CFD model may take longer time to be used for operational mode of the system, hence this calculation can be done offline.

In an embodiment of the invention, the method is provided for efficient real time thermal management of a data center. The procedure starts with step **102** in which measurement or prediction of power consumption of racks and measurement of temperatures at various locations is carried out at specific interval set by timer (**116**). Temperatures are measured using sensors which are typically thermocouples. These sensors may be placed at locations such as at inlets and outlets of racks, return and supply of CRAC. Typically, data center are equipped with only few number of sensors. Temperatures are predicted using influence indices where sensors are not present.

The power consumption of racks can be measured using iPDUs which measure the power consumption of devices connected to their outlets and can be polled over the network. Power consumption can also be measured by leveraging Lights On Management (LOM), which is built into the servers that includes remote management of servers including switching them off or on. A typical LOM architecture has separate management processer with its own system software and network interface. Current LOM installations measure the power consumption of the servers they control. This in turn can be polled through the LOM's network interface. Power consumption of servers inside racks can be predicted by using an estimation model too, where an empirical estimation is done by using CPU utilization which can be measured using software. These measured or predicted power consumption of racks and measurement of temperatures is then displayed to the data center manager on a display device through the user interface (**112**) as explained in **Figure 3**.

During the step **104**, temperatures at various locations are predicted using a fast thermal model and measurements of temperatures carried out at few locations. This prediction of various temperatures is done at a specified interval e.g. every 1 minute, as specified by timer (**116**). This fast thermal model makes use of method of prediction of temperatures using influence indices.

In one embodiment of the invention, temperatures at supply of CRAC and outlet of racks are measured and temperatures at other locations like inlets of racks, returns of CRAC are predicted using the fast thermal model. In an alternate embodiment of the invention, temperatures at supply of CRAC are measured and the temperatures at outlets of the racks along with temperatures at inlets of racks and returns of CRAC are predicted using the fast thermal model. The temperatures at outlets of the racks are predicted from temperatures at inlets of racks using equation (1) stated below:

$$T^{out}(R_j) = T^{in}(R_j) + \frac{P(R_j)}{\dot{m}^{in}(R_j) * C_p} \qquad \text{Equation (1)}$$

Where

$T^{out}(R_j)$ denotes temperature of air at outlet of a rack.

$T^{in}(R_j)$ denotes temperature of air at inlet of a rack

$P(R_j)$ denotes the power consumption of rack R_j.

$\dot{m}^{in}(R_j)$ denotes mass flow at the inlet of a rack

C_p denotes specific heat of air at constant pressure and room temperature

Temperatures at various locations in the data center are predicted using the fast thermal model and a temperature map is prepared. These predicted temperatures and temperature map are then displayed to the data center manager on a display device through the user interface (**112**) as shown in **Figure 3**. This prediction of temperatures using fast thermal model is also used during generation of recommendations (**108**).

In one of the embodiments of the invention, at the step **106**, various measured and predicted temperatures are analyzed. The measured or predicted temperatures at rack inlets are checked for hot spots by comparing with set threshold. Measured or predicted temperatures at supply and returns of various CRAC are analyzed to check for overloading of CRAC by calculating the amount of cooling provided by those CRAC. These temperatures are also analyzed to identify problems associated with CRAC such as compressor failure etc. These thermal problems may be communicated to the data manager using alarms and notifications at step **110** and also displayed to the data center manager on a display device through the user interface in step **112**.

In another embodiment of the invention, influence indices are used for causal analysis of a thermal problem. For example, if hot spot is determined after analysis of measured or predicted temperature, exact cause of the hot spots like hot air recirculation from a rack or higher supply temperature from CRAC etc can be determined from appropriate influence indices. This causal analysis can be displayed to the data center manager on a display device through the user interface (**112**). If a thermal problem like hot spot is detected, then the predicted or measured temperatures are observed for a specific interval of time, for example, 5 minutes specified by timer (**116**). This is carried out to mitigate fluctuating nature of temperatures. If the thermal problem is repeatedly observed during this interval, then recommendations are generated at the step **108.**

At the step **114,** the measured or predicted power consumption of racks from step **102** is analyzed for a specified observation interval as specified by the timer (**116**). This is done to analyze the dynamic nature of these variables. For example, the power consumption of racks is observed for half an hour and maximum and average power consumption levels are calculated. These levels are used for generation of recommendations rather than instantaneous power consumption levels. This is required to mitigate the dynamic and highly fluctuating nature of power consumption of racks.

