Performing complex parametric simulations with jEPlus

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ABSTRACT: Parametric study is a useful method for exploring alternative design options and establishing dependencies between design variables. The development of an open-source research tool, jEPlus, has been reported in 2009. The tool is designed to assist setting up parametric runs with EnergyPlus models, and to perform the simulations in "parallel" mode. This paper uses an example to demonstrate how jEPlus can be used for setting up complex parametric runs. In the example, four different building types and five HVAC system configurations were considered along with design parameters including insulation, glazing, temperature set points and day lighting control options. Further more, the simulations were carried out in three different climatic regions. Given that the total number of simulations exceeds 30,000, it would have been a tedious, if not impossible, job to set them up manually. jEPlus made it trivial, however, by automating the tasks such as generating input files for EnergyPlus, executing simulations, and extracting results.

Keywords: EnergyPlus, parametric study, jEPlus, HVAC, building simulation

1. INTRODUCTION

Parametric analysis is a powerful method for exploring design options and establishing parameter dependencies of the solutions. jEPlus has been developed [1] since 2009, and subsequently made available as an open-source project, to provide a tool for managing parametric simulations with EnergyPlus [2]. This paper uses a complex parametric design case to demonstrate the use of jEPlus in conjunction with EP-Macro (a pre-processing utility provided with EnergyPlus [3]). The theme of the case study is selecting building fabrics, layout and HVAC systems for typical office buildings in various UK regions. Some of the results of this study have been published in [4] [5] and [6].

2. JEPLUS

Since its introduction in September, 2009, jEPlus has been downloaded more than 200 times. The concept of jEPlus is fairly simple: it allows users to describe the parameters and their values in a graphical user interface; then automatically creates and carries out EnergyPlus simulation jobs. Index files are also created to assist users locating results. The conception is illustrated in Fig. 1. The distinct features offered by jEPlus include:

- Unique parameter tree for defining complex parametrics;
- Flexible syntax for specifying parameter values;
- Parallel simulation controller to make full use of the available computer processors;
- Index of simulation jobs are provided in both Excel (.csv) and database (.sql) formats;
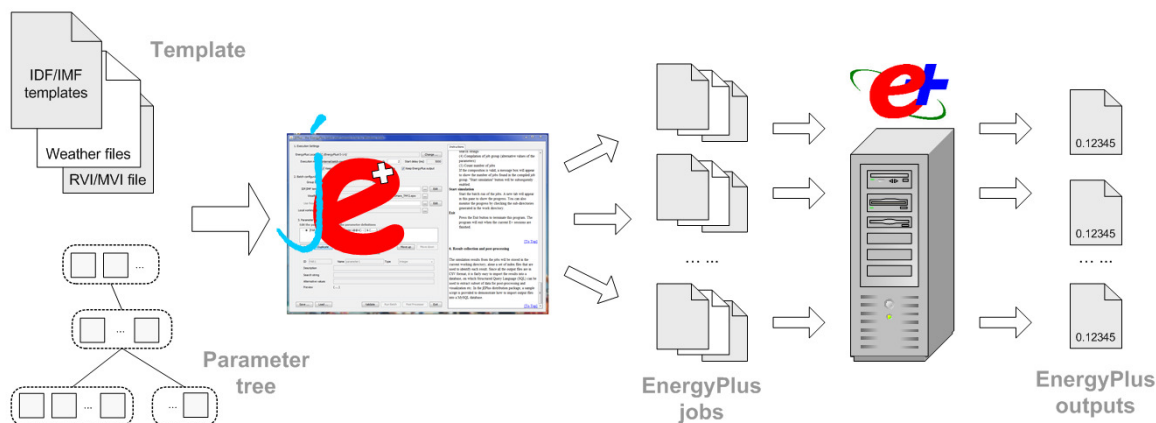- Supports both Windows and Linux versions of EnergyPlus.

