# BIM ENABLED BUILDING ENERGY MODELLING: DEVELOPMENT AND VERIFICATION OF A GBXML TO IDF CONVERSION METHOD

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## ABSTRACT

As part of the Design4Energy retrofit scenario a methodology is developed that uses Building Information Modelling (BIM) of existing domestic buildings to assess their energy performance using a Building Energy Modelling (BEM) technique. The focus is on the conversion process from gbXML BIM export file to an idf file for EnergyPlus[TM]. The conversion process is broken down into six steps of progressive addition of idf objects to enable verification. The measured operational data are used to assess the adequacy of the defaults being used.

## INTRODUCTION

Design4Energy is a EU project aiming to develop an innovative integrated evolutionary design methodology both at individual and neighbourhood level using BIM and BEM. One of the focuses of Design4Energy is on developing a comprehensive methodology for retrofitting existing buildings.

### From BIM to BEM

To improve consistency of construction information related to building energy analysis, Building Information Modelling can play a key role. BIM enables a collaborative way of working and better informs decision-making processes from the early design stage through to maintenance. By employing rapid energy analysis the potential of BIM in informing low energy strategies of buildings is highlighted (Hyun, Marjanovic-Halburd and Raslan, 2015). This is a fact recognised by the building analysis community in the design stage of buildings (Schlueter and Thesseling, 2009 and Kim, Kim and Seo, 2012). In the post-occupancy stage, a systematic methodology that would ensure that the building's thermal behaviour is monitored and the findings are incorporated in the decision-making process is still missing (Motawa and Carter, 2013). The main prerequisite for retrofit analysis is the development of a calibrated whole-building base-case model, used to implement and assess different retrofit scenarios (Miller et al., 2014). As advanced equipment is emerging in the domestic sector (e.g. Smart Home equipment) we are faced with a wealth of operational data from real-life households. However, BIM for sustainable design of existing buildings often relies on estimated values for some of the building's thermal characteristics, such as loads, schedules and airflows (Crosbie, Dawood and Dean., 2010). As retrofit decision-making in buildings is not supported by data, the accuracy of the retrofit analysis is limited (Miller et al., 2014). To overcome this limitation operational data from the building to inform the parameter estimation should be used (Motawa and Carter, 2013).

### Ifc and gbXML file formats

Many file formats exist for data transfer and exchange from BIM. Examples include HTML, XHTML, bcXML, gbXML, ifc and ifcXML (Volk, Stengel and Schultmann, 2014). The two main methods for extracting data for building energy modelling from BIM are the Industry Foundation Class (ifc) and the green building XML file type (gbXML) (Miller et al., 2014). The ifc file type is more comprehensive and generic and aims to represent the building project extensively with all the related information, whereas the gbXML file type is focused on the properties of the building project that are related to energy simulation (Dong et al., 2007). The same source suggests that the gbXML file format is more straightforward, more flexible and less complex that the ifc file type, characteristics that are making gbXML more suitable for web-based tools. Using the ifc file format to develop a complete idf model for EnergyPlus[TM] simulations (the free, open-source, and cross-platform energy simulation tool - funded by the U.S. Department of Energy's, DOE, and Building Technologies Office, BTO) is not a straightforward process (Ahn et al., 2014).

The gbXML file format is quickly becoming a standard file for exchange of information for the purposes of energy analysis. GreenBuildingStudio, DesignBuilder, IES VE, Arup's Energy2, DoE's energy-10 and NREL's OpenStudio are some of the gbXML compatible energy software (gbXML.org, 2016). One of the advantages is that the gbXML schema enables easy incorporation of additional information that might be required for energy analysis. One example can be found in the work from Dong et al. (2007) on including sensor data in a gbXML file using the 'Meter' node.

Even when using the two most popular file formats for data extraction from BIM, the user has little

control over the creation of the file formats and limited knowledge of the data contained in the files. The lack of full understanding of the data transfer process introduces interoperability challenges between BIM and BEM (Miller et al., 2014). These interoperability issues between BIM and energy analysis tools have been well reported (Steel, Drogemuller and Toth, 2010 and Cemesova, Hopfe and Mcleod, 2015).