In one of the embodiments of the invention, at the step **108**, various recommendations are generated. These recommendations are aimed towards either mitigation of thermal problems like hot spots or improvement of cooling efficiency of the data center. Recommendations regarding exact CRAC supply temperatures are generated using process (**200**) explained in **Figure 2**. A combination of CRAC supply temperatures is a tuple consisting of ordered list of supply temperatures of the individual CRACs. The optimum CRAC supply temperature combination is the one that maintains the rack inlet temperatures just below predefined threshold at the same time ensures minimum cooling power. The rack temperatures for a particular combination of CRAC supply temperatures are predicted using fast thermal model used at the step **104**. The predefined threshold is set for each rack according to the type of equipment housed in the racks. The cooling power can be calculated from step **118** using a relation between cooling power i.e. power consumed by the CRACs and CRAC supply temperature and CRAC flow rate. This relation can be determined by using component level models, manufacturer's data or by experimentation.

In one of the embodiments, exhaustive searching is used to search for the optimum combination of CRAC supply temperatures from all possible combinations. The complexity of this exhaustive search and time taken for searching increases rapidly with the number of CRACs but can be reduced using techniques such as Genetic algorithm, Hill climbing, Simulated annealing, etc. In another embodiment of the invention explained in later sections, genetic algorithm is used for searching optimum combination of CRAC temperatures. The various recommendations generated are displayed on a display device through the user interface at the step **112** or communicated to the data manager using alarms and notifications at the step **110.** At the step **110**, alarms and notifications are generated. Alarms such as electronic buzzers, visual clues in the user interface screen, SMSes/E-mails to the concerned people enable the data center managers to act immediately upon an emergency (in case of a hot spot, in case of equipment failure etc). These alarms are also displayed to the data center manager on a display device through the user interface shown at step **112**.

Figure 2: shows a flow diagram of the process for generating recommendation.

In an embodiment of the invention, the process (**200**) is provided for generation of recommendation. It calculates new CRAC supply temperatures under two circumstances - when at least one of the racks has been a hot spot for a time T_W (waiting interval) and when there are no any hot spots but time T_R (recommendation interval) has elapsed. These time intervals are specified by timer (**116**). In the former scenario, waiting for a time T_W ensures that recommendation are not generated for short-lived hot spots while in the latter scenario, though there aren't any hot spots, recommendations are generated periodically (every T_R) to optimize the CRAC supply temperatures. In step **204**, rack temperatures are predicted using the fast thermal model after specific time interval (e.g. every minute) as specified by timer (**202**). In step **206**, it is checked if time interval T_R has elapsed. If the outcome of the step **206** is Yes then the process proceeds to step **210**. If the outcome of the process **206** is No then the process proceeds to step **208**. In step **208**, every hot spot is checked to see if it has been a hot spot for a time T_W. If the outcome of the step **208** is Yes then the process proceeds to step **210**. If the outcome of the step **210** is No then the process returns to step **204**.

At the step **210**, the genetic algorithm based optimizer which optimizes the CRAC supply temperatures for a given power consumption levels of the racks is used. A genetic algorithm (GA) is a search heuristic that mimics the process of natural evolution. This heuristic is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. The evolution usually starts from a population of randomly generated individuals and happens in generations. In each generation, the fitness of every individual in the population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (recombined and possibly randomly mutated) to form a new population. The new population is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population.

