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Simulation-based assessment of thermal aware computation of a bespoke data centre

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Abstract

The role of Data Centres (DCs) as global electricity consumers is growing rapidly due to the exponential increase of computational demand that modern times require. Control strategies that minimize energy consumption while guaranteeing optimal operation conditions in DC are essential to achieve sustainable and energy efficient DCs. Unfortunately, the development and testing of novel control strategies are often slowed down, if not discarded. This is generally due to the lack of access caused by safety and economic reasons. Alternatively, simulation experiments represent a "safe" virtual environment to test novel control strategies, accelerating the process for their implementation in physical DCs.

The virtual DC testbed, originated in the GENiC project, supports the development and dynamic testing of control and energy management algorithms. This paper introduces its features and describes its functionality through a simulation-based assessment of thermal aware computation strategy. For this, the virtual DC will be based on a bespoke DC located in Cork (Ireland). This DC has 30 kW capacity, 40 m² floor area and its layout follows a hot aisle - cold aisle arrangement without containment.

The performance the IT Workload allocation under different scenarios and their influence both on the whitespace environment and overall DC performance are evaluated and quantified. Finally, the benefits of a coordinated operation between the thermal and the IT workload managements are discussed.

Keywords: Data Centre, Thermal Aware Computation, Simulation-based Assessment, Virtual Testbed, GENiC

1. Introduction

The role of Data Centres (DCs) as global electricity consumers is growing rapidly due to the exponential increase of computational demand that modern times require. With this growth expected to continue in the future, the focus lays on designing sustainable, energy efficient DCs. An optimal operation of DCs also plays a significant role in the minimization of total energy consumption and carbon footprint, while guaranteeing suitable operational conditions for housed Information Technology (IT) equipment.

Based on their function, the operation of a DC can be sub-divided in three management groups:

- IT Workload mgmt. allocates and executes IT jobs to/in individual IT devices.
- Thermal mgmt. operates the cooling system in order to guarantee suitable operational conditions for IT devices.
- Power Supply mgmt. guarantees uninterrupted power supply for all critical equipment in DCs and might, if available, operate on-site renewable systems.

A holistic energy management approach that coordinates these groups is essential in order to optimise the overall operation and energy performance of a DC. These supervisory energy management components also need to achieve cost-effective integration of heat-recovery and on-site renewable sources [1]. The international research project GENIC (Globally Optimized Energy Efficient Data Centres)[2] addresses these challenges through the development of a model-based control platform for wide optimization of DC operation.

Achieving such an approach requires of the development, testing and commissioning of novel control strategies. Unfortunately, the risks associated to physical testing, such as cost of downtime, breach of service level agreements (SLAs), or failure of mission-critical equipment under test conditions, often surpass the potential benefits gained. As a result, the implementation of novel strategies is often slowed down if not prematurely discarded.

Alternatively, simulation experiments represent a “safe” virtual environment to test control strategies, accelerating the process for their implementation in physical DCs. However, holistic management approaches require testing capabilities that are not available in one integrated platform. Some of these capabilities should:

- Allow assessments at different levels of resolution (from server to whole DC facility analysis)
- Emulating the transient behaviour of thermal and energy processes occurring in a DC that represents a multi-domain platform (workload, thermal, power supply processes)

- Enable in the loop (Fig.1) virtual testing of de-centralised, multi-developer components.
- Mimic the I/O structure and communication of monitoring and actuation systems from the physical DC. This simplifies and accelerates the implementation process of new EM components

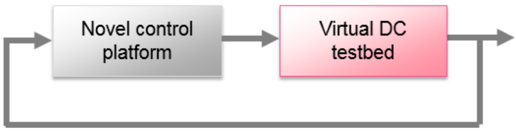

Fig. 1 Virtual DC concept: In the loop testing

All these requirements drove the development of a virtual DC testbed [3], that replicates the thermal and energy behaviour of a DC and is able to overcome the constrains of physical testing of novel control strategies.

With the sole requirement of complying to the I/O structure, the virtual DC testbed can interactively communicate with novel control algorithms and provide valuable feedback at various level of resolution (e.g. server, rack, whitespace, whole DC) to the algorithm developer. Considering interactive communication with multiple developers is important, because addressing an integrated control of such a complex and multi-domain system by one single developer is hardly feasible in practice. Thus the project Genic proposes modular architecture and communication framework considering multiple specialized developers [4].

This paper describes the features and functionality of the virtual DC testbed and the requirements that drove its development. It also presents a simulation-based assessment (SBA) of an IT workload allocation algorithm under different scenarios, including a thermal aware computation case. Its influence on the whitespace environment, as well as on the performance of the DC are evaluated and discussed. This SBA is performed based on a bespoke DC in Cork, Ireland [5].