Figure 1. The concept of jEPlus

3. WORKING WITH EP-MACRO

The EP-Macro program is provided as part of the EnergyPlus package, for advanced users. The pre-processing tool provides the following functions that allow users to:

- store blocks of model definition as separate files and incorporated in the main model file ("**##include**");
- conditionally activate/deactivate parts of model definition ("**##if … ##else …**");
- define parametric blocks ("**##def**");
- perform arithmetic and logic operations on parameters and values ("**#eval[...]**").

Working with EP-Macro, jEPlus can take blocks of EnergyPlus model as a single parameter that are useful for synchronous change of values at different places in the model and replace large chunks of model definition. For example, the following code is used to switch HVAC systems in the building model:

List 1. Example of "**##include**"

```
!- Use HVAC system type, choose from:
!-    sys0 (for ideal load system)
!-    sys1 (for CAV system)
!-    sys2 (for VAV system)
!-    sys3 (for FC+OA system)
!-    sys4 (for ChCl+OA system)
##include building1_@@HVAC@@.inp
…
```

jEPlus will search for "**@@HVAC@@**" and replace it with the correct system name, so that EP-Macro can import the HVAC system definition from the external file.

The next example shows the use of EP-Macro parameter blocks:

List 2. Example of "**##set1**", which is equivalent to "**##def … ##enddef**"

```
!- Insulation level, choose from:
!-    Best_Practice
!-    2002_Part_L
!-    1995_Part_L
!-    1990_Part_L
!-    uninsulated
##set1 INSULATION_LEVEL @@ fabrics@@
…
… (Elsewhere in body)
…
BuildingSurface:Detailed,
    F1Z1_floor, !- Name
    Floor, !- Surface Type
    Solid ground floor - INSULATION_LEVEL[],
    F1Z1,!- Zone Name
    GROUND,!- Outside Boundary Condition
    ,!- Outside Boundary Condition Object
    …
…
```

Again, jEPlus will search for "**@@fabrics@@**" and replace it with the correct building fabric standard name, so that EP-Macro can pointing all surfaces to the right materials and constructions specified in the "Materials" section.

jEPlus does NOT check linked files for inclusion. It first processes the main model file (a .imf if EP-Macro is used), before calling EP-Macro. The output of EP-Macro will be processed for a second time; therefore all search tags in the inclusion files will be replaced as well. However, due this approach and the limitations with EP-Macro itself, following constraints apply:

- EP-Macro processes inclusion before parametric blocks; therefore file names can NOT be defined as a parametric block;
- Parametric blocks are processed sequentially by EP-Macro. Dependency between parameters has to be check manually;
- jEPlus search tags can be placed in the EP-Macro's "**##include**" commands, but ONLY in the main model (.imf) file
- jEPlus search tags can be placed in the EP-Macro's "**##def**" commands anywhere in the model. However, if the parametric block is involved in subsequent "**##eval[...]**" commands, it should be defined in the main model file.

4. TEST CASE

A test case has been prepared to demonstrate the use of jEPlus in complex parametric simulations. The models of two building shapes (i.e. square and rectangular) with two floor layouts (open-plan and cellular offices) each, have been developed.

The building fabrics and glazing systems follows five levels of standard according to present and past British Building Regulations to represent a range of existing buildings constructed during the past decades. These standards include the current UK Best Practice, Part L 2002, Part L 1995, Part L 1990, and buildings with minimum insulation provisions.

The levels of glazing ratio (25%, 50% and 75%), the reflective coating options, and external shading devices (overhang present or otherwise) were also considered as design options.

Six HVAC systems were tested, including the "ideal load" system that serves as a reference. The other five systems are a constant air volume system (CAV), a variable air volume system (CAV), a Fan-coil and dedicated fresh air system (Fan-coid), and two chilled ceiling systems (with aluminium radiation panel or embedded pipes, respectively) (Chilled Ceiling).

The buildings were further tested for orientation, on which they are rotated at 45 degree intervals. Three sets of weather data for Scotland, North England and London (Southeast England) were used to provide a reasonable coverage of the geographical and climatic diversity of the UK.