In an embodiment of the invention, using genetic algorithm, randomly selected combinations of CRAC supply temperatures called the initial population are evolved to get to the optimum CRAC supply temperature combination which gives minimum cooling power and maintains the rack inlet temperatures below threshold. The determination of optimum CRAC supply temperatures is completed within few seconds because of use of fast thermal model and a formal optimizer such as genetic algorithm. Step **210** uses the fast thermal model from step **204** to predict rack inlet temperatures for any combination of CRAC supply temperature throughout this evolution process to check whether any rack inlet temperatures is exceeding the threshold. The cooling power can be calculated from step **214** using a relation between cooling power i.e. power consumed by the CRACs and CRAC supply temperature and CRAC flow rate. The measured power consumption levels of every rack over a time T_R specified by timer (**202**) are analyzed in **212** and the maximum power consumption level for each rack within that observation interval is calculated. These power consumption levels are used for prediction of rack inlet temperatures. This is done in anticipation that the instantaneous power of each rack in the next T_R interval would not overshoot the maximum power observed for that rack in the current T_R interval. In case of any breach that contributes hot spots at one or more racks for an interval of T_W, recommendations are generated immediately, as explained in step **208** above. Genetic algorithm based optimizer might struggle to evolve towards the optimal solution if the number of supply temperature combinations which don't contribute to any hot spots for the given power levels are very less. But the reliability of this algorithm can be improved by adding to the initial population, a supply temperature combination that doesn't contribute to any hot spots while corresponds to relatively less cooling power, before starting the evolution. This combination can be found by predicting the rack temperatures for a small specific range of CRAC supply temperature combinations for the given power levels and choosing the CRAC supply temperature combination that doesn't contribute to any hot spots while corresponding to least cooling power. In the step **216**, it is checked whether the new combination of CRAC supply temperatures correspond to lesser cooling power than the cooling power corresponding to combination of existing CRAC supply temperatures. If the outcome of the step **216** is Yes, the process proceeds to step **220,** where the new combination of CRAC supply temperatures are displayed on a display device through user interface **112** as recommendations or communicated to the data manager using alarms and notifications in **110**. If the outcome of the step **216** is No, then the process proceeds to step **218** where the recommendation is not implemented and the existing CRAC supply temperatures are kept unchanged.

In another embodiment of the invention, the invention may be adapted to optimize CRAC flow rates as well. In this case, invention makes use of appropriate set of influence indices calculated for that particular combination of CRAC flow rates. The invention then determines optimum combination of CRAC supply temperatures for many combinations of CRAC flow rates and the combination which gives lower cooling power and keeps rack inlet temperatures below threshold may be chosen as optimum combination of CRAC flow rates along with optimum combination of CRAC supply temperature.

Figure 3: shows a block diagram of the user interface displayed on a display device.

In an embodiment of the invention, the user interface is provided for keeping the data center manager informed of the datacenter operating conditions and alerts the data center manager in case of any thermal problems. The entire layout of the datacenter

(**302**) as seen from the top view is shown in the **Figure 3**. Labels on each rack indicate the rack name and predicted or measured temperatures at rack inlet. It may also include the power consumption of each rack. As a visual clue, the colors of racks change with their predicted temperature. Generated recommendations, alarms and causal analysis of thermal problems are displayed in the top-right corner of the GUI (**304**) while plots such as the temperature Vs time (**306**) is shown in the bottom-right corner of the screen.

The machine may comprise a server computer, a client user computer, a personal computer (PC), a tablet PC, a laptop computer, a desktop computer, a control system, a network router, switch or bridge, or any machine capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein.

The machine may include a processor (e.g., a central processing unit (CPU), a graphics processing unit (GPU, or both), a main memory and a static memory, which communicate with each other via a bus. The machine may further include a video display unit (e.g., a liquid crystal displays (LCD), a flat panel, a solid state display, or a cathode ray tube (CRT)). The machine may include an input device (e.g., a keyboard) or touch-sensitive screen, a cursor control device (e.g., a mouse), a disk drive unit, a signal generation device (e.g., a speaker or remote control) and a network interface device.

Dedicated hardware implementations including, but not limited to, application specific integrated circuits, programmable logic arrays and other hardware devices can likewise be constructed to implement the methods described herein. Applications that may include the apparatus and systems of various embodiments broadly include a variety of electronic and computer systems. Some embodiments implement functions in two or more specific interconnected hardware modules or devices with related control and data signals communicated between and through the modules, or as portions of an application-specific integrated circuit. Thus, the example system is applicable to software, firmware, and hardware implementations.

In accordance with various embodiments of the present disclosure, the methods described herein are intended for operation as software programs running on a computer processor. Furthermore, software implementations can include, but not limited to, distributed processing or component/object distributed processing, parallel processing, or virtual machine processing can also be constructed to implement the methods described herein.

