

## 562: Input dataflow management for the simulation of community energy use

Aikaterini Fragaki\*, Donald Alexander, Phil Jones, Simon Lannon, Ann Smith

*Welsh School of Architecture, Cardiff University, UK*

\**FragakiK@cardiff.ac.uk*

### Abstract

Existing detailed simulation methods generally address the energy use of individual buildings, through the specification of its fabric, ventilation, fuelled services and occupancy patterns. Current concerns in developing sustainable built environments however often focus on groups or communities of buildings. In the Virtual Village (VIRVIL) project, means of extending detailed simulation methods to this level have been explored, in order to produce a detailed, dynamic simulation of the energy use of a community. That community must contain (simulations of) a varied mix of old and new housing, commercial and industrial properties, and include renewable energy generation systems. The building simulation tool used for this project is EnergyPlus. The existing capability of EnergyPlus is used to simulate individual buildings in parallel, with diversity as found in reality, communicating through a database. Key element of this procedure is the concept of a meta-description file. The development and the implementations of this concept are discussed in this paper.

Keywords: EnergyPlus, energy use, community, meta-description

### 1. Introduction

For sustainable urban planning and decentralized energy production there is a need to consider large numbers of buildings, up to a whole city. Therefore, recent research in developing sustainable built environments often focuses on groups or communities of buildings. This is a different approach to the building design process, which generally considers buildings on an individual basis or in small groups [i]. A number of models and methods have been developed in order to simulate the city-level energy consumption [i,ii,iii,iv,v,vi]. In the Virtual Village (VIRVIL) project, the intent has been to produce a detailed, dynamic simulation of the energy use of a community, and means of extending existing detailed simulation methods to this level have been explored. The VIRVIL model community must contain (simulations of) a varied mix of old and new housing, commercial and industrial properties, and include renewable energy generation systems. VIRVIL is not intended as a replication of any particular community, but rather a representation of village-like features. Each building is to be simulated to the best capability available coupled with empirical data and virtual reality facilities to visualize, compare and explore the results.

A key aspect in the energy usage of multiple buildings is diversity, and the diversity of individual buildings, and the usage of buildings, found in reality must be replicated in VIRVIL. The building simulation tool used for this project is EnergyPlus [vii]. Rather than expanding the EnergyPlus code to allow multiple buildings to be described and simulated simultaneously, the existing capability is used to simulate individual buildings in parallel, communicating through a

database. This is achieved through the development of a meta-description file.

EnergyPlus reads input and writes output as text files. A number of interfaces [viii] (Demand Response Quick Assessment Tool, Design Builder, EFEN, Hevacomp, and HLCP) are currently available, other are available in development versions or recently announced. These interfaces create and run EnergyPlus input files and display results graphically. They address various aspects of building design like, for example, assessment for various demand responsive strategies (Demand Response Quick Assessment Tool) and energy impact and effectiveness of fenestration systems (EFEN). The typical approach to facilitate the description of individual buildings is to create templates of common building constructions, activities, and systems. The concept of templates has been implemented in the software such as DesignBuilder, which allow the user to compile a building from previously edited data. We are proposing a different approach where the "templates" are held within a single file, the meta-description file, which will have all the interactions accounted for. This approach ensures consistency and accuracy in the simulation of individual buildings in parallel.

The concept of the meta-description file and its implementations are discussed in this paper. Further developments are also suggested.

### 2. The meta-description file

#### 2.1 The meta-description concept

Individual buildings are characterized by a diversity which must be replicated in VIRVIL. Different buildings, though of notionally the same

design, must obviously have different orientations, occupancy, etc. However in addition, they may also have different fabric specification and provision of services.

