Extending the use of parametric simulation in practice through a cloud based online service

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Abstract

The aim of the present research is to facilitate the implementation of parametric energy studies among the Architecture, Engineering & Construction (AEC) industry by creating an online service to execute parametric energy simulations using cloud computing.

A web-based service was developed to submit parametric simulations based on the open-source energy simulation program EnergyPlus. An adapted version of jEPlus (parametric shell for EnergyPlus) was created to handle the jobs execution on the VENUS-C [1] cloud infrastructure. In addition, a web client called HUB-Engineering (HUB-E) was developed. The latter allows submissions of parametric simulations and results retrieval from any device connected to the internet. The results can be visualized and explored with a freeware interactive Parallel Coordinates Plot (PCP).

Finally, a workflow is proposed to integrate the online cloud-based service within design processes of architectural and engineering practices. The workflow is tested with the parametric simulation of the energy performance of a building simulating 221,184 design options. By developing the first version of the service, which will be accessible to the AEC community, and by testing it successfully, the research shows the potential impact of cloud computing when coupled with parametric energy simulation.

1. Introduction

1.1 Background

On a global average, building-related activities consume more than 40% of a country's energy. The reduction of new and existing buildings' energy consumption is an issue that the AEC industry is facing. The effective use of parametric building performance simulation can contribute by optimizing building energy design, as it allows in-depth analysis.

In general, there are two strategies (Fig. 1) for thinking about the generation and evaluation of design alternatives: the conventional way is to generate a model, evaluate it, change design variables, re-evaluate the model, change design variables again, and so forth, until the final design is satisfactory. Conversely, a parametric strategy consists of generating several design solutions at the same time, evaluating them by the desired criteria and choosing the most "performative" one.

Thus, parametric studies show a wider range of solutions and contribute to maximum energy savings (Paoletti et al., 2011; Pratt et al., 2011). Despite this potential, parametric energy studies are rarely used because they require a long time to run the computations as well as powerful hardware. Complex and detailed parametric analysis models require simulation to a scale that is nowadays only available to large private, academic and government research laboratories.

There are two ways to extend the use of parametric simulation to a large group of users: either reduce the number of computations by using optimization algorithms (e.g., Coley and Schukat 2002; Nielsen 2002; Wetter and Wright 2004) or increase the computational power by using parallel executions of EnergyPlus using local computer clusters (Zhang 2010; Garg et al., 2010; Zhang et al., 2010; Hopkins et al., 2011; Pratt 2011).

However, the use of cloud infrastructures is still a novel approach (Hopkins et al 2011; Li et al 2011; Burton et al., 2012). Therefore, the present research focuses on developing a fast and user-friendly online service to run parametric studies on the cloud, allowing a quick evaluation of many design alternatives. The service is based on the parametric shell jEPlus v1.3. In a future research, a more recent version named jEplus+EA, which uses an optimization algorithm (GenOpt [2]), can be implemented to evaluate the potential of coupling cloud computing with optimization techniques.

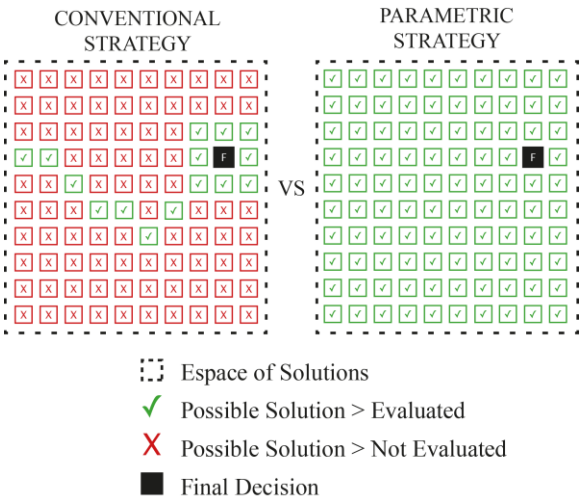

Fig. 1 – Conventional strategy vs. parametric strategy

1.2 The research project

One of the aims of this research project is to use an industry-quality, highly scalable, and flexible Cloud Computing infrastructure to empower parametric energy simulations through the easy deployment of an end-user service for architects and engineers.