The illustrations of arrangements described herein are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the elements and features of apparatus and systems that might make use of the structures described herein. Many other arrangements will be apparent to those of skill in the art upon reviewing the above description. Other arrangements may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. Figures are also merely representational and may not be drawn to scale. Certain proportions thereof may be exaggerated, while others may be minimized. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

The preceding description has been presented with reference to various embodiments. Persons skilled in the art and technology to which this application pertains will appreciate that alterations and changes in the described structures and methods of operation can be practiced without meaningfully departing from the principle, spirit and scope.

WE CLAIM:

1. A method according to any claim of our patent application **465/MUM/2012** additionally characterized by efficient real time thermal management of a data center using a fast thermal model and an optimizer, said method comprises processor implemented steps of:

   monitoring and predicting one or more operational parameters of the data center in real time; generating optimum and precise recommendations regarding operational parameters of CRAC; and

   displaying real time monitored and predicted operational parameters, and generated recommendations regarding operational parameters of CRAC on a display device through a user interface.

2. The method as claimed in claim 1, wherein the operational parameters of the data center are monitored in real time with the help of sensor network or predicted at locations where sensors are not present.

3. The method as claimed in claim 1, wherein said one or more operational parameters of the said data center are selected from the group comprising of but not restricted to power consumption of racks, temperatures at various locations in the data center, CRAC supply temperatures and CRAC flow rates.

4. The method as claimed in claim 1, further comprises of generating and sending SMS alerts, emails, and displaying alarms, notifications and recommendations on the display device including a user's personal communication device.

5. A system according to any claim of our patent application **465/MUM/2012** additionally characterized to efficient real time dynamic thermal management of a data center using a fast thermal model and an optimizer, the system comprising of at least one data center having a plurality of computing devices, a plurality of

sensors for monitoring one or more operational parameters and at least one display device, displaying real time monitored and predicted operational parameters, and generated recommendations regarding operational parameters of CRAC on a user interface.

6. The system as claimed in claim 5, wherein said one or more operational parameters of the said data center are selected from the group comprising of but not restricted to power consumption of racks, temperatures at various locations in the data center, CRAC supply temperatures and CRAC flow rates.

