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Online Tool to Evaluate the Implementation of Energy Efficiency Strategies and Renewable Energy into Data Centre Portfolio.

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Abstract

Data centre facilities are complex building where their operationally is affected by many factors, such as location, size etc. Moreover, there are several energy efficiency strategies and renewable technologies available in the market. Therefore, reliable tools are mandatory to analyse the current state of data centres and to select the energy efficiency strategies and renewable technologies that fits better in our system. The following paper present a new online tool aimed to evaluate different energy efficiency strategies in pre-design phase, as well of use of renewable-based supply energy systems. The main milestones followed to develop the tool are presented and an example about the utilization of the tool is shown.

Keywords: Data centres, online tool, energy efficiency strategies, renewable energy.

1. Introduction

In the framework of European funded project RenewIT project [1], holistic and dynamic energy models to characterize the overall energy performance and the life-cycle economic impact of data centres have been developed. The final outcome of the project is the RenewIT tool, a public web-site platform, that allows evaluate the implementation of different energy efficiency strategies and renewable-based supply energy systems in the data centre portfolio. The RenewIT tool incorporates some of the most promising electrical and cooling concepts for data centres and is aiming to shows the energetic and economic results for five different data centre configurations in 61 European locations. The computational engine of the tool is based on meta-models which are simplified models generated by surface-response methods from the detailed energy models.

The paper is structured as follows: section 2 describes the strategies and concepts for cooling and power supply; section 3 explains the main steps followed to develop the engine of the tool; section 4 describes the functionality and the parts of the tool: the graphical user interface and the computational engine; finally, section 5 shows an application of the tool and some of the results that is able to provide.

2. Energy Efficency Startegies and Technical Solutions in RenewIT Tool

2.1 Energy Efficiency Strategies

The energy efficiency strategies are technical solutions that can be applied in almost all the data centres and combined with any system to supply cooling and power with or without renewable energy source (RES) to them. Because of the complexity of the data centre infrastructures, it is possible to apply energy efficiency measures over different load demands such as the IT, electrical and cooling. Therefore, it is recommended to start analysing the strategies that allow to reduce as much as possible the load demand, before studying the use of the renewable resources available in the data centre's location. RenewIT tool has the option to calculate the effect of a set of energy efficiency strategies and concepts which are briefly described here.

Efficient IT management

Allocation: The objective of this strategy is to allocate the virtual machines, necessaries to satisfy the IT workload demand, in the minimum number of servers. Therefore some servers are working at full load and the rest are kept in an idle state.

Consolidation: Is a complementary strategy to the allocation method, where the servers that are not being used are turned off, instead of being in an idle state.

IT scheduling: When it is possible, the IT workload can be scheduled according to the availability of RES. For example, a data centre connected to solar PV schedules batch applications to the hours when the solar radiation is higher.

Efficient power distribution

Modular UPS: The design of a modular UPS is based on parallel-connected modules, where each module can be activated or deactivated separately depending on workload, i.e. the capacity of the UPS is adjusted to the magnitude of the power to be transmitted. Thus, the efficiency of UPS system is maximized.

Bypassed UPS: In order to minimize the UPS losses, Bypassed UPS avoids, when is possible, one or both UPS converters. Basically, the conditions that allow us to work with a bypassed UPS, depends on the grid power quality and the relation between the PSU ride-through time and UPS transfer time as is explained in [2].

Efficient cooling distribution

Free cooling: In this strategy, the cooling demand of the data centre is reduced due to utilization of the available natural resources as a source of cooling. An extensive description about types of free cooling and their control strategies applied to data centres can be found in [3].

Hot/Cold aisle containment: It consists to separate the IT room in hot and cold corridors for a better air management. The objective of this strategy is to avoid that air streams were affected by different phenomena such as bypass, recirculation and pressure air drop, decreasing cooling efficiency and creating vicious cycle of rise in local temperature [4].

Variable air flow: With this measure, the airflow supplied to the white space is adjusted to the required cooling load, leading to a reduction of the fans consumption.

Increase allowable IT temperatures: An increased whitespace temperature leads to improves energy efficiency for any type of cooling concept, if proper measures are taken. The main savings come from the fact that an increment of the allowable IT temperatures, results on an increment of the annual hours with free cooling strategy. Moreover, the chiller operates more efficiently at higher chilled water supply temperature [5].