This was done by creating a structure that allows the running of EnergyPlus [3], a whole building energy simulation program, on the Venus-C Cloud infrastructure through the adaptation of jEplus [4] and the development of the web client HUB-E [5].

One of the objectives of this paper is to structure the general workflow (Fig. 2) of the developed online service that allows its incorporation into building design practice. The description of reduced computational time and the possibilities of energy savings achieved by the service is introduced.

2. Online Service

The architecture of the proposed service includes four layers:

- The VENUS-C infrastructure provides the virtualization layer where to execute the simulations;
- The platform level includes the COMPSs programming framework (Lezzi at all., 2011), onto which jEplus is ported;
- The HUB-E website implements the client interface for submitting and managing jobs on the cloud;
- The Protovis-based, high-dimensional visualization tool allows for the analysis and presentation of results.

2.1 VENUS-C infrastructure and COMPSs

Venus C (Virtual Multidisciplinary EnviroNments USing Cloud Infrastructures) is funded under the European Commission's 7th Framework Programme. Developed in the Barcelona Supercomputing Center (BSC), the COMP Superscalar (COMPSs) is a programming framework to provide users with interoperability and dynamic scalability of computational resources in the context of the VENUS-C platform.

Multi-threaded processes can be migrated to the Venus-C platform by implementing a Java wrapper that incorporates the COMPSs workflow (Lezzi at all., 2011). This approach significantly simplifies the process of implementing multiple EnergyPlus executions into the cloud.

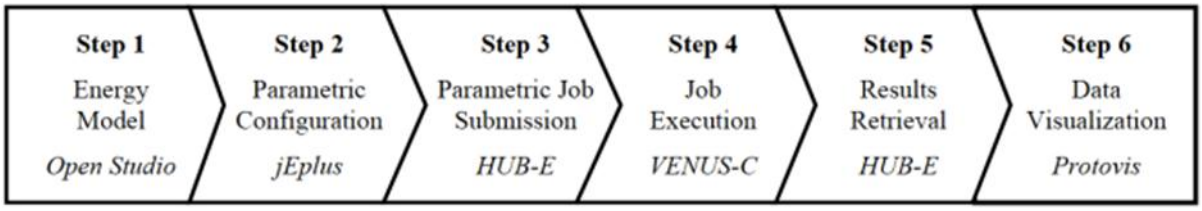

Fig. 2 – Proposed workflow

2.2 jEplus-VenusC

jEplus is an EnergyPlus simulation manager designed especially for parametric studies (Zhang, 2009).

It can carry out parallel executions of EnergyPlus models on various platforms, including multi-core computers, computer networks, and clusters.

The porting of jEpus to the Venus-C platform further expands its capability. jEplus-VenusC is the developed execution agent that implements COMPs' workflow using APIs. Users can now submit jEplus-VenusC, EnergyPlus executables, and jEplus project files to the Venus-C platform in order to run simulations on the cloud.

2.3 HUB-E client interface

Engineering HUB (HUB-E) is a web-based platform that provides cloud-powered services for architects and civil engineers. HUB-E is adapted to the VENUS-C Infrastructure and it is the component that allows users to interact with the cloud, submit the energy parametric package files and retrieve results with a user-friendly graphical interface.

HUB-E is connected to the Barcelona Supercomputing Center (BSC), where the simulations are run. The available hardware infrastructure consists of 80 cores:

- Nodes with 12 Intel Xeon X5650 Six Core at 2.6GHz processors, 24GB of memory and 2TB of storage each;
- Nodes with 16 AMD Opteron 6140 Eight Core at 2.6GHz processors, 32GB of memory and 2TB of storage each.