Sheet No: 1/3

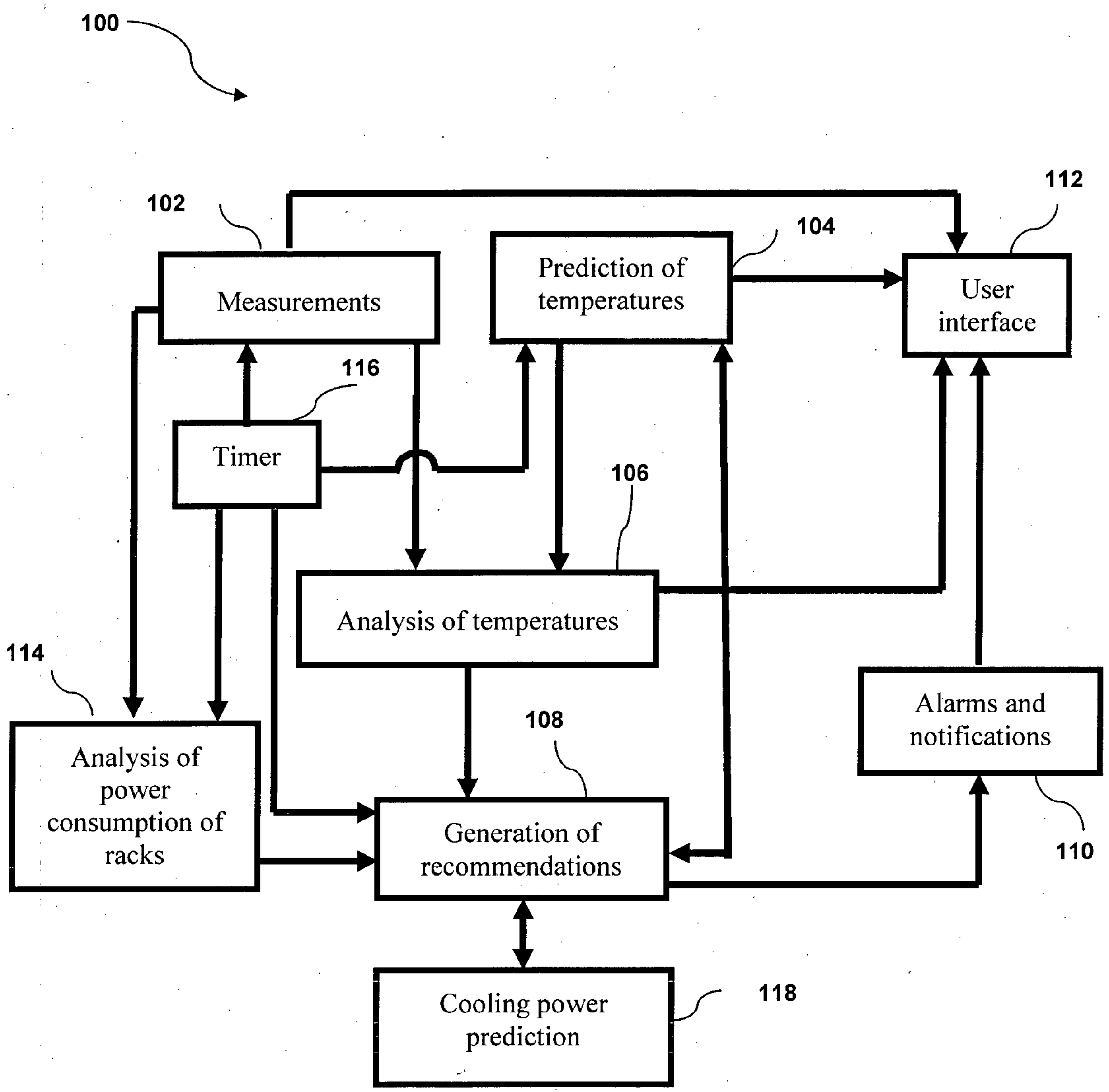

Figure 1

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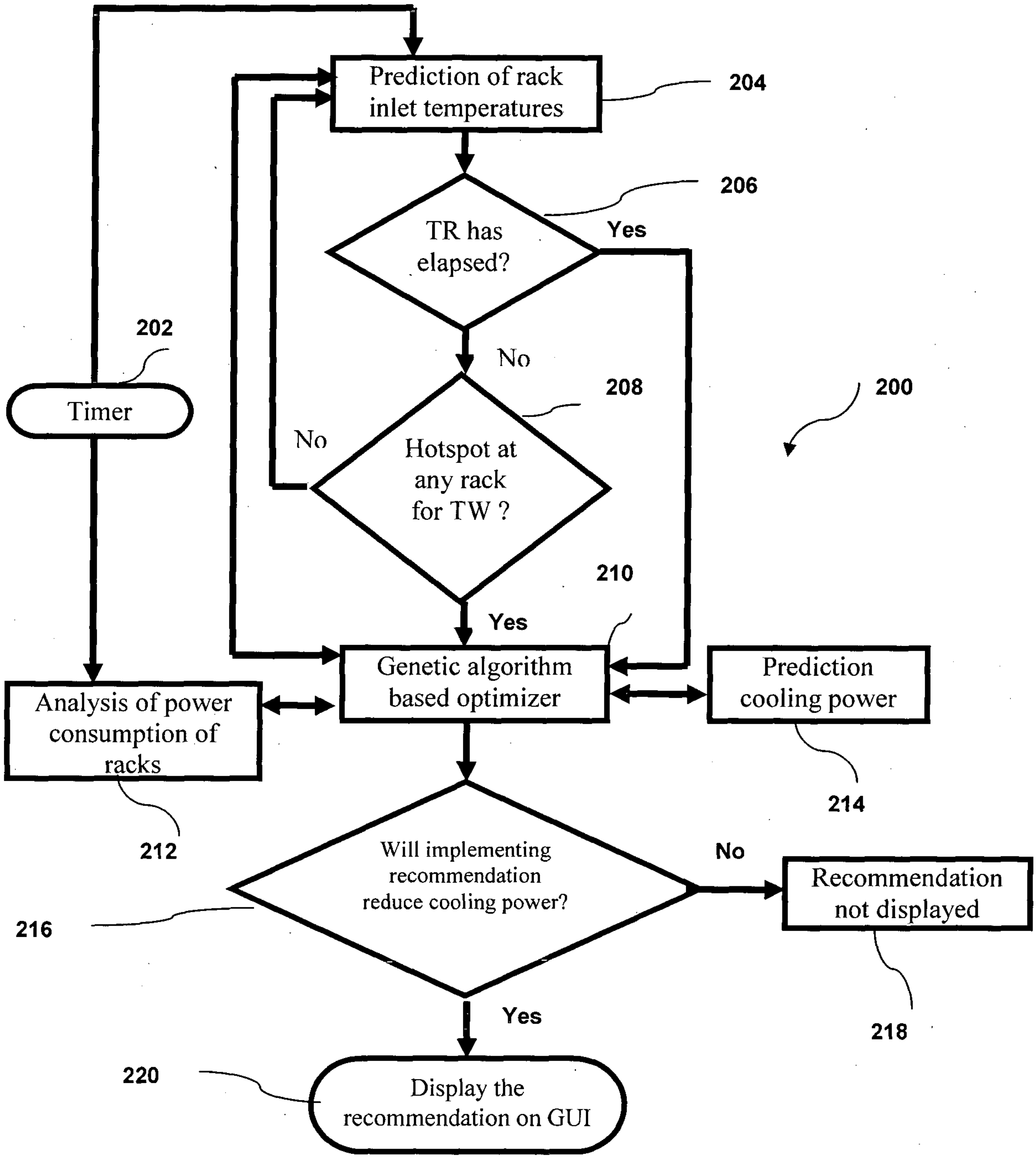