2. Virtual Data Centre Testbed

As stated before, testing in DC facilities is generally restricted due to safety and economic reasons. A way to avoid the risks associated to physical testing is the use of computational models that are able to replicate the energy performance of the real DC. These computational models form a virtual DC testbed that represents a 'safe' environment to support the development and testing of operation/control strategies. However, in order to develop a virtual DC testbed suitable for this purpose, a number of requirements must be taken into account.

2.1. Features of virtual DC testbed

Based on their function within the DC, energy models are grouped in four main modules, which are shown in Fig. 2. These modules are: IT devices model, DC whitespace representation (represented by building energy and airflow models), Heating, Ventilation, and Air-conditioning (HVAC) system model and Power Supply model. These modules are independent of each other and their complexity can differ based on the specific testing needs.

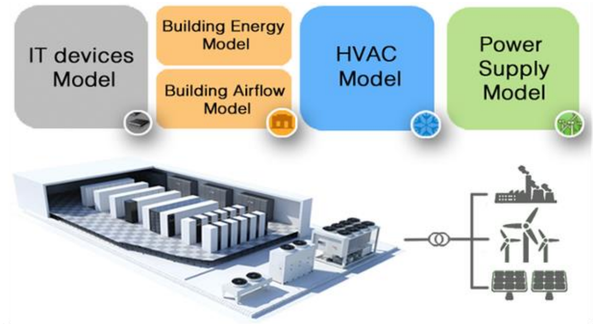

Fig. 2 Virtual DC testbed: Modular Structure

Such a modular structure enables a large variety of testing possibilities for different types of algorithms belonging to different management groups. For instance, if only a novel thermal control algorithm is tested, the HVAC module can be use in isolation or combined with the other modules. This other modules, additionally, can vary their complexity depending on the type of performance assessment needed. Thus the virtual testbed can be easily tailored to the specific purpose and the whole testing process can be optimized.

Virtual testing of operation strategies requires a dynamic in-the-loop interconnection with the tested control algorithm. An in-the-loop approach allows to replicate the real operation process. The virtual DC testbed is embedded and dynamically interacts within the control loop. This requires an open interface for algorithm developers and a communication framework. Then, once complying with the I/O structure, the control algorithm, that remains private, can be remotely tested via internet.

The computational time required for virtual testing depends on the interactive in-the-loop communication. Consequently, the overall testing process benefits from a fast computing testbed.

2.2. Virtual DC method

With measurements rarely available for the testbed development, this is usually based on technical DC specifications. Therefore, the physics based models (white-box models) are preferred. Building Energy Simulation (BES) was found as the most suitable method to fulfil the requirements stated above. Building Energy Simulation (BES) has been developing for the last 50 years, offers sophisticated computational engines for modelling building physics and building services systems. BES tools allow simulation of the transient behaviours of Buildings and HVAC systems, as well as advance systems such as on-site renewable energy systems. In addition to this, there is usually sufficient support for co-simulation or integration of user models [6], [7].

Even though a BES method satisfies most of the requirement, BES tools are not that common among the DC community. However, its application in research in the DC domain is experimenting recent growth. For instance Phan and Lin investigated a multi-zone representation of a DC with cold and hot aisle arrangement for BES [8]. Similarly, Salom, Oro et al. introduced dynamic modelling of data centre whitespace and also a modelling review for support of renewables integration in DC [9], [10]. For the work presented in this paper, existing models of cooling and power supply devices including renewables, are complemented with a representation of DC whitespace based on a multimodal airflow network presented in [3].

The virtual data centre testbed is developed in one of the well-known BES tool called Transient System Simulation Tool (TRNSYS). TRNSYS offers embedded libraries with models of Building zones, HVAC, Power or Controller components called types. The complex model is compiled from individual types according to the specific case and is able to simulate the thermal and energy behaviour of such systems. More information about the TRNSYS tool can be found in [11], [12]. In order to simulate the thermal behaviour of a general DC whitespace at rack or server levels, higher complexity needs to be applied. The multi-zonal Airflow network method is used for the calculation of air flow patterns and heat fluxes in the DC whitespace. The airflow network is defined in Contam [13] and then co-simulated with the thermal zones defined in the TRNSYS environment. Detailed information about the used models can be found in [14]. The virtual DC testbed is developed based on a case-study described in section 4.

3. Thermal Aware Computation Concept

Literature related with thermal aware computation [15], [16] shows that a coordinated control involving IT workload allocation and thermal management can minimize the IT consumption while reducing the risk of hot spots (recirculation of used hot air back to IT devices) in the whitespace. However evaluations of the temperature distribution in the DC whitespace and the total DC energy consumption are still missing.