2.4 PROTOVIS visualization tool

Protovis.js [6] is an open-source script that allows users to create Parallel Coordinate Plot (PCP) graphs. PCP is interactive and manages high-dimensional data sets, allowing a quick interpretation of the results. This way architects are able to determine the most efficient design option among several of them.

3. Proposed Workflow

For the purpose of making parametric energy studies accessible to architects and engineers beyond the research community, special attention was paid to inter-operability, user-friendliness and usage of open-source services. An architectural design-oriented workflow (Fig. 2) was designed. The first step of a six-step workflow (see below) is based on any of the third-party EnergyPlus interfaces. The second step uses jEplus and steps three to six are implemented using the developed online service. The actual version of the online service has integrated the third to fifth steps, while the sixth and final step has been partially implemented and this step will be subject to further refinements.

3.1 Step 1: Energy model

The designer creates the energy model with a tool that is able to generate *EnergyPlus input files* (.IDF, .RVI), such as OpenStudio [7] or DesignBuilder [8]. Other user-friendly EnergyPlus GUIs can be used, such as Ecotect [9] or Vasari [10] (Fig. 3).

3.2 Step 2: Parametric configuration

The parametric study is defined by jEplus, which allows the user to set different options to be tested (i.e. types of windows). Once the parameters are configured, the project is saved and packed in a ZIP file together with the files described in step 1 and the weather file(s) (EPW) (Fig. 4).

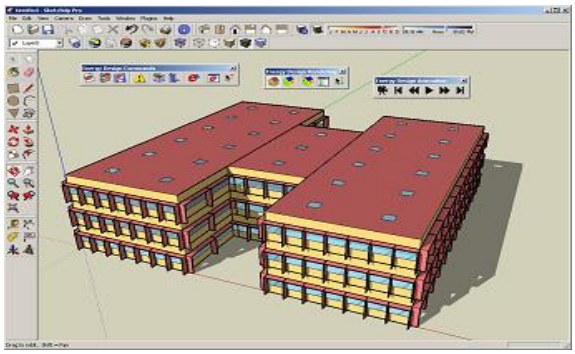

Fig. 3 – Step 1, Energy model (OpenStudio)

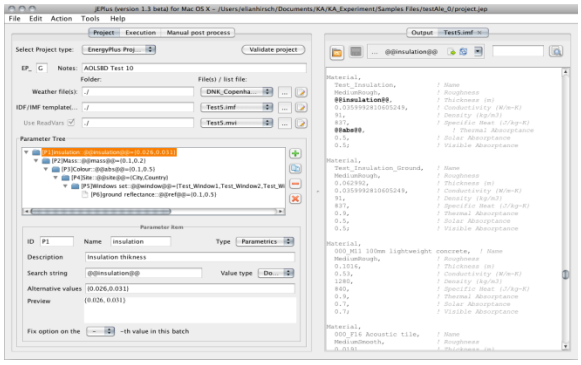

Fig. 4 – Step 2, Parametric Configuration

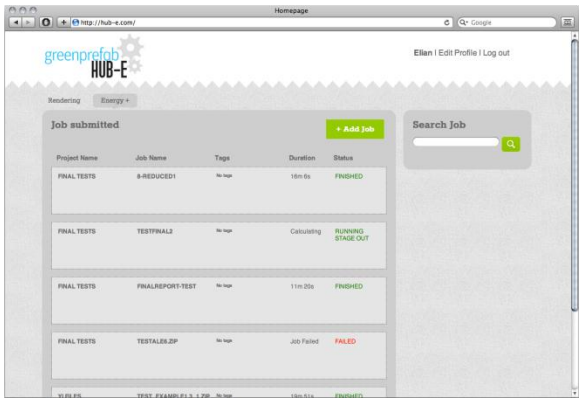

Fig. 5 – Step 4, Job submission, execution and retrieval results (HUB-E)