2.2 Technical solutions for cooling and power supply with or without RES

This section presents the technical solutions to provide cooling and power supply to data centre included in the RenewIT tool. The main goals of these solutions are to increase the amount of RES and minimize the operational cost of the system.

Conventional system

This system represents the conventional configuration of a data centre where cooling is provided by vapour compression chillers. The system is included in order to allow the user to study a conventional data centre and evaluate, solely, the potential benefits of some of the energy efficiency measures, which are already included by default in the rest of the concepts, such as: hot/cold aisle containment, free cooling or utilization of high energy efficiency components.

District cooling and heat reuse:

The chilled water for air-cooling is supplied by a district cooling system and the water for direct liquid cooling is cooled by a heat pump, which provides heat for space heating and domestic hot water. This is an interesting option, because allows reach low costs. The concept will be included in the RenewIT tool, because district cooling is becoming a popular system, especially in norther locations, and will be a usual implementation in the near future.

Wet cooling tower:

This system is mainly based on exploit the utilization of free cooling strategy and wet cooling towers. When outdoor temperatures are appropriate direct or evaporative free cooling is used to cold down the data centre. Otherwise, backup vapour compression chillers along with the cooling towers are used to satisfy the cooling demand.

Thermal and electrical energy storage:

Batteries and a water storage tank are used for decoupling power and cooling generation from cooling demand. Nowadays, this system hardly reduce the costs of the data centre due to the high investment cost of these storage technologies compared with the low savings achieved on the operational expenditures. Even so, this system will be in the RenewIT tool as the inclusion of storage technologies to optimize the data centre operation might be an option in the near future with increasing differences of electricity prices between peak and peak-off periods.

Biogas fuel cell:

A biogas-fed fuel cell is applied for generating both power and heat, which is used for driving an absorption chiller during summer. In winter, indirect air free cooling avoids the operation of the chillers. The waste heat from the fuel cell can be recovered for space heating or might also be dissipated by a wet cooling tower. This concept has good results from an economic and environmental point of view, if there is the possibility of export heat and power.

Reciprocating engine CHP with biogas:

This concept is based on biogas-fed tri-generation by means of a reciprocating engine CHP plant. The heat from this plant is used for driving a single-effect absorption chiller during summer and to provide space heating for offices or buildings close to the data centre. Additionally, indirect air free cooling is implemented during winter. As in the previous case, this system shows good results from an energetic and economical point of view, due to the possibility of export heat and power. The CHP systems with heat reuse are a basic and popular option already, so the consortium will include two concepts related with this technology.

3 Methodology for the Engine Development

3.1 Selection of the Technical Solutions Based on Dynamic Simulations

The RenewIT project has evaluated a total of 18 different technical solutions for provide electrical and cooling energy to data centre. After a preliminary evaluation of the concepts 4 of them have been discarded, due to the low primary energy savings achieved versus the high investment and operational costs of the systems. Later on, the rest are modelled and evaluated though dynamics simulations in TRNSYS [6]. Finally, six of the most promising technical concepts have been selected, which are described in section 2.2.

Each of the 14 concepts has his own model, and each model is composed by different subsystems. There are more than 800 parameters identified during the modelling phase which characterize each concept. These parameters have been categorised, in three types: variables, constants and computed parameters. This classification, allows control all the parameters and correlations of the models from outside facilitating the parametric analysis of the concepts.

The parameters and inputs quantities feds into the energy models effects on the results of the model during the dynamic simulation. Therefore, it’s important to study the potential of the concepts by means of a multi-dimensional analysis considering multiple scenarios. For this, a Monte Carlo sampling of the parameter space and 100 simulations with one year duration were performed, for each concept. The performances of the concepts are evaluated through the most important metrics defined in of the project [7], both environmental and economic indicators. For the selection of the technical solutions, not only the quantitative results of the concept are taken into account also the qualitative analysis provide by real case studies linked to the RenewIT project [8]. Due to the huge variation of requirements suggested by data centre owners, the consortium considers interesting to include concepts with different technologies. Therefore, the final comparison is done between concepts with similar technologies and the best of them are implemented in the RenewIT Tool.