In total, there were 34,560 simulations to be carried out. Since the simulation results are not of interest in this paper, further model details are omitted.

5. PARAMETRIC CONFIGURATION

To define the 34,560 jobs in jEPlus, 49 EnergyPlus input file plus three weather files were required, which were substantially fewer than preparing the jobs manually. Fig. 2 shows the organization of the parameters of the parametric simulations.
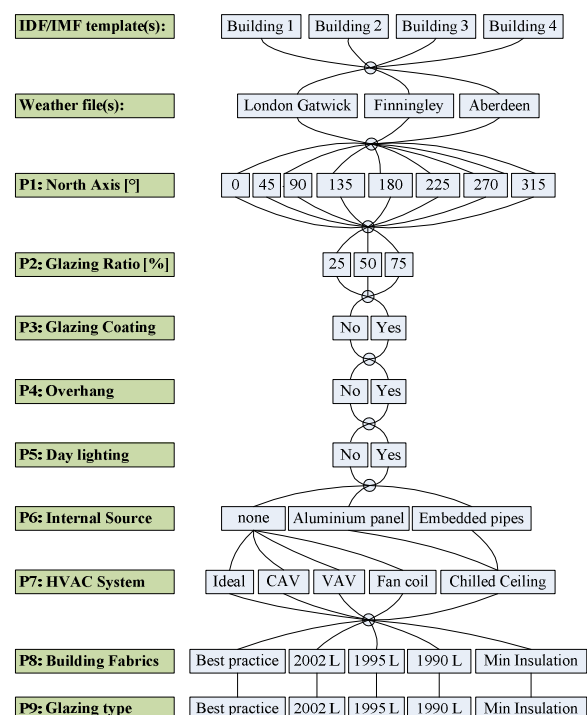
Figure 2. Parameter tree

Four main EnergyPlus models (**building1 ... building4.imf**) capture the two shapes by two floor layouts of the office buildings. Weather files include that of Aberdeen, Finningley, and London Gatwick, respectively.

Orientation of the building is defined as a jEPlus parameter by changing the North Axis value at 45° intervals. In jEPlus, the parameter values are specified as: **[0:45:359]**, which is equivalent to **{0, 45, 90, 135, 180, 225, 270, 315}**.

Fenestration definitions are prepared in separate files. Since the geometry of the windows is bound by the geometry of the buildings, several files have to be prepared for each building. As a result, **building[x]_g[yy].inp** files are present in the directory, where **[x]** represents building numbers and **[yy]** represents glazing ratios (**25, 50 or 75**). These files are selectively imported into the main model by using a "**##include**" command.

HVAC system files are prepared separately for each building as well, due to different zone arrangement. The input files are named "**building[x]_sys[z].inp**", where **[z]**

can be 0~4, depending on the system to incorporate. Similarly, overhang files ("**building[x]_overhang.inp**") for the buildings are incorporated with a "**##include**" command.

Glazing and fabrics insulation standards are implemented by defining an EP-Macro parameter block. For an example, see List 2. So are the coating options for the glazing systems.

In Fig. 2, each path in the parameter tree represents one EnergyPlus simulation job. After defining the tree, jEPlus will iterates through the parameters and executes all the jobs.

6. EXAMPLE RESULTS

The 34,560 jobs were carried out on the 256-core Linux cluster at the IESD during a weekend.