Thermal aware computation links closely the thermal and IT workload managements. It basically consists of the allocation and migration of IT workload, which constitutes the DC internal heat gain, based on the thermal situation in the whitespace. Thermal aware computation is discussed more in detail in section 3.2 . However to understand the thermal aware computation concept, the term “virtualization” of IT devices needs to be explained.

3.1. Virtualization and Energy Savings Related with Data Migration

Virtualization, allows optimal IT workload allocation or migration to individual servers. It is a technique that decouples hardware from application (software). By using a numerical representation of a server called virtual machine, incoming IT jobs are analysed before their allocation to hardware. Hardware requirements e.g. CPU (Central Processing Unit), RAM (Random Access Memory) or Hard Drive utilization are estimated beforehand for an optimal allocation. In other words the application is not associated with the specific hardware anymore and IT workload can be allocated or migrated to any server within the virtualized cluster. Virtualization provides operation flexibility and leads to higher utilization of hardware [17]. The operation flexibility can be beneficial in many ways. For instance only by migrating IT workload to hardware with higher computational efficiency and switching unused server to the standby mode IT load can be significantly reduced. Fig. 3 depicts different computational efficiency of servers released in between years 2006 to 2012, and illustrates the relative difference between each individual server, which may be housed in the same DC room. The variety of idle power versus standby power is also worth to notice, and indicates the saving potential. Since IT workload represents heat dissipation in the DC whitespace, virtualization advantages can also be used by the thermal management.

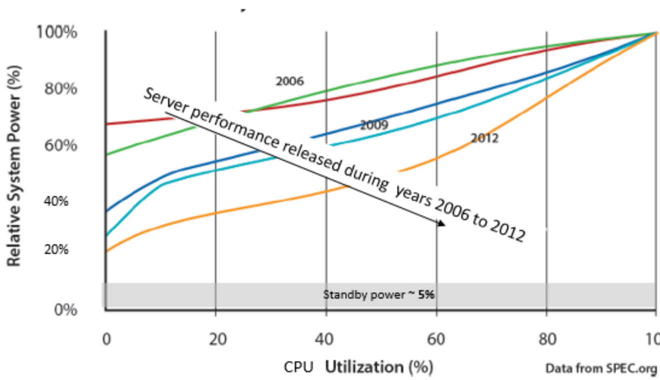

Fig. 3 Server computational efficiency between years 2006 and 2012 [18]

3.2. Thermal Aware Computation

The scope of the thermal management usually ends at the Computer Room Air-conditioning (CRAC) unit settings. These temperature or airflow set points are set for the whole DC whitespace or a section of it. The controller usually operates at room or section level based on a single temperature value, which is taken as reference for the whole related whitespace. Generally, the return air temperature or an average value of multiple sensors in the whitespace is used to control the unit. Nowadays IT devices are often equipped with embedded temperature sensors, which can be integrated into the DC sensor network and communicated with the control platform [19]. Such a sensor network offers high-resolution monitoring of temperature in the whitespace. However the potential of such a high-resolution monitoring is not fully used due to the lack of actuation of thermal management at rack or server levels. In other words, thermal management has no option to adjust conditions for individual racks or even servers. On the other hand the thermal management is able to analyse the high-resolution monitoring data and generate thermal preferences for IT workload management. By migrating virtual machines (representative of IT workload) to thermally preferable hardware, the distribution of dissipated heat can be controlled. Thermal aware computation allows thermal management to act at rack or server level, avoids hots spots and potentially increases the part load efficiency of the CRAC unit.

4. Bespoke Data Centre Case-Study Specification

The development of the virtual DC testbed and the dynamic testing of the thermal aware computation algorithm is based on a case-study of a small-size university data centre located in Cork (Ireland) shown in Fig. 4.

Fig. 4 Photo of demonstration DC

This Data Centre is the demonstration site of the European project Genic and has been chosen due to its testing and validation availability. The data centre has approximately 40m^2 of floor area, laid out in a hot and cold aisle arrangement without containments. The nominal load of IT devices, housed in eight racks, is 30kW. Under floor air distribution is applied in the whitespace. The cooling unit supplies conditioned air to the space below the raised floor and from there the air enters to the whitespace through perforated floor tiles in front of IT devices (Fig. 5). Then the air is forced into the IT devices to remove the dissipated heat caused by computation processing. The warm air is taken bellow the ceiling by the cooling unit. The layout of the demonstration DC is shown in Fig. 5.

