

AN APPROACH TO FACILITATING DATA EXCHANGE BETWEEN BIM ENVIRONMENTS AND A LOW ENERGY DESIGN TOOL

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ABSTRACT

Building Information Modelling (BIM) has many benefits, and can be used throughout the building lifecycle. At the initial planning stage building performance simulation (BPS) can be used to inform design decisions. Data can be exchanged between BIM and BPS tools using data transfer schemas such as the Industry Foundation Classes (IFC). The IFC schema lacks an energy domain, so an extension is proposed which contains energy concepts from a BPS tool called Passive House Planning Package (PHPP). The extended schema was used to create an object oriented tool which facilitates the transfer of data. The process of geometry extraction has been validated with several case studies which are based in Hannover Kronsberg, Germany and Ebbw Vale, Wales.

INTRODUCTION

BIM provides many benefits, ranging from cost and time savings to improved control throughout the project lifecycle (Bryde et al. 2013). As part of the BIM process, BIM authoring tools are used to plan an initial building design. This can be iteratively improved later in the design stage based on an analysis of its performance using 'downstream' applications. The downstream applications can also be used for purposes such as to check compliance with building regulations (Keiholz et al. 2009), or to support a certification process. An example of the latter is the Excel-based low energy design tool Passive House Planning Package (PHPP). This tool is part of the certification process of a Passivhaus to the Passivhaus standard (Feist 2012).

The Passivhaus standard is a fast growing low energy standard with over 30000 buildings certified worldwide (BRE Ltd. 2011). It relies on design principles such as passive solar design, high air tightness and high levels of insulation (e.g. triple glazing for windows). Low energy designs are becoming increasingly important, as the UK plans to reduce its emissions according to the Climate Change Act 2008 (Department of Energy and Climate Change 2013) and control buildings energy efficiency with standards such as the Fabric Energy Efficiency Standard (Zero Carbon Hub 2009). PHPP uses steady state calculations, but has been proven to be accurate in comparisons with real measured data

(Schnieders & Hermelink 2006) and results from dynamic tools (Feist et al. 2007).

Interoperability between BIM tool and PHPP is very low. Attempts to transfer data include 'workarounds' (Duncan 2011; DesignReform 2011) and a proprietary solution from ArchiCAD in version 15 (GRAPHISOFT n.d.). Duncan (2011) focusses on exporting wall schedules from a BIM tool to PHPP, and (DesignReform) involves more building elements. These are all incomplete solutions as they only focus on exporting a section of information needed for an energy analysis. They are also time consuming, and prone to human error. It must also be noted that the later version of ArchiCAD, version 16, does not seem to support PHPP as thoroughly as version 15 (Pickering 2012).

In order to avoid data repetition and redundancy, data can be transferred between BIM authoring tools and downstream applications using data transfer schemas. The IFC (buildingSMART 2013) is a data transfer schema that can describe the whole building lifecycle. The key limitation of this schema is that it does not include a description of an energy domain in the main specification. Research on an extension is described by O'Donnell et al. (2011). Its purpose is to support data exchange between HVAC design applications and energy analysis applications. It would not be suitable for data exchange between BIM and PHPP. To the authors' knowledge, there is no published research supporting interaction between IFC and PHPP.

Cemesova et al. (2012) proposed "PassivBIM" - a methodology to extend the IFC schema with key energy entities. This paper describes the implementation of PassivBIM, and its application to existing Passivhaus buildings in two locations. The first study focuses on buildings from the Hannover Kronsberg project. The second is a detached house in Wales called Larch House. One of the main challenges in implementing the Passivhaus system was the extraction and processing of geometrical data from an IFC file. The resulting object oriented building design tool PassivBIM can process input from IFC files, PHPP and user input. The IFC files are generated with a BIM tool called Autodesk Revit Architecture (Autodesk, Inc. 2013). PassivBIM creates a link between BIM-based tools and PHPP, and can inform users on design possibilities.

The next section contains a brief overview of the interoperability between BIM and energy tools. This is followed by an overview of the geometrical data needed for the PHPP annual heat demand calculation. The PassivBIM methodology is then described in more detail. The case studies used are then detailed. Finally, the importance of the results is discussed and conclusions are drawn on the PassivBIM tool.

SUMMARY OF BIM AND ENERGY SIMULATION

Current practice in the energy domain involves an architect designing a building and an energy specialist manually recreating it in an analysis tool, and adding missing data such as a U-value (Bazjanac & Kiviniemi 2007). Automating data exchange can change this, and can result in savings in time, a reduction in error and offer model reproducibility. Exchanging building data often relies on changing between model views of a building so data can be analysed by different domains. In the energy domain, an 'architectural view' is often transformed into a 'thermal view' (Wilkins & Kiviniemi 2008). Such transformation is necessary for various reasons. For example, software tools are often standalone with different ways to represent a model, and concepts need to be mapped from one to another.