To overcome the transfer of data limitation a conversion process needs to be developed to enable transparency of data exchange at each step. One such example is the work done by Ahn et al. (2014) where the ifc file format has been used to develop a semi and a fully automated interface for energy analysis, enabling a varying degree of user involvement in the selection of the energy analysis parameter values. Other conversion processes/tools include the ifc-based file converter by Kim, Kim and Seo (2012), the SimModel by O'Donnell (2013) and the semi-automated BIM to BEM data exchange from O'Donnell (2014) using the ifc file format.

This work is part of a wider project dealing with BIM-BEM processes for existing buildings for retrofit decision-making. The focus is on describing the conversion process of the existing building's BIM gbXML file to the EnergyPlus input idf file. In the next sections, the logic behind the conversion process is described in more detail and a case study of a real-life UK domestic building equipped with in-home sensors is used. Both for development of the required tools and verification of the conversion process. The operational data arising from the in-home sensors are used to inform the model building. The potential and limitations of the proposed methodology in assessing the building's energy performance and in informing retrofit advice are explored.

## BIM - BEM MODEL DEVELOPMENT FOR EXISTING BUILDINGS

### Suggested workflow

Figure 1 is a flowchart presenting the proposed steps for existing building model development and calibration based on the BIM gbXML output. The blue coloured boxes suggest those relevant process/tool which do exist already, whereas the green coloured boxes indicate the process/tool which need to be developed. The selected BIM software is Autocad's REVIT and the energy modelling software is EnergyPlus. The latest software version 8.4 is used for analysis. The process begins by conducting a building survey and collecting operational data from the existing building. Using the collected data and once the decision for retrofit has been made a BIM model is developed. Information that is needed for energy modelling using EnergyPlus and can be supported by the gbXML schema is added to the gbXML file using a gbXML editing tool. To create the idf file a gbXML to idf conversion tool is

developed. As much information as possible are drawn from the gbXML file and additional parameter values are specified to create the idf file which EnergyPlus uses as its input file to perform the analysis. The energy modelling results can then be exported in csv file formats for further analysis and to proceed with the model calibration. The modelling results in terms of Key Performance Indicators (KPIs) are compared to the operational data to assess the agreement between the measured and predicted. In the case where the modelled results deviate significantly from the measurements, calibration of the model is required to increase the model's adequacy in representing the real building. Multiple iterations of the calibration process using the gbXML editing tool might be required to achieve good agreement between the modelled and the actual building energy performance. The calibrated and verified model can then be used as a base-case to model alternatives for retrofit decision support.
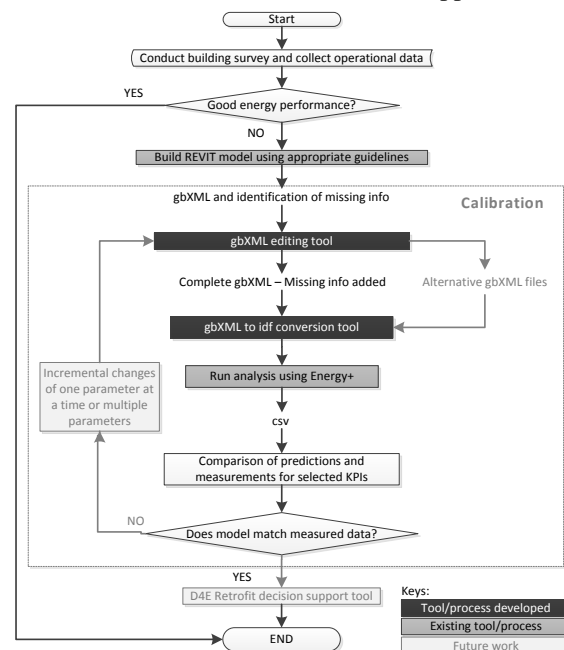


*Figure 1 Existing building model development and calibration flowchart*

### GbXML editing tool

Figure 2 shows how the gbXML editing tool works, the inputs required and the tool output. The gbXML file as exported from REVIT (here denoted as the original gbXML file) can sometimes omit information that is needed for energy simulation, information that can be supported by the gbXML schema. The missing information is included in separate XML files together with appropriate instructions on how the original gbXML file needs editing to incorporate the additional data. The editing tool can then use the editing instructions of the XML files to edit the original gbXML file and output the edited gbXML file containing appropriate information to proceed with the next steps of the

process. This editing tool can also be used together with appropriate editing instructions to create alternative gbXML files that are based on the original gbXML file to serve for model calibration or on the base-case (i.e. once calibrated) gbXML file to produce the alternative options for retrofit decision making purposes.