In order to avoid the need to develop and maintain (potentially) thousands of individual building descriptions for EnergyPlus, the concept of a meta-description file has been developed. The meta-description file exploits the capability of EnergyPlus files to contain information, originally intended as comments, that is not interpreted by the software. Testing has shown that the amount of extra information included in this way does not affect memory requirements or execution. The meta-description file can therefore contain all (predefined) variants on a building type that are to be included in the system, embedded within a single file completely compatible to the EnergyPlus system. Thus, the description of a particular, common, 1970s semi-detached house (a building “type”) describes not only the baseline (with, perhaps, uninsulated cavity walls and single glazing), but can also contain descriptions of, for instance, wall constructions with retro-fit cavity insulation, double glazing, an add-on conservatory, a kitchen extension, and a loft extension. Each of these is a “variant” of the basic type. Variants may act alone, or in combination to produce a specific “building” to be simulated. Variants may also include differing occupancy patterns; a two adult, two children family, young couple, or elderly sole occupant. When an individual building is located on a plot in VIRVIL, it will be instantiated from an appropriate building type, together with any variants necessary for that building. An individual EnergyPlus IDF file will still be associated with a given building, but each is prepared through manipulation of the meta-IDF of its basic type. Maintenance or modification therefore requires only maintenance or modification of the meta-IDF’s. Figure 1 shows the data-flow through the simulation system.

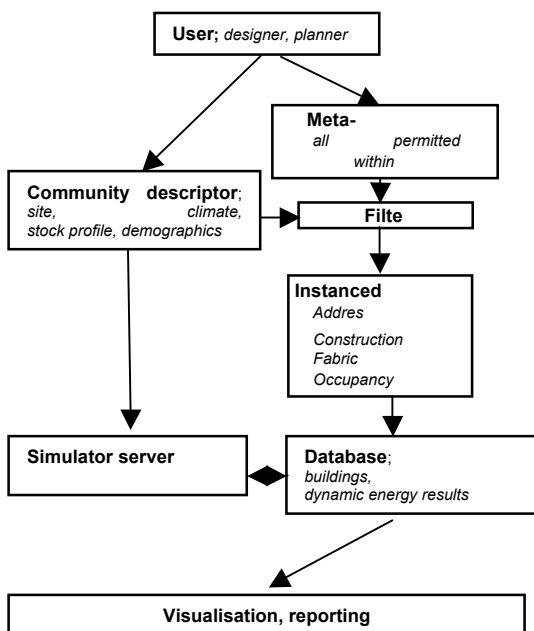


Fig 1. Data flow through the simulation system

It is presented in this paper how the meta-description file is designed and manipulated to set the required information for the simulation of a specific building.

## 2.2 Modelling tools

EnergyPlus is used in this work for the simulation of the building and the development of the meta-file. As a well established software tool for building simulation, its use is intended to provide VIRVIL with a level of capability and credibility that would be difficult to attain with a newly developed code. In EnergyPlus a building and its services and operation is described by the input data File (IDF). The user can create an IDF using the IDF editor, but it is in a simple text file, it is also possible to edit it manually, and we utilise that capability in creating a meta-IDF. That is, we will utilise the IDF format to contain the extra information directly.

In order to assist in the editing and processing of the meta-description file and to generate the necessary permutations of a building type, a filter programme and a user interface have been defined in the language PHP. PHP has been chosen for two reasons. Firstly, one of its most powerful features is its ability to process data submitted in text form, making it easy to create an efficient user interface. Secondly, it is designed around communication with database systems, in this case with the VIRVIL database, written in MYSQL.

## 2.3 Development for consistency

The information in an EnergyPlus IDF file can be provided in groups, e.g. :

- Construction;
- Occupancy;
- Electric Equipment;
- Lighting;
- Heating;
- Photovoltaics.

Clearly unstructured options in a meta-description could lead to logical inconsistencies; for instance an occupancy pattern using an appliance that does not exist. In order to ensure consistency and accuracy, logical links between options may be made, so that dependencies and prerequisites can be highlighted in the user interface. This helps, but does not guarantee that each possible variant of the type leads to a consistent EnergyPlus model. As an aid, each planned variant building to be contained in the meta-description can be tested for consistency in isolation, and melded into the meta-IDF through a reverse filter.

The filter programme also enables/disables EnergyPlus output variables as appropriate to the variant selections of the building systems. For example if electric central heating is selected as a variant, gas input for central heating will be removed from the output report specification of the simulation for that building.