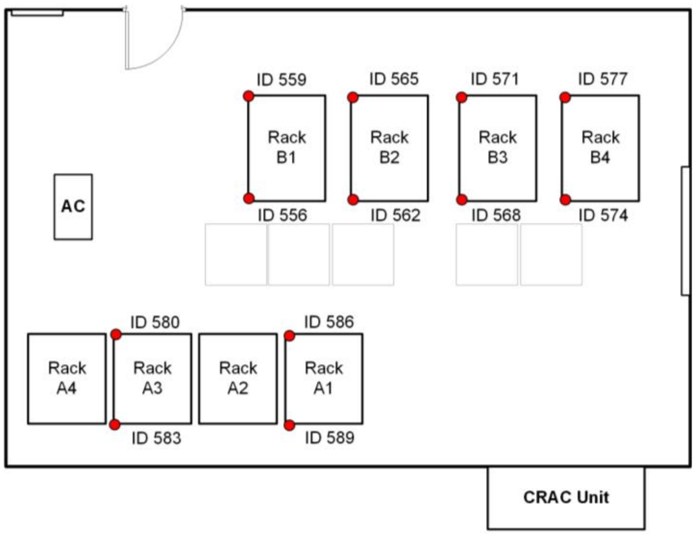

Fig. 5 DC Case study in Cork (Ireland): Layout of the whole whitespace and placement of cooling devices

Other than racks A2 and A4, every rack is occupied by different number and types of servers. Each rack is equipped by temperature sensors at the inlet (cold aisle) and at the outlet (hot aisle) sides, at heights 0.3, 0.9, 1,5m. Based on these measurements, the first prototype of the virtual DC testbed is validated and calibrated based on measurements. Normalized root mean square error (NRMSE) of the simulation of CRAC return air temperature is around 5%. Calibration of this temperature is more important than other whitespace temperatures because this temperature is representative of the whitespace for the HVAC system. The overall NMRSE of the simulation of whitespace temperatures at the inlet of the IT devices is below 10%. All details of validation results of the testbed are presented in [20].

Cooling in the whitespace is ensured by a CRAC unit with nominal capacity of 40kW.The CRAC unit contains a direct expansion (DX) unit with a water economizer that bypasses the DX unit in periods when outside air temperature is lower than the inside air temperature. The heat from the CRAC unit is removed by a water circuit that connects to a roof mounted dry cooler, where it is released to the outdoor environment. A schema of the cooling system is shown in Fig. 6

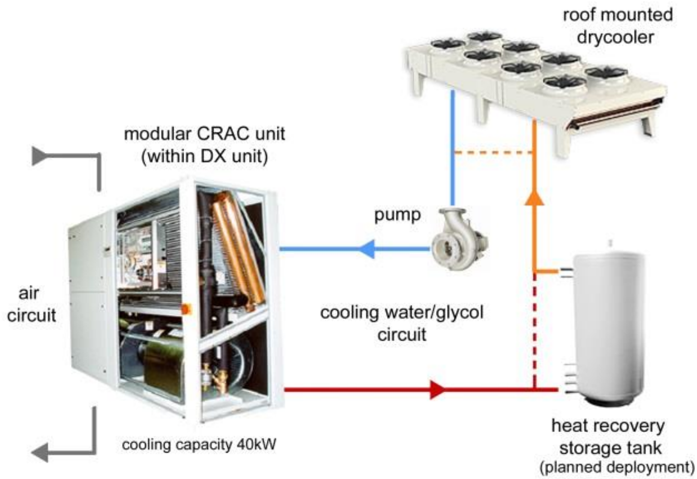

Fig. 6 Schema of the cooling system for the case-study DC

The heat recovery storage tank, which will be a future addition to the original system, and the small air-conditioning (AC) unit that acts as an emergency unit are not taken into account in this study.

Current operation strategy of the CRAC unit is an ON-OFF controller of the cooling source: DX unit and the economizer. The return air temperature set point is constant at 20°C. The airflow set point is also fixed at 10000 kg h^{-1} to ensure a high air changes in the room. The described control strategy is taken as baseline HVAC control for the simulation.

The development of the Virtual DC testbed follows the geometry of the case-study layout and the technical specifications of the cooling system [21]. Fig. 7 demonstrates the level of resolution of the multi-zonal airflow network method for the white space and an enhanced visualisation achieved through post-processing of the simulated data (3D linear interpolation). Fig. 7 shows the temperature distribution in the whitespace at different heights. Each black dot in the layout represents a computational node. The value of the IT workload (in kW) for each third of rack is also displayed.