*Figure 2 gbXML to idf process flowchart*

**GbXML to idf conversion tool**

Figure 3 shows how the gbXML to idf conversion tool works. The edited gbXML file using the previously described editing tool as the input file to the conversion tool. The first step in the conversion process is the conversion of the gbXML file in a XML file containing all the information required for EnergyPlus to run. This file is named the idfXML file. To create this, a template idfXML file is used relating the idf objects to the relevant nodes of the gbXML file. Using the mapping process contained in the template idfXML file, the idfXML file is populated with the available information from the gbXML file. Appropriate default values are selected for the information that is missing from the gbXML file but is required for energy analysis. The idfXML file can now be converted into idf format. The idfXML file, which is the middle stage of the conversion process, serves as a facilitator for easy manipulation of the mapping process, better handling of the defaults assigned to the idf parameters and transparency of the conversion process. Multiple files can be handled at the same time.



*Figure 3 gbXML to idf process flowchart*

Figure 4 shows the components of the idfXML file which is used to create the idf file. The idfXML file consists of a minimum of 35 nodes and any additional nodes needed to specify the output variables required for energy analysis. Each node represents a particular type of idf object and is named after the idf official object name. Multiple objects of one particular type might be produced in the final idf file based on each node. For example, the 'Material' idfXML node links directly to the 'Material' idf object and is used to create as many 'Material' objects in the idf model as required for the specific gbXML file that is being converted. Based on the number of elements that each idf object consists of, an equivalent number of child nodes is introduced in each idfXML node, each one representing a particular idf object element. The child nodes of the idfXML file contain the address of the gbXML file from where the equivalent information can be found in the form of an XPath (syntax for defining parts of an XML file). When the required information is not specified within the gbXML file, appropriate default values are selected that can easily be accessed and edited as required.



*Figure 4 idfXML template containing the mapping instructions and default values*

## CASE STUDY: A REAL-LIFE HOME IN LOUGHBOROUGH

To create the gbXML to idf mapping process, test and verify the tools developed, an existing typical UK domestic building is used from the REFIT project repository. REFIT was a EPSRC funded project that looked into Smart Home technologies and energy demand reduction. As part of REFIT a field study was conducted in 20 UK homes. Building survey data and operational data are being made available for all the participating homes (REFIT, 2016). One building is selected and used to create a BIM model and export the gbXML file. For the same building, the SketchUp's OpenStudio plugin is used to create a idf file. The gbXML and the idf files are then used to identify the mapping process between the two files. Step by step of the mapping process the idfXML template file is populated, the gbXML file is converted in a idf file and ran in EnergyPlus. There are six steps of progressive addition of idf objects; the basic model consisting only of construction elements and materials; with added windows; with added internal mass; with added heating and schedules; with added infiltration; and finally the complete model with added internal loads. The results are analysed to verify the conversion tool. In the end, the complete building energy modelling results are plotted against the operational data.

### House description

The house is a two-storey traditional semi-detached house built in the early 1970s, situated in Loughborough, UK. The ground floor consists of an entrance hallway, a living room, a kitchen-dining room and the first floor has three bedrooms and a family bathroom. The total floor area amounts to approximately 78m$^2$. The external construction consists of insulated cavity walls and double glazed openings. The floor to ceiling height is 2.4m. The central heating system is a typical wet system with radiators and a central boiler. The condensing combi boiler, model of 2013, uses gas as its primary fuel.

Table 1summarises the measured data and provides further details on the time intervals and equipment used. 'Hobo U12' and 'Hobo Pendant' temperature data loggers were placed in each room at a head high level away from obstacles, direct solar radiation, currents and heat sources (when possible) to capture the internal air temperature. The Loughborough University campus weather station in close proximity to the house's location was used to collect weather data including external air temperature, solar gains, wind speed, wind direction and precipitation. Based on the weather data collected a epw weather file was created to be used for analysis in EnergyPlus. A time-period of one year of operational and weather data is used in this work, beginning on the 1$^{st}$ of January 2014 at 00:30 and ending on the 31$^{st}$ of December 2014 at 23:30.