3.2 Meta-models Development

TRNSYS simulations cannot be used as the engine of the tool due to the high computational time required by these simulations. Therefore, the engine of the tool will be based on meta-models, which are a simplified models generated by surface-response methods from detailed dynamic models. This methodology allows us to improve the time response of the tool without compromise the reliability of the results.

Before start with the development of meta-models a sensitivity analysis is performed, for the selected concepts, along the input parameters space. The aim was screen the parameters of negligible relevance in the simulations results and remove them from the sampling before proceeding with metamodeling, minimizing the simulations needed and maintaining the simulation time within a reasonable scale. For this, a Morris method is used. The results showed a high degree of interaction among parameters for most of the concepts. After this analysis, the set of most influent parameters for each of the concepts are known, and the metamodeling phase of the concepts is started.

Once completed this exploratory analysis, several functional transformations for the initial parameters are tested and a handmade variable selection has been performed iteratively and interactively (introducing new parameters one by one and considering new transformations based on the results). The aim was to obtain a final model with a good predictive behaviour. In this phase, the information used for this filtering iterative work has been:

- The R-square coefficients, as a goodness-of-fit measure
- The t-statistics of the fits.
- The analysis of the relative residuals.

Furthermore, only statistically significant variables are introduced in the final model. Multicollinearity is taken into account and some redundant variables are eliminated, but some collinear variables are kept in the final equation because they do not reduce the reliability of the model and, moreover, it is observed that coefficients do not change erratically with small data changes. In Jobson et al [9] there is a complete discussion on linear models analysis. Figure 1 shows the results a version of the meta-model that will be used to model the IT power consumption. It shows how the meta-model fits the simulation results values and the distribution of its error.

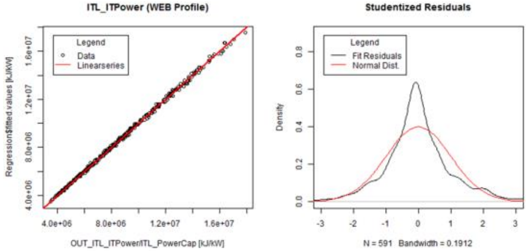

Fig. 1 Lineal fitting and error distribution of meta-model: IT power consumption

At the end of the mathematical process, several models are evaluated. The models finally selected are chosen because they balance simplicity and goodness of fit. In order to calculate all the outputs included in the RenewIT tool, has been necessary to develop more than 95 meta-models for different outputs of the simulation results.

4 Description of the RenewIT Tool

4.1 Functionality and structure

The RenewIT tool is oriented to planners, managers, investors, owners and designers of the data centres interested to evaluate the implementation of energy efficiency strategies and renewable energies in their facilities. The tool allows evaluate the performance of different data centre configurations in different European locations, and compare the results of up to five different scenarios. The results are provided from an energetic and economic point of view, where a variety of metrics and visualization methodologies are used to understand the differences between scenarios.

4.2 Graphical User Interface

The Graphical User Interface (GUI) of the RenewIT tool is divided in six different sections, which allow the user to define the characteristics of the data centre that wants evaluate, and after the calculation process shows the results obtained for such scenario.

The first section defines the general information of the data centre, such as location and different energy factors associated to the location as the share of renewables in the electrical grid or the electricity prices. Moreover, the user will define the period for the economic analysis, Figure 2. In section two, the user is requested to fill the information related with the IT infrastructure, such as the IT power capacity, IT workload, IT safety margin factor, average rack density etc. Additionally in this section the user can select the efficient IT management policies that have been explained above in section 2.1.

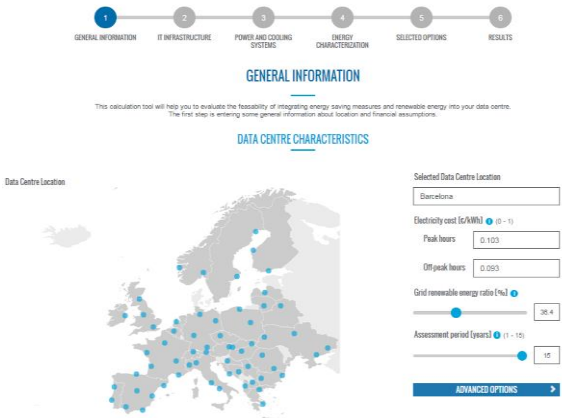

Fig. 2 General information section in the RenewIT tool Graphical User Interface (GUI)