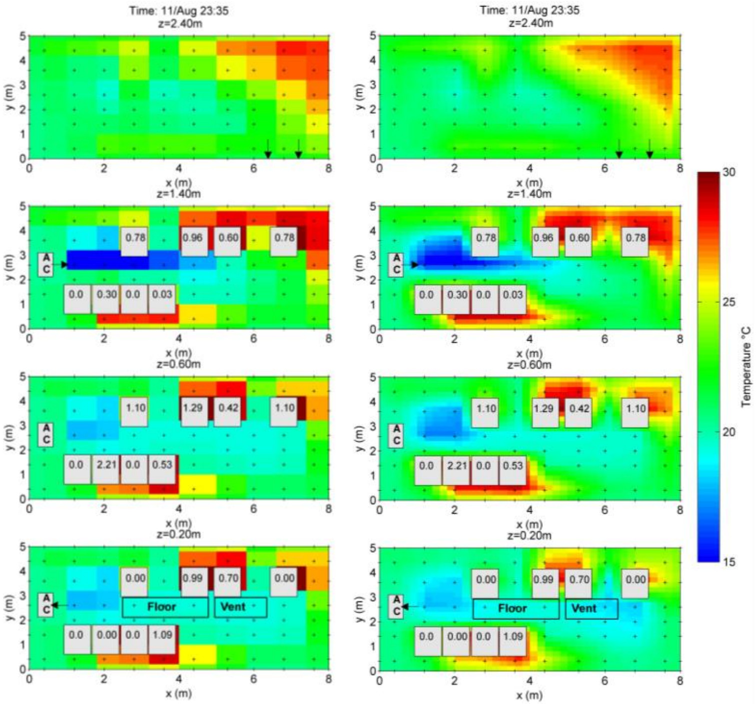

Fig. 7 Level of resolution of multi-zonal airflow network method versus post-processed visualisation

5. Simulation Based Assessment

The Simulation-based Assessment is executed for one day in January. Three scenarios: a baseline case, acting as reference and two virtual experiments, are presented in this paper. The three scenarios only differ in their IT workload management. The IT workload allocation (kW) per 3rd of rack, presented in each scenario, is product of the allocation algorithms developed by Castineiras et al. [22]. All the other settings such as layout, IT and HVAC configuration, and HVAC control strategy that have been mentioned in section 4 are similar for every scenario.

5.1. Scenario I: Baseline scenario

The baseline workload profile was generated based on anonymous traces of virtual machine traffic from the case-study DC. The baseline operation doesn't consider any workload migration. Once IT jobs (represented by virtual machine traces) are allocated by the workload allocation algorithm to a server, they are processed at this server. This is in line with the current common practice of IT workload allocation. The IT workload profile is fairly constant at 11kW with minor fluctuations in the range of +/- 1kW. The average value of IT workload over the length of the experiment (24h) for each rack is shown in Fig. 8. Each rack can be localized in the whitespace layout presented in Fig. 5. Each bar is divided into three areas, indicating the utilization (kW) at the bottom, middle and top sections of the rack.

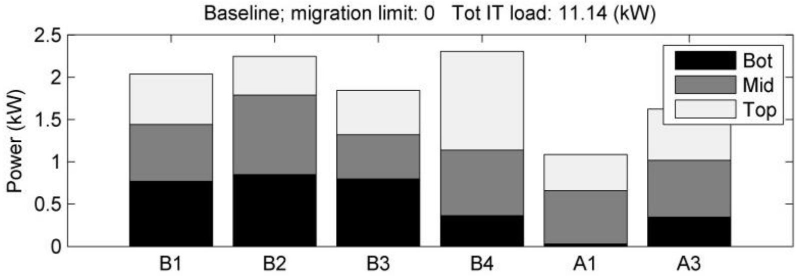

Fig. 8 Baseline IT workload distribution

5.2. Scenario II: Optimized workload allocation

For this scenario, the same virtual machine traces are used, however the IT workload allocation algorithm is changed. Migration of virtual machines is allowed. The workload allocation algorithm seeks for the optimal allocation every 10 minutes and can execute up to 100 migration in this time. This case represents migration without any restriction. By optimizing server utilization and switching off unused servers, the total IT workload of the DC is significantly decreases to 4.31kW. The average value of IT workload for each rack over the experimental period (24h) is shown in Fig. 9. One third of rack level of resolution for bottom, middle and top level is indicated.

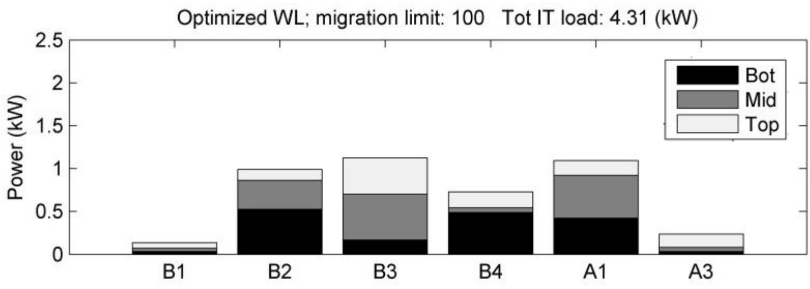

Fig. 9 Optimized IT workload allocation, unlimited migration

5.3. Scenario III: Optimized workload allocation with thermal awareness

This scenario demonstrates thermal aware workload allocation. In this case, the optimized IT workload allocation algorithm with unrestricted (100) migration also needs to take into account the thermal behaviour of the DC whitespace. It does this by considering a prescribed thermal priority based on the thermal analysis of the whitespace. This thermal priority is calculated from the temperature distribution of the baseline scenario, and with a granularity of a third of rack. The dimensionless Supply Heat Index (SHI) [23] is used to evaluate the whitespace. The SHI is defined as the ratio between Enthalpy raised due to infiltration into the cold aisle and Total Enthalpy raised at the rack exhaust, which can be seen in equation 1