*Table 1 Operational data captured, monitoring equipment and time interval used*

| Monitoring of | Positioning | Equipment used | Interval (min) |
|---|---|---|---|
| Internal air temperature | One in each room including hallways and landing | HOBO U12 - HOBO Pendants | 30 |
| Weather data | Loughborough University Campus | Weather Station | 60 |

### BIM model and gbXML export options

Figure 5 shows the BIM model created using Autodesk's REVIT. The 'EDSL Guide for Revit gbXML Files' (EDSL, 2016) is used to ensure that a good gbXML can be exported. The guide gives instructions on the optimum options and design practices that when followed in REVIT can ensure that the exported gbXML file of the modelled building will have properly defined building elements and spaces adequate for further energy analysis.



*Figure 5 REVIT model designed using good gbXML export guidelines*

Figure 6 shows the options selected when exporting the gbXML file. The export options that need to be specified relate to the specific building characteristics, such as the building type, location, building services and infiltration. Additional export options need to be used to determine the type of the exported information, such as the complexity of the building detail that is needed, the representation of the building using the designed rooms or spaces, methods for determination of the building element functions and the building phase. The conversion tool developed works using the 'Export Complexity: Simple' and 'Export Category: Spaces' options. Additional energy related settings are defined using 'Energy Settings', 'Building/Space type settings' and individual space energy analysis properties. Two zones are used, one for the main occupied building spaces and one for the roof.
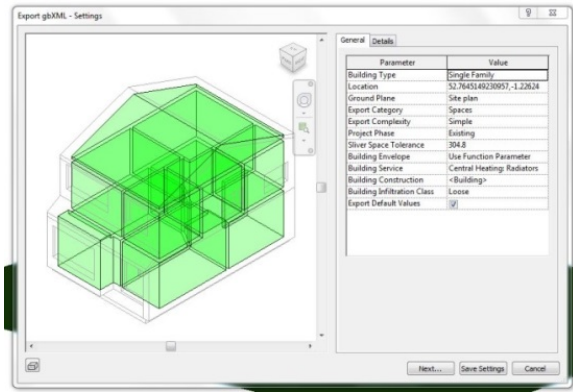
*Figure 6 REVIT options for gbXML export*

**GbXML to idf mapping process**

Figure 7 shows an example of the mapping process between the gbXML node and the relevant idf objects, for the idf 'Construction' object. In this example, the 'Construction' idf object needs to include two types of information; the name of the construction; and the layers of the construction. The name of the construction is located in the gbXML file 'Construction' node as the 'id' attribute. The XPath of the attribute is created and incorporated in the 'idfXML_template' file. To identify the layers of the construction, the 'Construction' node's child node named 'LayerId' and the relevant 'layerIdRef' attribute's value need to be located. Using the 'layerIdRef' value the 'Layer' node is located, listing all the materials in its child nodes named 'MaterialId' that compose the construction. The XPaths for the 'materialIdRef' attribute values need to be used to form the layers of the 'Construction' idf object. Due to the complexity of the process of identifying the layers of the construction, the methods for adding the idf layer names is included in the conversion tool code. Similar processes of increasing and decreasing complexity ate followed to populate the 'idfXML_template' file and to form the conversion code for each of the required idf objects.

To support the conversion tool a 'GbXML to idf Conversion Tool' report has been developed. The report summarises all the necessary information regarding the mapping process and the coding logic used to make the conversion. In the report the fixed default values selected for the idf file are listed.

**BEM development for the case study house**

Firstly, the gbXML editing tool is used to add missing information regarding heating schedules, the heating attribute in zones, activity level schedules, infiltration schedules and the azimuth of the project in the REVIT exported original gbXML file. For heating, a standard schedule is used with heating set to ON from 6:00-12:00 and from 18:00-24:00 for all days of the week and across the year. The heating setpoint selected is 19°C. Infiltration and activity level are both set on a 24/7 schedule. The output of the editing tool is the edited gbXML file containing all the information that is missing from the gbXML file and are required for EnergyPlus to perform the analysis. The addition of as much information as possible in the gbXML file is considered the best solution, as this enables sharing of the file and saves on extra work if rerun is required.

The second step relates to the use of the conversion tool to create a idf file for the edited gbXML file. To do so the 'idfXML_template' file is used to populate the 'idfXML_output' file with information from the gbXML edited file and the specified fixed default values. 24% of the information included in the 'idfXML_template' is linked to information included in the edited gbXML file. The remaining 76% are default values selected by the user or set as autocalculate for EnergyPlus to estimate. The 'idfXML_output' file is then converted in an idf file. The conversion is done incrementally in six steps as defined in the beginning of this case study section. The complete idf file consists of 156 objects.