In the third section, the user must select one of the technical solutions already described in section 2.2, depending on the concept will be necessary to introduce some extra parameters such as the ratio of cooling provided by air and liquid cooling systems or the amount of heat generated with CHP that can be reuse. In section four the user can select to apply one of the efficient cooling and power management strategies described in section 2.1. Additionally, the tool gives the possibility to include two kinds of renewable energies, solar panels or wind turbines. The sizing of the solar panels can be done defining the total installed solar power or the available square meters. In a similar way, the size of the wind turbine installation can be defined introducing the total installed wind power or defining the number of wind turbines. Due to the wide range of data centre sizes, two different wind turbines can be implemented small size and medium size, 50 kW and 600kW respectively. Section 5 shows a summary of the parameters defined. The last section of the tool, section 6, is focus on providing a detailed analysis of the results through three different visualization methodologies. In the first one, called scenario tab, it’s possible to analyse solely the metrics of one scenario, where the relative metrics are calculated respect a reference case which is automatically generated. In the second one, called comparison tab, the most important metrics to evaluate the data centre performance are compared between scenarios. Finally, in the third one, called relative comparison tab, it is possible to realize a detailed comparison between two scenarios, where the relative metrics will be computed between them.

4.3 Computational Engine

The engine of the tool is in charge of process the complex request of the user, such as the energetic and economic analysis of the scenario or the exportation of results by email. Due to the flexible programming of the GUI this interaction between user and server is kept decoupled until that the user press the calculate button. After that, the GUI sends a class, thought the URL, with all the parameters that the user has defined. This information is managed by the engine to calculate the energetic and economic expenditures of the scenario. In order to do that the engine realizes a set of calls to the meta-models, in order to feed them with the inputs and parameters necessaries to compute the outputs. Moreover, the engine realizes some calls to data bases in order to enrich the meta-models with additional data.

5 RenewIT Tool Case Study and Results

This section shows the evaluation of a case study using the RenewIT tool. The results are explained depicting graphical outputs from the GUI. Due to lack of space only the results of one concept and location are presented. Nevertheless, the tool is able to evaluate the performance of a concept in different locations, being that extremely relevant as it has shown by Depoorter et al [10].

The example analysed evaluates the potential benefits introduced by some of the energy efficiency measures and renewable energies available in the tool. For this, a conventional Data centre of 1,000kW located in Barcelona is used as reference case. The IT workload is set to HPC, the IT safety margin factor is increased to 0.9, and for the economic analysis, the assessment period is set to 15 years and the cost of the CO_2 emission is considered. The rest of parameters are kept with default values. After that, four new scenarios are added where in each new scenario is accumulated the implementation of different energy efficiency measures. Furthermore, in the last scenario a PV system is added. The set of scenarios and the new energy efficiency measures introduced in each case are listed in Table 1.

The non-renewable primary energy is defined as the energy required to supply one unit of delivered energy, taking account of the non-renewable energy required for extraction, processing, storage, transport, and any other operations necessary for delivery it to the data centre. The conversion from delivered energy to the amount of non-renewable primary energy required is done though the non-renewable primary energy factors. The total cost of ownership (TCO) is calculated as the sum of the investment and operational expenditures (CAPEX and OPEX) of the data centre. Savings of the non-renewable primary energy ($PE,_{DC,nren}$) and total cost of ownership (TCO) for each scenario are calculated respect to the reference scenario and presented in Table 1.