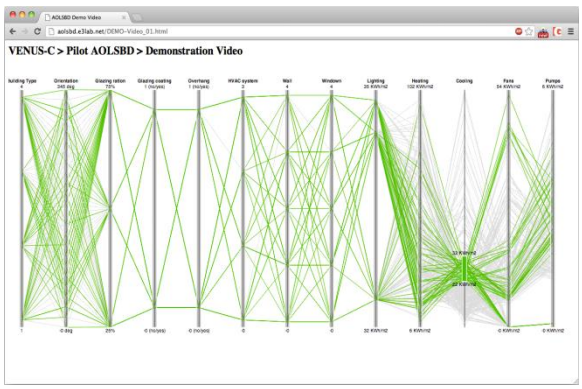

Fig. 6 – Step 6, Data visualization (PCP)

3.3 Step 3: Parametric job submission

The user logs into www.hub-e.com and creates a new "Parametric Job", assigns tags to it, uploads the ZIP file, and executes it.

3.4 Step 4: Job Execution

Once the parametric job is submitted, the user is redirected to a "Jobs List" where jEplus jobs are ordered by submission dates and displayed with their corresponding statuses as well as the duration of the simulations (Fig. 5).

3.5 Step 5: Results retrieval

When the execution is finalized, the job status will read "Finished" after which the user can download the results in a zipped file (three CSV files). The SimResult.csv file shows a raw data output.

3.6 Step 6: Data visualization

Finally, the user is able to post-process results by using any spreadsheet application and high-dimensional visualizing tool such as Parallel Coordinates Plot (PCP) (Fig. 6).

4. Test case

The beta version of the online service was tested by a selected architect with basic skills of energy modeling and a good understanding of building energy design. He created a large parametric experiment of architectural optimization with 221,184 variable combinations. The objective is to show how, by using the proposed workflow, an architect could address an energy design problem with methods that are usually only accessible to a few research centers equipped with computation clusters.

A "shoe box" energy model was designed using OpenStudio. The test building has a total floor area of 1600 m^2 and four thermal zones (Fig. 7) and it is located in Copenhagen. Occupancy, internal gains and thermostat-schedule settings are those of a standard office.

4.1 Variables

The test case model was parametrized as followed:

- Ground reflectance: 3 steps, from white to black;
- Orientation: 16 discrete 22,5 degrees increments of rotation;
- Façade color: 3 different solar absorption coefficients of the external walls;
- Insulation thickness of external walls: 8 steps that progressively increase from 0.12 m to 0.4 m.
- Glass type: 6 different window sets within the following ranges: U-value (0.6-1.4 W/m²K), SHGC factor (0.4-0.7) and VT (0.55-0.8);
- Thermal mass: 4 different concrete thicknesses (external walls) ranging from 0.1 m to 0.4 m;
- Overhangs depth: 4 steps that progressively increase from 0 m to 1.2 m;
- Ground floor assembly: 2 different floor assemblies, heavy and light, of 0.4 m and 0.1 m of concrete thickness, respectively.

All of the above constructive solutions comply with the Danish standard BR10 [11]. "Ideal air loads heating energy" and "ideal air loads cooling energy" (annual) are the output variables added in the .rvi file.

In order to understand the applicability and the advantages of the proposed service in comparison to conventional ways of utilizing simulations, a parallel experiment was conducted. Starting from the same "shoe box" model, the same architect was asked to optimize the building performance in accordance with his typical design routine. He tested 50 design options (according to his intuition, expertise and experience) with a standard dual-core pc.