Finally, the six idf files together with a weather file created using the weather data obtained from the Loughborough University weather campus are used in EnergyPlus to run energy analysis and retrieve the energy analysis results in csv file format.



*Figure 7 gbXML nodes to idf object mapping example for the 'Construction' idf object*

**Basic model – free running**

Figure 8 shows the indoor air temperatures for the two zones of the building, the roof and the main occupied zone, for the basic model in free running mode and the external air temperature. The free running mode indicates that there is no mechanical heating or cooling involved. Windows have not been simulated at this stage. The external air temperature ranges from -3.0$^{o}$C temperatures during the winter months to higher temperatures in summer peaking at 30.9$^{o}$C in June. As expected due to the lack of any means of temperature conditioning, the indoor air temperature in both zones follows closely the external air temperature. The roof zone has a higher percentage of surface area exposed to external conditions per volume of the zone than the main building zone. As expected, the roof zone is more influenced by the external air temperature and is colder than the main zone in winter (minimum of 4.6$^{o}$C and 8.8$^{o}$C respectively) and warmer in summer (maximum of 25.3$^{o}$C and 23.0$^{o}$C respectively).
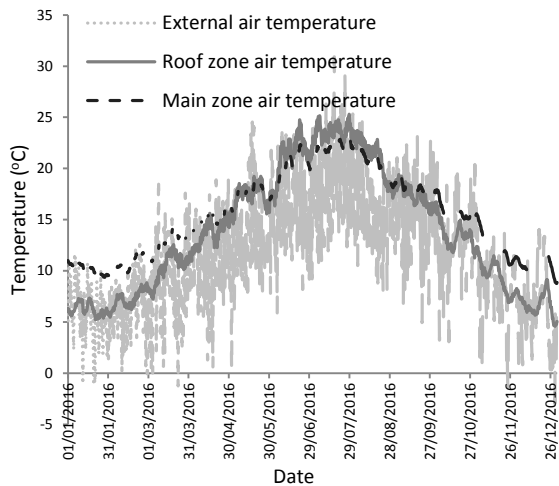


*Figure 8 External air and internal zone air temperatures ($^{o}$C).*

**Windows added – free running**

Figure 9 shows the main zone indoor air temperature and heat losses and heat gains through the windows for the same zone. The main zone air temperature presents higher variance when compared to the previous output from the basic model. The standard deviation indoor air temperature has increased to 5.95$^{o}$C from 4.12$^{o}$C. The lowest presented temperature is 5.6$^{o}$C and the highest is 30.0$^{o}$C. This was expected as the incorporation of the windows of the building structure in the thermal model induced additional heat losses and heat gains that significantly affected the indoor air temperature. The heat losses through the windows range from 0 to 741W and the heat gains from 0 to 2679W. Both heat losses and heat gains are more significant during the warmer summer months.
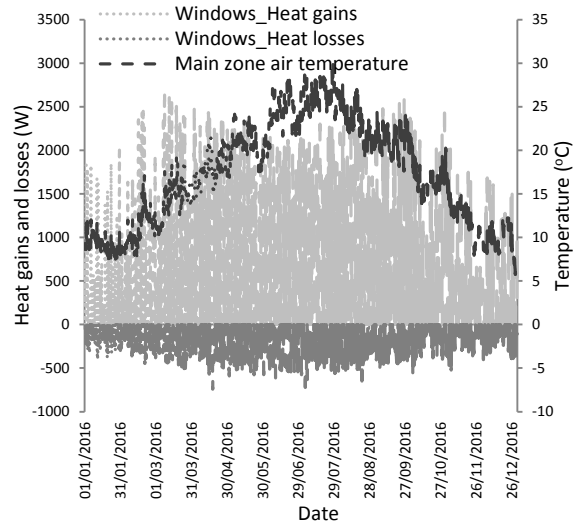


*Figure 9 Internal air temperature ($^{o}$C) and heat exchange rate (W) through windows for the main zone.*