$$SHI_{i,j} = \frac{T^{i}_{in\,i,j} - T_{sup}}{T^{f}_{out\,i,j} - T_{sup}} \quad (1)$$

The SHI for i^{th} rack and j^{th} height level (bottom, middle, top) is calculated as the difference between inlet air temperature to the server in location $_{i,j}$ ($T_{in\,i,j}$) and supply air temperature from the CRAC unit (T_{sup}) divided by the difference of server outlet temperature for the given location $_{i,j}$ ($T_{out\,i,j}$) and supply air temperature (T_{sup}). If SHI is equal to 0, the inlet air temperature at location $_{i,j}$ is the same as the supply air temperature and there is no recirculation air. If SHI is equal to 1, the inlet air temperature at location $_{i,j}$ is the same as the outlet air temperature for the given location, thus only recirculated air is supplied (full recirculation). The results of the SHI analysis for the baseline scenario is shown in Table 1

Table 1 Results of SHI analysis for the case-study whitespace

SHI	B1	B2	B3	B4	A1	A3
Top	0.086	0.281	0.271	0.286	0.131	0.127
Middle	0.073	0.104	0.037	0.079	0.077	0.241
Bottom	0.014	0.043	0.026	0.035	0.118	0.220

This thermal priority, based on the SHI analysis is then used by the IT workload allocation algorithm to optimise the migration of IT workload, while complying with the thermal prescriptions.

The total IT workload for the whole DC is very similar to the one from scenario II in section 5.2 about 4 kW. The average value of the IT workload for each rack over the experimental period is shown in Fig. 10. One third of rack level of resolution for bottom, middle and top level is indicated.

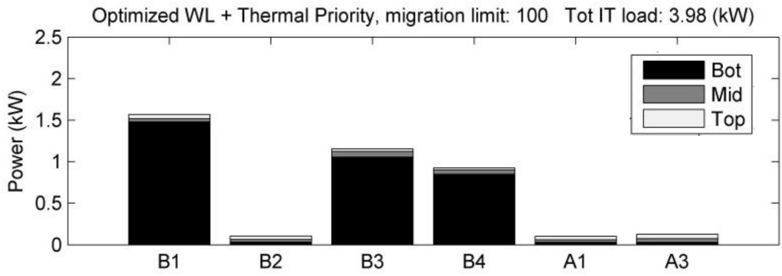

Fig. 10 Optimized IT workload allocation with thermal awareness

5.4. Simulation results for all scenarios

A simulation is executed for these three scenarios and the results from virtual DC testbed are analysed and reported. The results that indicate the influence of different IT workload allocation scenarios on the temperature distribution of the DC whitespace are shown in Fig. 11 and Fig.12. Total DC consumption, a breakdown per each pillar and performance indicators such as Power Usage Effectiveness (PUE) and IT Equipment Utilization (ITEU) are also reported and shown in Table 2.

Table 2 Simulation results for experimental period

Experiment description	Total cons. (kWh)	IT cons. (kWh)	HVAC consp. (kWh)	Other (kWh)	PUE	ITEU
Baseline	1107.64	525.06	384.46	198.12	2.11	0.46
Optimized 100mig	652.85	202.96	371.08	78.81	3.22	0.18
Thermal Priority 100mig	624.39	187.03	364.51	72.85	3.34	0.16

The comparison between temperature distributions, influenced by the baseline workload allocation versus optimized workload allocation are shown in Fig. 11. The temperature distribution for four layouts at different height levels is provided. IT workload in kW is presented for each third of a rack. The marked spots **A**, **B** and **C** are further explained in section 6.