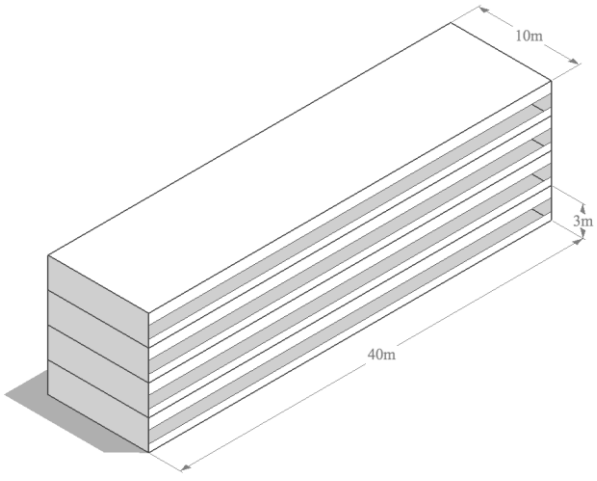

Fig. 7 – Building energy model

5. Discussion and results

There are two main factors of interest to be compared between a conventional workflow and the one proposed here: the time it takes to run the computations and the level of energy saving potential.

Figure 8 shows the time comparison between the conventional design and our cloud-based workflow. Even though the proposed cloud-based design requires approximately double the time, the clear advantage is related to the larger number of design alternatives (221,184 vs. 50). It is worth mentioning that the computational time for running the parametric simulation in the cloud was 71 hours and 20 minutes (1.17 seconds per job) and that such a large experiment, if run on a standard dual-core pc, would take 122 days.

Despite the fact that the analysis of the test case results is not the scope of this paper, a brief description is given.

This description is presented to highlight the "energy saving potential" of the proposed workflow. Figure 9 compares energy consumptions (heating and cooling) obtainable by a conventional design approach to parametric simulation processes performed on a desktop computer, a cluster and on the proposed cloud service, respectively. According to the available cpu power and the time of computation, a number of variables deemed relevant by the authors were selected and investigated.