**Internal mass added – free running**

Figure 10 shows plots of the internal air temperature before and after the addition of internal mass. The addition of internal mass increases the thermal mass of the building and is expected to affect the indoor air temperature in two ways; to smooth down the temperature peaks and lows and decrease the air temperature variance; and to create a lag in the temperature peaks as a result of the flywheel effect. Regarding the first point, as expected in this day example the internal air temperature peak is decreasing by 0.46$^{o}$C from the internal air temperature prior to the addition of the internal mass. The lowest temperature is also significantly higher after the addition of internal mass and the air temperature is closer to the average temperature of the day. The standard deviation of the internal temperature is now 5.93$^{o}$C. In terms of time lag, the addition of internal mass does not have a significant impact on the resulting zone air temperature. This could mean that the hourly timestep selected does not provide a fine enough resolution for the impact of the internal mass to be measurable.
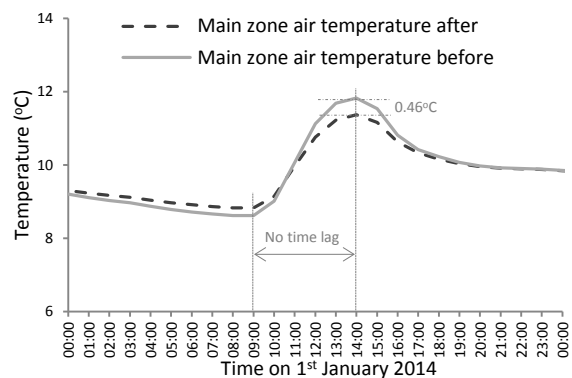


*Figure 10 Main zone air temperature ($^{o}$C) before and after the addition of internal mass.*

### Heating added

Figure 11 shows the main zone air temperature and the heating rate due to the addition of the ideal loads heating system in the energy model. The selected setpoint is 19°C. This can be clearly seen in the internal air temperature data. During the colder months the internal air temperature rises up to the setpoint temperature when heating is used. Since there is no provision for cooling, during the warmer months the internal air temperature is the same as before the addition of the heating system. This means that the addition of the heating system has been performed correctly. The heating rate ranges from 0W in summertime and up to 3401W in December.
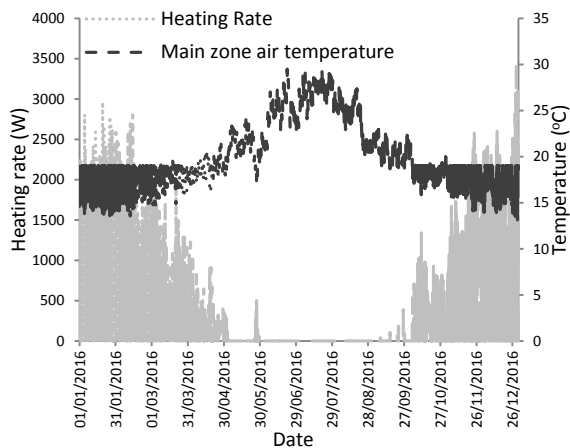


*Figure 11 Main zone air temperature ($^{o}C$) and heating rate(W).*

### Infiltration added

Figure 12 shows the temperature difference between the main zone internal and the external temperature and the heat losses due to infiltration. As expected, the infiltration heat losses follow closely the temperature difference between internal and external air, peaking when the temperature difference is highest. The heat losses due to infiltration for this example day are highest late in the night, when heating is ON and the external air is low.
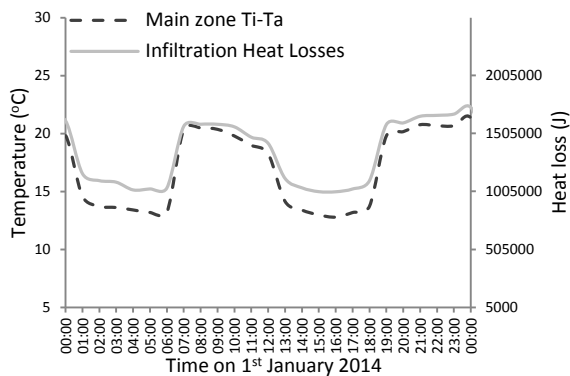


*Figure 12 Temperature difference between main zone and external air temperature ($^{o}C$) and the resulting infiltration losses(J).*