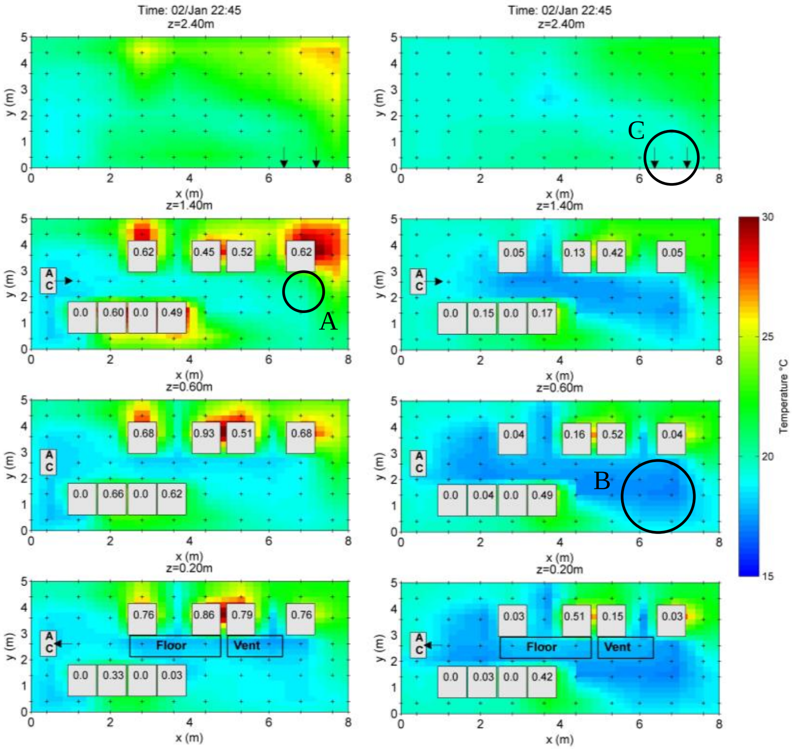

Fig. 11 Temperature destribution in the DC case study: Baseline workload allocation (left), Optimized workload allocation (right)

The comparison between temperature distributions influenced by baseline workload allocation versus optimized workload allocation with thermal priority are shown in Fig. 12. The temperature distribution is again provided for the four layouts at different height levels. IT workload in kW is presented for each third of a rack. The marked spots **A**, **D** are further explained in section 6.

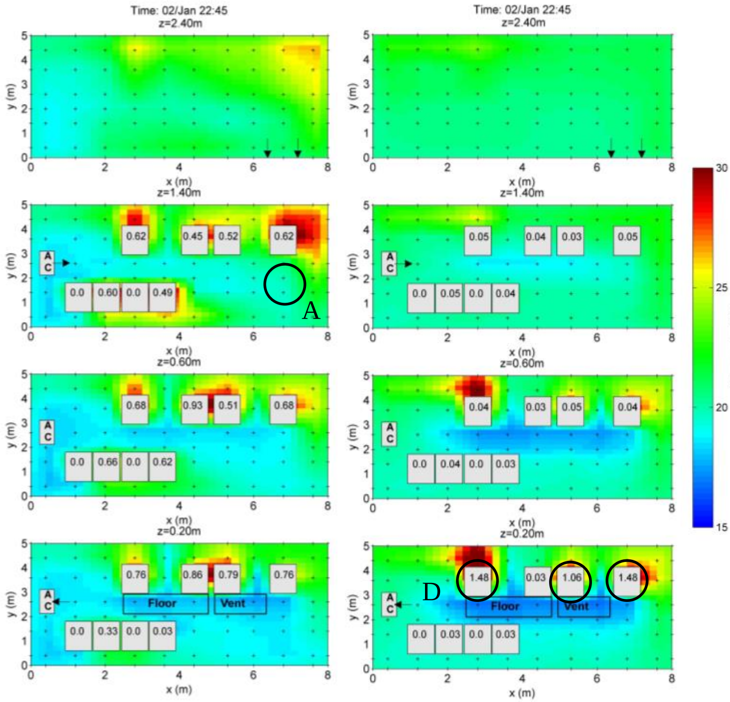

Fig. 12 Temperature destribution in the DC case study: Baseline workload allocation (left), Optimized workload allocation with thermal policy (right)

6. Discussion of results

The temperature distribution across the DC whitespace for the 3 scenarios: baseline, optimized workload allocation, optimized workload allocation with thermal awareness is shown in Fig. 11 and Fig. 12, and can be used to analyse the thermal behaviour of the whitespace.

6.1. Assessment of scenario I: Baseline

The results obtained from the baseline scenario indicate a risk of a hot spot in the top layer of the rack B4 (spot **A** in Fig. 11). The supply air temperature is approximately 18°C, however the inlet temperature of the particular group of servers is approximately 23°C. This rise of temperature is due to infiltration of hot air from the hot aisle to the cold aisle. The ITEU value for the baseline scenario is relatively low at 46%. An increase of the ITEU value and especially the utilization of the servers housed in the top layer would result in a higher potential for hot spots (recirculation of used hot air back to IT devices in this layer) in this location is even higher.