Figure 2

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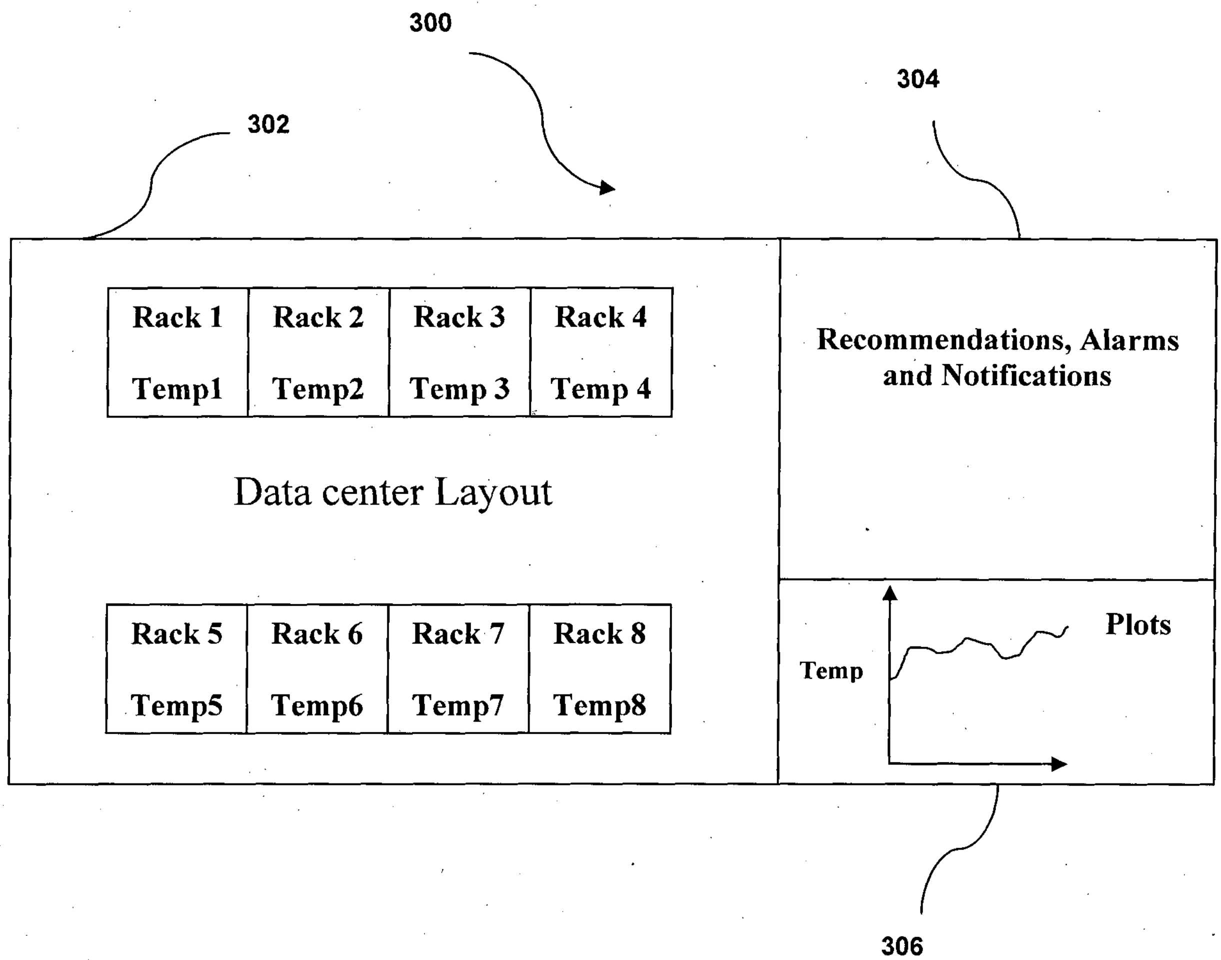