Total execution time with jEPlus, including preparing jobs and pre-processing with EP-Macro, was 26 hours and 56 minutes for the 34,560 jobs. This is equivalent to 2.80 second per job. On the cluster (with Intel E5530 CPUs), each job took in average 83.69 seconds to run with EnergyPlus (without EP-Macro). As a result, the acceleration ratio is 29.8.
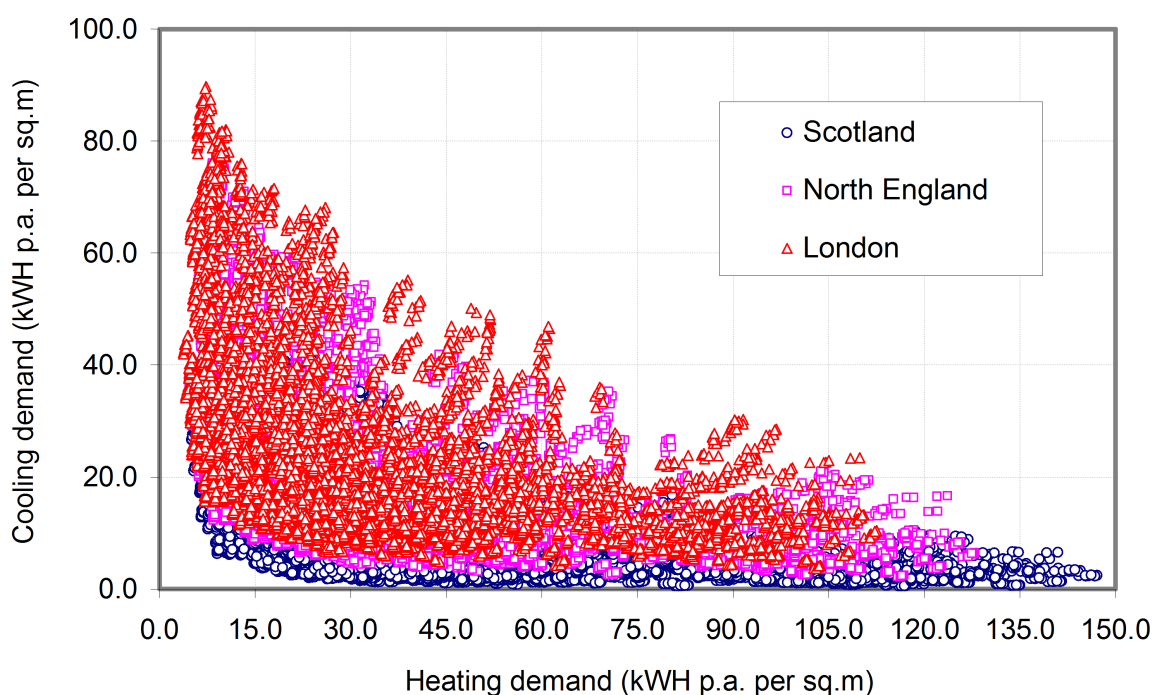

Figure 3. Simulation results of 34,560 jobs

Significant overheads were observed during the execution. Since the pre-processing with EP-Macro was performed in a single thread, the total time for the preparation step was 5 hours and 11 minutes, accounting for ~20% of total execution time. Other performance losses and bottleneck may be attributed to file operations, network transportation and the load management software of the cluster. Further performance optimisation is required to get the most out of the hardware.

Fig. 3 shows all results in a scatter chart, in which the geographical impact on buildings' heating and cooling demand is evident. Details of the results will be presented separately in future publications.

7. CONCLUSION

jEPlus is a convenient tool for managing large and complex parametric simulations. However, to our experience, most time spent in parametric studies is in fact on developing and testing simulation models, as well post-processing and interpreting results. To these, there is not any shortcut to take.

It is envisaged that further functionalities, if implemented, may further enhance the usability of jEPlus:

- Post-processing: customizable post-processing utilities, e.g. arithmetic calculations and statistical function can be used to produce useful results directly after the simulations.
- Support for open distributed computing frameworks: the current version jEPlus supports only single computers. Ad-hoc interface has to be implemented to run jobs on a cluster or networked PCs. Adoption of open frameworks, such as Java Parallel Processing Framework (JPPF) may be a desirable solution.
- Interfacing with optimisation packages: the number of jobs would quickly become infeasible if more parameters/values are involved. Using an optimization algorithm are usually

preferred over the "brutal force" method if coming up with a design solution is the objective. Work is currently under going at the IESD to incorporate this function.

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