Table 1. New energy efficiency measures added, PV power installed and savings achieved in each scenario.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Energy Efficiency measure	*None*	*Consolidation*	*Hot/Cold aisle containment and High energy efficency components*	*Variable airflow, Increase White space Delta T and Increase inlet air Temp (21 to 25ºC)*	*Modular UPS and Enhance UPS converter*
PV Capacity [kWp]	-	-	-	-	*2,500*
$PE,_{DC,nren}$ savings [%]	-	*3.48*	*15.82*	*18.65*	*72.76*
TCO savings [%]	-	*1.52*	*6.46*	*7.69*	*19.34*

As can be appreciated, after the implementation of the measures listed, the total reduction achieved is 72% over the $PE,_{DC,nren}$ consumption, where a 50% of the savings comes from the utilization of the PV system. These reduction on the $PE,_{DC,nren}$, leads to a 19% of savings in the TCO. In order to know in more detail the effectiveness of the energy production and distribution, the power usage effectiveness (PUE) and cooling seasonal performance cooling factor (SPF) metrics are analysed. The PUE is calculated as the total energy consumption of the data centre divided by the IT power consumption, and gives the relation of the extra amount of power consumed in order to keep the servers working properly. The SPF metric calculates the relation between the cooling energy produced and the amount of electrical energy consumed to produce it, showing the efficiency of the cooling system. Figure 3 shows how the results are presented in the RenewIT tool GUI. Table 2 depicts the evolution of the PUE and SPF between scenarios.

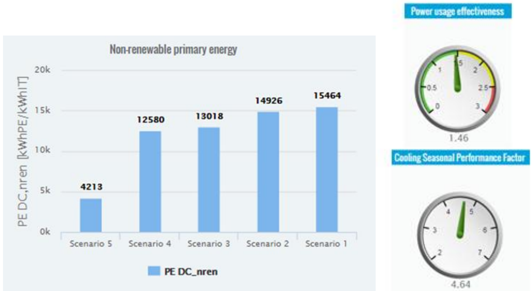

Fig. 3 Left: PE,$_{DC,nren}$ of all scenarios (comparison tab) Right: PUE and SPF of scenario 5 (scenario tab)

Table 2. Evolution of PUE and SPF along the scenarios.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
PUE [-]	1.81	1.83	1.6	1.54	1.46
SPF [-]	2.24	2.2	3.84	4.64	4.64

Analysing the results from Table 2, it can be observed how the SPF metric is only affected by application of thermal energy efficiencies measures as it is expected, scenario 3 and 4. The SPF of the reference case is 2.24 and after the implementation taken increases until 4.64, indicating that the cooling production and distribution is improved in almost a 50%. The PUE value is affected by all the improvements done, the initial value is 1.81 and after the implementations it reaches a value of 1.46. An interesting fact, important to know in order to not misunderstand the metric, is that PUE value increases after the implementation of consolidation, because consolidation achieves a reduction of the IT power, which is the denominator of the PUE equation.

Looking at the comparison tab, one can see the evolution of the renewable energy ratio (RER) after the implementation of the PV system (Figure 4, left). The RER measures the percentage of energy consumed by the data centre that comes from renewable sources. When the system do not account with PV installation, scenario 1 to 4, the RER value is kept to 20% which is the RER of the grid. After the implementation of the PV system the RER increases up to 61%. This implies save 2,151 tons of CO_2 emissions. The reductions achieved in the OPEX and the increment on the CAPEX can be observed in Figure 4 (right) which is produced by RenewIT tool GUI. The CAPEX has increased in 2,700,000€ after the energy efficiency measure taken and the implementation of the PV system in scenario 5, respect the CAPEX of scenario 1. In contrast, the OPEX has been reduced in approximately 500,000 €/year. Therefore, with the data provided by the tool, it is possible to estimate the return of the investment for the measures and implementations done.

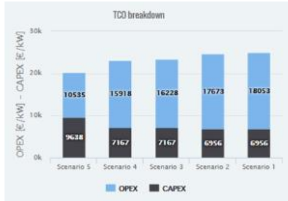

Fig. 4 Left: RER for scenario 4 and 5. Right: overlapped OPEX and CAPEX, of each scenario

6. Conclusions

A friendly-user tool in order to evaluate different technical solutions and energy efficiency strategies for energy systems in data centre has been developed. The GUI of the tool has been carried out considering the different potential users. Therefore, a big effort has been done in order to reduce as much as possible the number of parameters in the GUI, simplifying the user interaction. The engine of the tool is based on meta-models. This methodology allows to reproduce complex calculations with reliability, in a shorter period of time. This is really interesting for web tool applications, where time response is a key factor. The technical solutions and the main energy efficiency strategies included in the tool are described. Additionally, an example is presented showing some of the main metrics and visualization options available in the tool.

Acknowledgment

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