Figure 3

PATENT COOPERATION TREATY

PCT

DECLARATION OF NON-ESTABLISHMENT OF INTERNATIONAL SEARCH REPORT

(PCT Article 17(2)(a), Rules 13*ter*.1(c) and (d) and 39)

Applicant's or agent's file reference PAT-TCS-554	**IMPORTANT DECLARATION**	Date of mailing *(day/month/year)* 05 JUL 2013
International application No. PCT/IN2013/000103	International filing date *(day/month/year)* 18 February 2013	(Earliest) Priority Date *(day/month/year)* 01 March 2012
International Patent Classification (IPC) or both national classification and IPC IPC(8)- G06F 1/20 (2013.01); USPC-702/130; CPC: G06F 1/206 (2013.01)		
Applicant TATA CONSULTANCY SERVICES LIMITED		

This International Searching Authority hereby declares, according to Article 17(2)(a), that **no international search report will be established** on the international application for the reasons indicated below.

1. ☐ The subject matter of the international application relates to:
   - a. ☐ scientific theories
   - b. ☐ mathematical theories
   - c. ☐ plant varieties
   - d. ☐ animal varieties
   - e. ☐ essentially biological processes for the production of plants and animals, other than microbiological processes and the products of such processes
   - f. ☐ schemes, rules or methods of doing business
   - g. ☐ schemes, rules or methods of performing purely mental acts
   - h. ☐ schemes, rules or methods of playing games
   - i. ☐ methods for treatment of the human body by surgery or therapy
   - j. ☐ methods for treatment of the animal body by surgery or therapy
   - k. ☐ diagnostic methods practised on the human or animal body
   - l. ☐ mere presentations of information
   - m. ☐ computer programs for which this International Searching Authority is not equipped to search prior art
2. ☒ The failure of the following parts of the international application to comply with prescribed requirements prevents a meaningful search from being carried out:

   ☐ the description ☒ the claims ☐ the drawings
3. ☐ A meaningful search could not be carried out without the sequence listing; the applicant did not, within the prescribed time limit:
   - ☐ furnish a sequence listing on paper complying with the standard provided for in Annex C of the Administrative Instructions, and such listing was not available to the International Searching Authority in a form and manner acceptable to it.
   - ☐ furnish a sequence listing in electronic form complying with the standard provided for in Annex C of the Administrative Instructions, and such listing was not available to the International Searching Authority in a form and manner acceptable to it.
   - ☐ pay the required late furnishing fee for the furnishing of a sequence listing in response to an invitation under Rule 13*ter*.1(a) or (b).
4. ☐ A meaningful search could not be carried out without the tables related to the sequence listings; the applicant did not, within the prescribed time limit, furnish such tables in electronic form complying with the technical requirements provided for in Annex C-*bis* of the Administrative Instructions, and such tables were not available to the International Searching Authority in a form and manner acceptable to it.
5. Further comments:

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/203 (April 2005)