### 3. Methodology and Results

#### 3.1 The filter programme

The function of the filter programme is based on feature of the IDF editor to retain any text preceded by the ASCII symbol '!'. Comments are inserted in the meta-description file next to the information that is subject to modification. Thus the filter programme can identify the particular input. Conditional statements in the filter programme point to modifications according to user selections. A suitable PHP function in the filter programme replaces the flagged out input and the comment accordingly. In the following paragraphs it is described how this is implemented to filter the variants that describe each group of input information in the meta-description file.

#### 3.2 Construction

In the usual use of EnergyPlus, the IDF file, the input that defines a building element, e.g. a window, includes in that definition a construction name to be used e.g. 'DoubleGlazed\_LowE\_TimberFrame'. That construction name links to a specific construction definition provided elsewhere in the IDF file. In our treatment, a number (potentially unlimited) of alternative objects (e.g. different window constructions) are supplied, but are commented out so that they are not visible to the EnergyPlus system, but visible to our pre-processor filter. EnergyPlus comments are preceded by the ASCII symbol '!' in the IDF file. Embedded in the comments are phrase-codes that can be interpreted and manipulated by the filter; the symbol '!' is used therefore by the filter to search for its own commands in the meta-IDF.

Variants in the meta-IDF may be defined as groups; for instance the phrase-code name EXTWINDOWS may be coined to flag all external windows. Instructions can then be given to replace all external windows in that group with an alternative construction. The original construction name (the basecase) and the phrase-code are replaced by the filter programme with the desired variant construction name, e.g. 'SingleGlazed\_Timber Frame'. Figure 2 shows an extract of a meta-description file that defines a window. The embedded phrase code is '!C1C2 EXT WINDOWS'. The phrase code is constructed to be a text fragment unlikely to be found elsewhere in the IDF file, so that it can be identified by the filter. The phrase code parameter EXTWINDOWS defines that this particular window construct belongs to that named group. Figure 3 shows how the filtered file has been modified after the selection of a different construction option.

A variant option may include several editing actions, so that, for instance, the variant definition that altered the window construction above could also in addition be configured to alter the wall construction to remove cavity fill insulation; such a combined variant may be selected as "downgraded insulation" by the user.

```
Surface:HeatTransfer:Sub,
  Subobj:0007,           !- User Supplied Surface Name
  WINDOW,               !- Surface Type
  DoubleGlazed_LowE_TimberFrame,!C1C2 EXTWINDOWS, !- Construction
  Name of the Surface
  obj:0001,             !- Base Surface Name
```

Fig 2. The phrase code '!C1C2 EXTWINDOWS' in the meta-description file marks the construction of the window 0007 for modification

```
Surface:HeatTransfer:Sub,
  Subobj:0007, !- User Supplied Surface Name
  WINDOW, !- Surface Type
  SingleGlazed_TimberFrame, !- Construction Name of the
  Surface
  obj:0001, !- Base Surface Name
```

Fig 3. The file generated using the filter programme, where the construction of the window 0007 has been changed to 'SingleGlazed\_TimberFrame'

#### 3.3 Lighting and Electric equipment

The input information in the EnergyPlus related with lighting and electric equipment refers both to system type and usage profile. Parameters that describe the system type are parameters like the radiant and the latent fraction and the peak power consumption. Their values depend on the type of equipment; for lighting this may be conventional or low energy, wall mounted or suspended lights. The usage profile is imposed by the occupancy pattern. When in EnergyPlus the usage profile of the lighting system of a building zone is set to the 'off' option this lighting system does not exist in the building. By default, in the meta-description file all lighting systems of all zones are set to the 'off' option in this way. Similarly with the case of the construction choice, phrase-codes are used in the file to mark the available alternate lighting systems of each zone. The filter programme can then insert for each zone a usage pattern in one of the lighting systems in order to enable this system and its usage. In the meta-description file there can be potentially the descriptions of all lighting systems usage patterns that may exist in reality in this building type of the VIRVIL. Figure 4 shows the IDF editor view of a generated file where one lighting option is enabled. The schedule name is the name of the usage pattern and links with its description somewhere else in the file. The "Design level" is the peak power consumption. The input 'AlwaysOffSchedule' in the field 'SCHEDULE Name', effectively deactivates the corresponding option.