### Complete with internal loads

Figure 13 presents the main zone indoor air temperature for each of the six steps of the conversion process; the basic model, with windows added, with internal mass added, with heating added , with infiltration added and the complete model with internal loads. The internal air temperature resulting from the basic model presents low variation throughout the day. The addition of windows results in added heat gains and losses and thus in increased variance of the air temperature, which is peaking in midday when the solar gains are higher. The internal mass addition is smoothing down the highs and lows of the internal air temperature. The most significant impact on the indoor air temperature is resulting from the addition of the ideal loads heating system. A clear heating pattern can be seen, causing a significant increase in the indoor air temperature. The addition of infiltration results in more heat losses from the building envelope and lower indoor air temperature which can be clearly seen during the time periods that heating is not used. Finally, the complete model incorporates internal heat gains due to occupancy, electricity and lights causing an upward shift in the indoor air temperature.
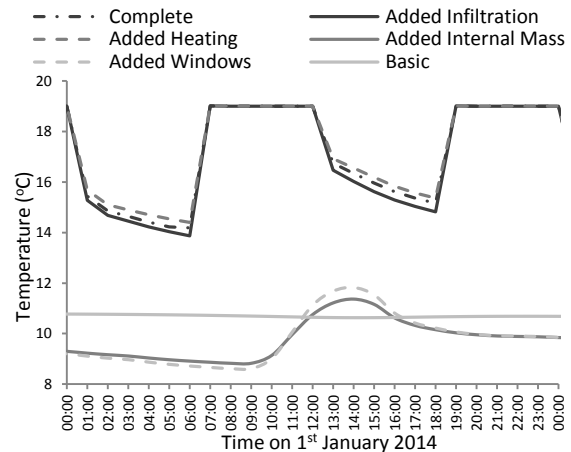


*Figure 13 Main zone air temperature ($^{o}C$) for each of the six steps of the conversion process.*

### Comparison with measured data

Figure 14 shows plots of the main zone indoor air temperature as modelled and as measured. Although a slight deviation can be observed, given that no calibration has been performed at this stage, the modelled and the measured indoor air temperature present a moderately good agreement. The assumptions made for the creation of the idf file using the conversion tool adequately resemble what is happening in real life. The main differentiation is during the colder months when heating is used. During these months the calculated air temperature remains constant at the required setpoint and drops when heating is off. A real-life heating system would not be able to maintain such constant air conditions. As observed in the plotted measured data, the internal air temperature overshoots when heating is used. The

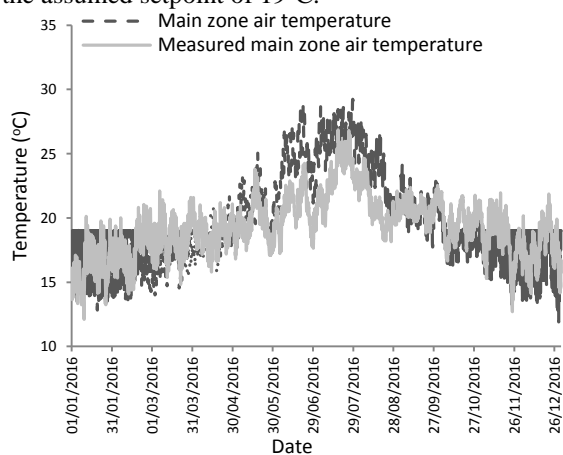real temperature setpoint can differ significantly from the assumed setpoint of 19$^o$C.



*Figure 14 Main zone air temperature ($^o$C) as modelled and as measured.*

## CONCLUSION

A gbXML editing tool and a gbXML to idf conversion tool were developed using a case study of an existing UK house. The conversion tool step by step verification showed that the conversion process from BIM to BEM does not present any significant errors and abnormalities in the resulting energy data. At each step of progressive addition of elements (windows, internal mass, heating, infiltration and internal loads) to the basic model the main zone air temperatures were calculated. The addition of windows increased the standard deviation of the main zone air temperature from 4.12$^o$C to 5.95$^o$C and the addition of internal mass decreased it to 5.93$^o$C. The addition of heating changed the profile of the main zone air temperature completely with a clear pattern of heating times. As expected, the addition of infiltration and internal loads caused additional heat losses and heat gains quantified as a drop and rise in the main zone air temperature respectively.

As with most energy modelling techniques, the process developed in this work requires defaults to be set for numerous parameters used in energy modelling, including temperature setpoints and schedules. The most significant assumption made is that the heating system can be represented by a ideal loads system. Here, calibration of the model to the measured data has not been performed. Keeping these three points in mind, the modelled data present relatively good agreement to the measured data. The deviations observed between the modelled and measured temperatures highlight the importance of transparent data exchange and default setting when forming the energy model. The structure of the developed editing and conversion tools on an XML-based format serves to facilitate defaults setting, future model calibration and retrofit decision-making processes. Future work includes further validation of the tools presented in this work using additional BIM models and development of a decision support tool.

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