6.2. Assessment of scenario II: Optimized workload allocation

The same amount of IT jobs can be executed with an ITEU of only 19% by optimizing the allocation of workload and switching off unnecessary servers. Lower ITEU values also mean lower heat dissipation into the DC whitespace, thus lower temperatures are observed across the DC whitespace. Since the IT workload is distributed over several servers across the room, the cooling air is taken by servers from the cold aisle area in many places and this causes wider spread of cold air across the space (i.e. the cooling air is dispersed even out of cold aisle area to places without any rack and without any needs of cooling (spot **B** in Fig. 11). Moreover, the cold air distribution tends to bypass the servers, directly returning to the CRAC unit, causing a lower than expected return air temperature (spot **C** in Fig. 11). This is the reason for the decrease in cooling efficiency

6.3. . Assessment of scenario III: Optimized workload allocation with thermal awareness

The ITEU value for the optimized workload allocation with thermal awareness is very similar to the one in scenario II, approximately 18%. The difference is negligible, however the temperature distribution varies significantly. The Thermal awareness scenario ensures that the air will flow along the shortest path from the cold air supply (perforated floor tiles) to the heat source. The cold air is mainly taken by thermally preferable servers in the bottom layer (spot **D** in Fig. 12). The typical cold aisle-hot aisle temperature distribution can be observed in this case. The inlet temperature of all **active** servers is approximately 18°C.

6.4. Summary

The energy savings caused by the optimized workload allocation strategy considering unlimited migration, for the given period mentioned, are in the range of 39 to 41%. These savings are mainly a result of the IT power reduction. Focusing only on the Cooling systems, it results in energy consumption savings of 3.3%. It is worth to note that no adaptive thermal management is considered in this study. All scenarios consider the same baseline control for the Cooling system. This is the main reason of minor savings at HVAC consumption. The HVAC consumption is practically same for each scenario, which leads to increasing of PUE indicator. Part-load efficiency of CRAC unit and constant HVAC set points are the key factors. Currently, HVAC components (e.g. EC fans, variable speed compressor) generally offer sufficient part-load efficiency and a wide operational range, however variable set points are rarely applied due to lack of actuation possibilities at the rack or server levels. With a high-resolution sensor network and thermal aware IT workload distribution, thermal management has enough information and actuation possibilities to limit the optimization of temperature and airflow set points to active servers only.

This SBA indicates a positive influence of the thermal aware IT workload distribution over the DC whitespace environment. The comparison of IT power consumption between scenario II and III (optimized workload allocation with and without thermal awareness) is negligible. The IT workload allocation algorithm is not restricted by the thermal priority input. Dynamic cooperation with an adaptive thermal management would improve savings and demonstrate the full potential of thermal aware computation

7. Conclusion and Future Work

This paper describes a virtual testing approach for data centres capable of capturing the physical dynamic processes occurring in the DC whitespace at a level of resolution that enables performance assessments of thermal aware computational strategy

The motivation and requirements for the development of the virtual DC testbed was discussed and the BES approach was identified as the most suitable method. The virtual DC testbed simulates thermal and energy behaviour to support development and commissioning of novel control strategies for DC. The Building Energy Simulation tool offers suitable compromise between complexity level and computation time, which is crucial for interactive (in the control loop) testing of operational algorithms.

A virtual DC testbed is based on a 30kW bespoke DC and according real DC and its technical documentation. The DC is the demonstration site of the European project Genic Features of the virtual DC testbed is demonstrated by assessing thermal aware computation algorithm. The virtual DC testbed provides energy consumption and temperature distribution results. The influence of different IT workload allocation strategies to the whitespace has been assessed. Three scenarios have been simulated

- Baseline scenario without migration of IT jobs during processing
- Optimized workload allocation allows migration of IT jobs during processing
- Optimized workload allocation allows migration of IT jobs during processing with thermal awareness

The Simulation based assessment of the workload allocation strategies tested proves significant IT power reduction potential by optimizing IT workload allocation. It also shows the positive influence that thermal aware workload allocation operation is able to have on the whitespace temperature distribution. The Simulation based assessment indicates that thermal awareness computation operation does not limit the performance of the IT workload allocation algorithm for the simulation experiments performed, and for the given IT equipment configuration. On the other hand, no significant

energy savings related to the cooling system have been observed. This is due to the fixed set points of the cooling unit considered for the scenarios.
Thermal aware computation will benefit further from the dynamic cooperation between the IT-workload and Thermal managements, as well as from an adaptive thermal operation (variable temperature and airflow set points). A future SBA integrating these elements will show the full potential of thermal aware computation for the DC analysed,

In general this is first stage of virtual testing. The stand-alone IT workload allocation module has been successfully tested in order to evaluate its functionality and to demonstrate the main features of the virtual DC testbed. The next step is to test a group of these modules and further evaluate the performance of the overall supervisory control platform GENiC.

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