In a similar way the filter programme sets the electric equipment. An occupancy option and electric equipment option that includes clothes washer and/or dishwasher will set, in addition to the electricity consumption profile, the water consumption profile of these machines.

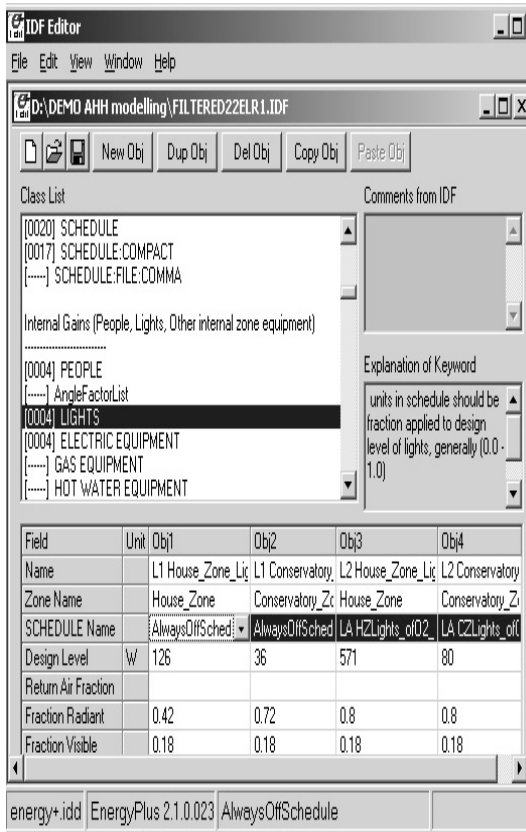


Fig 4. The IDF editor view of the generated IDF file where the filter programme has enabled one lighting option for the House Zone and the Conservatory Zone

### 3.4 Occupancy

The filter programme links the occupancy to the usage profiles of the systems since these are occupancy dependent. The selection therefore of a different occupancy option sets apart from the occupancy pattern, the usage profiles of ventilation, showers and sinks, lighting system, electric equipment system and heating system as well as the profile of heat gains from people's activity. These changes are defined in the filter programme.

### 3.5 Heating

Regarding the central heating, currently the available options are either electric or gas or no heating system at all. Similarly with the lighting and electrical equipment there is input data related with the system parameters, input data related with the usage -for the heating system this is the thermostat settings- and in order to enable a system that exists in the file a usage profile already described in the file is enabled.

### 3.6 PV

The filter programme may also enable a PV system which is described in a file. Figure 4 shows the input in the meta-file that should be modified in order to have the PV system enabled. This input is only part of the PV system description in the file. There are two modifications that have to be made which are marked in Figure 5. The first is to replace the construction of the roof surface that will accommodate the PV array

with a construction with integrated PV and the second to activate the class 'Electric Load Centre'. The phrase-code that marks the text in the file to be modified is 'Photovoltaics'

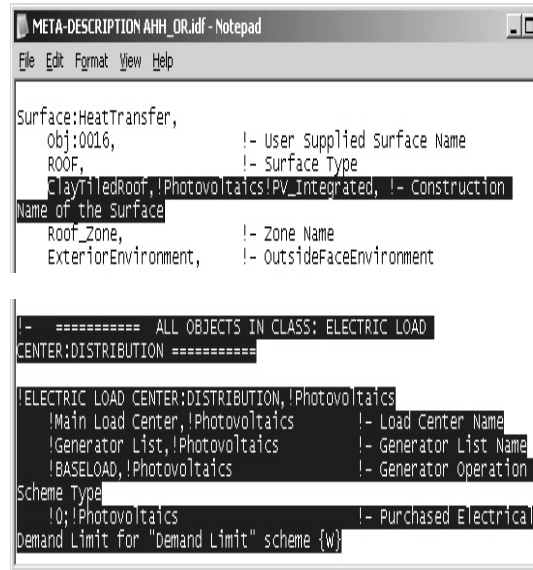


Fig 5. The marked input in the IDF file is modified by the filter programme in order to enable the PV system

### 3.7 Output report variables

Typically the EnergyPlus user specifies in the IDF project file the variables to be reported in the output of a simulation. These variables are selected amongst a number of available output variables. EnergyPlus allows for the additional input of a 'Key value', which indicates which instance of variable is reported and may also be specified. For example the variable "Baseboard Heating Energy" gives the output for space heating energy. The 'Key value' in this case is the name of the heating unit that generates this energy and it is set in the IDF file.