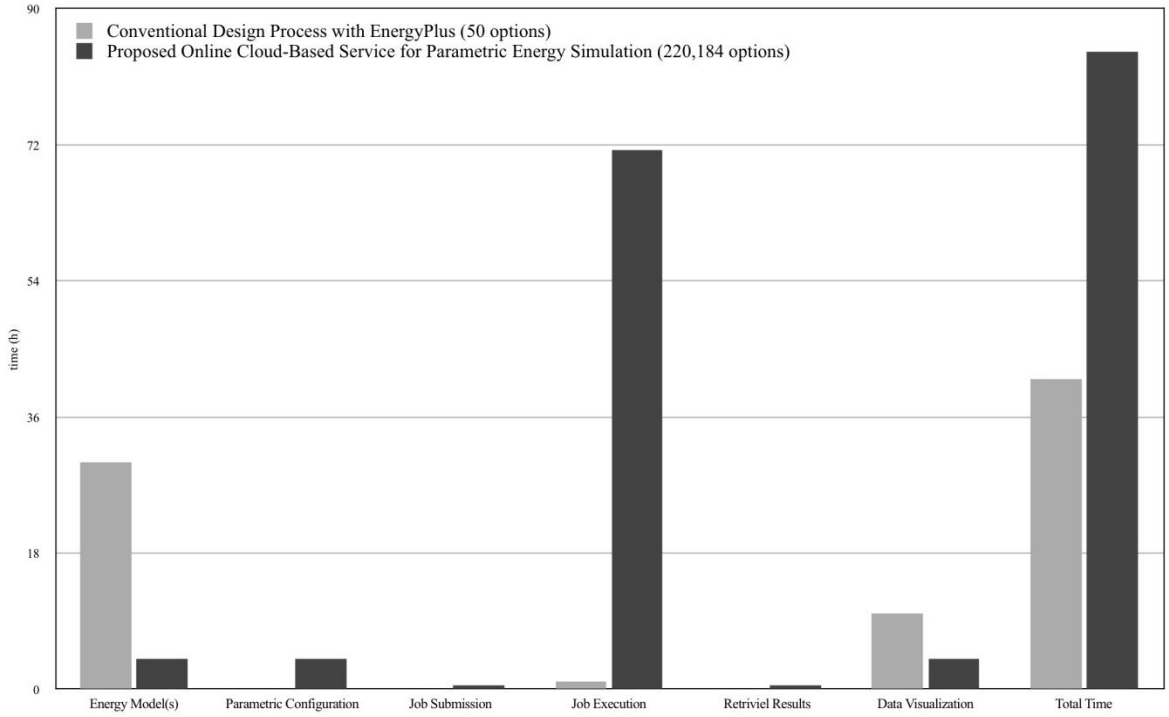

Fig. 8 – Time comparison: conventional design vs. proposed workflow

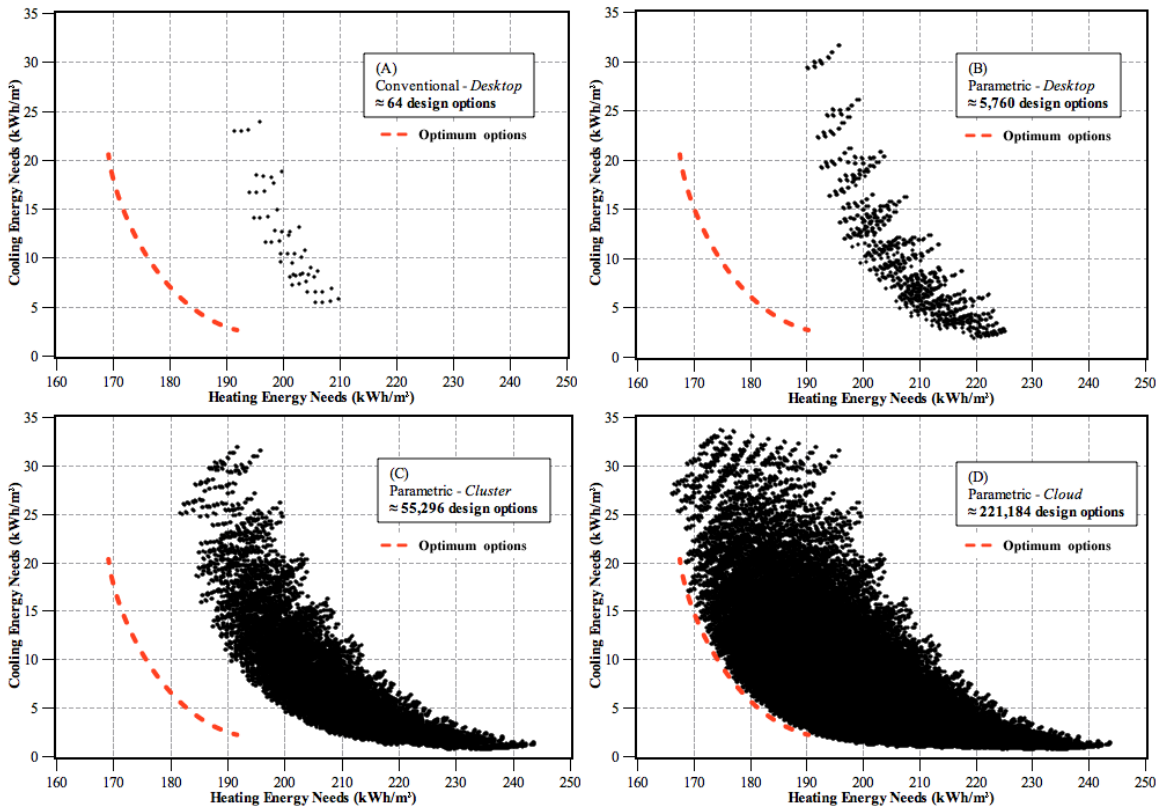

Fig. 9 – Energy comparison: conventional workflow vs. proposed workflow

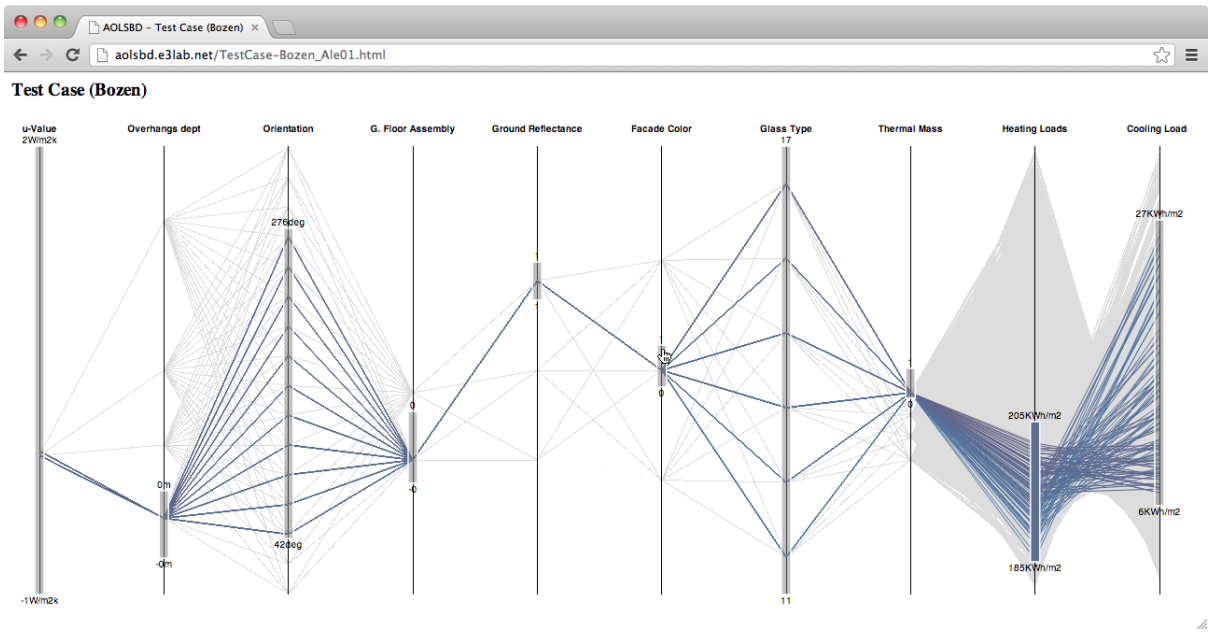

Fig. 10 – Parallel Coordinate Plot representing the results of the experiment

71.3 Hours (time used by the Cloud) was taken as a reference point to analyze how many jobs could run on a desktop computer and on a standard cluster (Table 1).

	Cores	Time	Design options
Desktop PC	2	71.3 h	5,760
Cluster	20	71.3 h	55,296
Cloud	80	71.3 h	221,184

Table 1 – Design options according to computational time

The graph, which illustrates the comparison of heating and cooling shows how the increasing number of variables lead to a range of simulations closer to the optimum set of solution (red curve). For instance, the cloud-based parametric study allows to reach the design option with the lowest heating energy need (166,09 kWh/m2). When comparing such a value with the best performance obtained with a conventional design process using a desktop PC, the energy saving is increased by 33%.

Finally, in order to understand the relationship between design variables and energy consumption, an interactive PCP was created (Fig. 10).

This allows architects to quickly visualize the most "performative" solutions filtering the results through selected variables.

6. Conclusion

The authors have identified and developed an open-source and cloud-based service that can be applied in architectural and engineering practices, spreading the use of parametric energy simulation beyond the confinements of research centers.

The developed cloud-based workflow is user-friendly and suitable for architects familiar with energy simulation. It has been shown that it significantly reduces computational time for parametric simulations and that it could reduce buildings energy consumption to a higher degree than in a conventional design process.

The online service needs some further development, particularly with respect to completing the incorporation of the interactive Parallel Coordinate Plot into the online service and conducting a pilot study for architectural and engineering practices. In addition, further developments should include the implementation of optimization algorithms into the proposed workflow.

7. Acknowledgements

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