In EnergyPlus simulations some of the output report variables may be requested but not generated. This may happen for two reasons. Firstly, when the IDF file does not contain certain elements then the variables associated with these elements are not generated. For example, if a solar collector system is not simulated in the IDF file then the variables like "Solar Collector Heat Transfer Energy" will not be generated even if they are requested. Secondly, when a 'Key value' has a name that is not recognized then the associated output variable will not be generated. This latter feature is applied in the meta-description file in order to filter the output variables. In the meta-description file all the key values of the variables associated with modelled systems that may or may not be enabled by the user are given names that do not exist elsewhere in the IDF file and therefore they are not recognised. When a system is enabled the filter programme changes the name of the appropriate key values to "meaningful" names and the associated reports are thus generated. Figure 6 shows the IDF editor view of the meta-description file after modification by the filter programme. The user in this case has selected hot water

central heating system for this building. The key value of object 14 has been replaced by the filter programme with the name 'HOUSE\_ZONE BASEBOARD' which is the name of the heating unit in the hot water system. The associated report that gives the "Baseboard heating energy" for the hot water system heating unit will be generated and the output of the simulation will report the heating energy of the hot water system. On the contrary, the key value "ELR IN" is not defined in the file as the name of a heating unit, so the variable "Baseboard Electric Consumption" which gives the electricity input for the electric heating system will not be generated although the electric heating system is also modelled in the file.

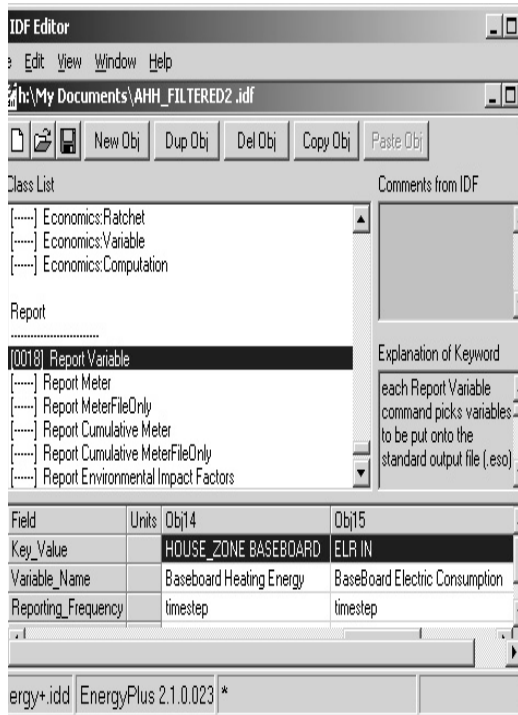


Fig 6. The IDF view of the generated file when the user selects hot water system for this building; the key value of Obj 14 has been changed to the name of the hot water system heating unit and the associate report variable will be generated for this unit

### 3.8 Interface

An HTML form is used as an interface to the meta-description file using PHP (Figure 7). The software ingests the meta-description and collates all the defined variants. Drop down lists are presented to show those available options. Regarding the lighting and the electric equipment the user, having made an occupancy choice, selects only the system, since the usage profile will be determined by the occupancy selection. 'Help' buttons are linked to pop-up menus which display the descriptions of the available options. The meta-description file is called from the VIRVIL server, manipulated by the filter programme and a new, building specific IDF generated according to the user selections. This then becomes available for the VIRVIL system to submit a new EnergyPlus calculation job and update the results database.

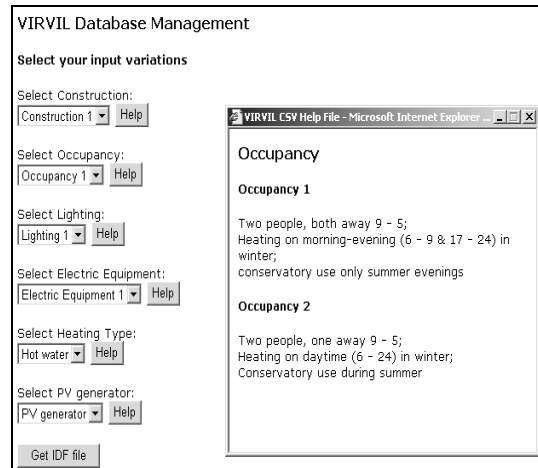


Fig 7. User interface for the generation of the permutations from a particular building type

Figure 8 shows, for a single property, the calculated monthly net electric energy demand from the grid, for the baseline and with roof integrated PV selected from the variants. Embedded within a community with diversity in demand, orientation and up-take, such data, when aggregated across the community can provide a view on potential impact of energy alternatives.

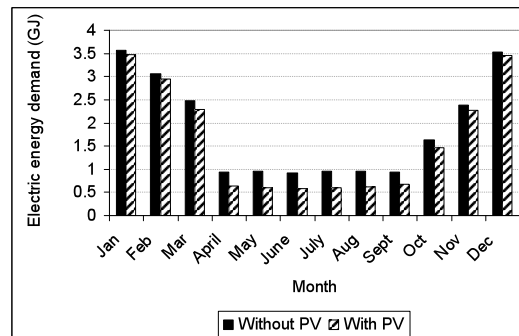


Fig 8. Comparison of monthly electric energy demand of a house without PV generation and the same house with roof integrated PV.

### 4. Discussion and further research

The method developed here for creating and processing the meta-description file can be used with any simulation tool that uses text files with comments as a way to process them. Thus for instance, the same approach can be used to prepare a meta-description file for the 3D representations of the buildings in the VR visualisation for VIRVIL [viii]; internally consistent visual representation of the semi-detached house with and without conservatories can therefore be prepared and displayed according to the current selection for a particular address.

The method ensures consistency and accuracy. These outweigh the main disadvantage of the method which is the limitation of the available choices to predefined groups. It is not the aim in VIRVIL to include all conceivable variations; rather the variants stored in the meta-description file will reflect the demographic and statistical

data for the building type and the community in the region being simulated. The variants required will be enabled when a building is instanced on a building plot in VIRVIL.

There are several further improvements possible which are described briefly here.

#### Occupancy

There is currently a one-by-one link between the occupancy and the usage profile of each system. However, there is the potential to develop more usage profiles of each system linked to the same occupancy choice. This will also allow for studies related with changes in occupants' behaviour in VIRVIL buildings.

In addition, further diversity in usage profiles can be achieved through a second level of filter, adding a level of random variation between individual days, and between buildings set to notionally similar patterns.

#### Heating

There is the potential to model more central heating systems in the meta-description file e.g. air-conditioning systems. Furthermore, it is possible to expand the number of choices regarding each heating type. For example, several hot water heating systems, each one with different boiler type can be included in the file. The effect of more efficient systems on the overall energy use can then be studied.

#### PV

Currently, in the meta-description file there is the description of an integrated PV system designed for this particular building type. There is the potential to simulate several PV systems in the building file that differ in orientation, age, size and system parameters. The selection of the PV system should then be linked with the occupancy and the orientation of the building in the system. The possibility to have multiple PV system choices for the same building type will allow for studies that include the effect of PV degradation due to ageing, or the effect of different PV technologies in the overall energy use.

#### Meta-description syntax

Further development of the syntax of the embedded information and variant will be needed to ensure robust and simple operation for end users.

## 5. Conclusion

In order to avoid the need to develop and maintain (potentially) thousands of individual building descriptions for and application aimed at the detailed dynamic energy simulation of a community, the concept of a meta-description file has been developed for EnergyPlus, and other software. The meta-description file contains all variants on a building type that are to be included in the system, embedded within the file, using the target software's capability to recognise (and ignore) comments. As each variant will be described within the context of the type, the overall description can be developed for

consistency and accuracy. When instanced as an individual building on a plot in VIRVIL, a filter program draws the meta-description from the database and enables the variants required for that plot. The methodology can be used with any simulation tool that uses text files with comments as a way to process them. Further developments of the meta-description file that will lead to more options increasing the versatility are possible.

## 6. Acknowledgements

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## 7. References

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