BIM is a good candidate as a base from which data could be extracted to different domains (Eastman 1999), such as daylighting (Krygiel & Nies 2008). BIM is also an opportunity to hold data centrally, thereby avoiding data redundancy and repetition. Designers could improve their building iteratively as changes to a building would influence for example energy demand in real time. However, research into the interoperability of BIM and BPS tools reveals many still unresolved issues (Osello et al. 2011; Moon et al. 2011; O'Donnell et al. 2011). These indicate that data is often transferred using the IFC schema and the gbXML schema. The advantage of the gbXML schema is that it is supported by many BIM and energy tools (Moon et al. 2011). However, the IFC schema has been identified as the "only public, non-proprietary and well developed data model for buildings and architecture existing today" (Eastman et al. 2011). It has a wider scope than gbXML, which is seen as an important factor (Cormier et al. 2011).

Previous research has identified six stages of an ideal workflow from BIM to energy tools (Maile et al. 2007, p.36). These stages are: 1) defining the location of the building so it can be linked with weather data; 2) defining the geometry, constructions and materials and space types of a building; 3) assigning spaces as thermal zones; 4) assigning space and lighting loads to spaces; 5) defining in detail the HVAC system and its components; 6) running an energy simulation. The PassivBIM system focuses on developing the second stage in the transfer from a BIM tool to PHPP. This stage is an active research area

(Hitchcock & Wong 2011), with early efforts including the creation of data schemas such as COMBINE (Augenbroe 1992). Lawrence Berkeley National Laboratory (LBNL) has developed several IFC transformation utilities, such as the '*Geometry Simplification Tool*', which translates geometry from IFC compatible CAD tools to applications which can read gbXML (Bazjanac & Kiviniemi 2007). This tool is not yet publically available. BIM to energy simulation is also the topic of ASHRAE research project 1468. A reference BIM model was developed for energy simulation, and presented in a seminar at the ASHRAE 2013 Winter Conference, but no published work is currently available on this project.

Model geometry usually involves some degree of pre-processing and post-processing (Cormier et al. 2011). Pre-processing involves preparing raw data from a BIM tool, such as deleting elements or connecting surfaces and spaces using logic. Post-processing involves mapping data between the IFC format and the simulation tool. The PassivBIM project relies on both processing types. PHPP is quite different to most BPS tools, for example, it is spreadsheet-based and assumes there is only one thermal zone. It is to be expected that challenges in transforming geometry data to this tool will differ to challenges presented for other energy tools in studies such as (Osello et al. 2011; Hetherington et al. 2011). For example, automatically determining wall placements can result in holes in thermal models, but a PHPP model uses external dimensions to define areas thus the process is more explicit. The next section contains details on the areas that PHPP uses.

PHPP GEOMETRY

PassivBIM replicates the calculations for the annual heat demand section of PHPP. This involves balancing internal and solar gains with transmission and ventilation heat loss. The area of the thermal envelope of a building is needed for the transmission loss, and it should not have any voids. External dimensions of the thermal envelope are used. The building elements are the floor slab, walls and windows, roof and doors. The window and door area depends on the total height and width. The window areas are sorted by orientation to determine solar gain. The floor slab dimensions rely on the external corners of the building walls, not points inside the walls. The wall area depends on the location of the thermal boundary. As dimensions should convey the total external distance, the floor slab thickness is included. The location of the insulation at the top of the building is also important. If the thermal boundary is the slab that represents the highest ceiling, its height is the upper limit of external wall area and the top floor area is used as the roof area. If the insulation is in the roof, the whole wall area (including the roof thickness) counts as a wall area, and the roof area is calculated based on the actual roof. The roof area should not include any overhang.

The treated floor area (TFA) is also calculated, and used to normalise the annual heat demand. The TFA is the clear floor area inside the thermal envelope of a building. It is based on the German Floor Area Ordinance. The inclusion of areas in the total TFA depends on rules based on characteristics such as their use and height (Hopfe & McLeod 2010). In certain cases, the areas of reveals are also included in the TFA. A methodology which uses this information to transfer data from a BIM-based environment is outlined below.

METHODOLOGY

As this project is supporting the tool PHPP, the system needs to be compatible with MsExcel and be able to read IFC files. One of the aims of this project is to produce a non-proprietary solution to geometry extraction, which is compatible with a range of BIM tools. By using the IFC schema, the system remains generic and can be applied to any BIM authoring tool that exports IFC files. Another aim is to address the need to store behavioural data alongside static data such as geometry (Rezgui et al. 2010). The extension of the IFC schema therefore not only includes terms necessary for the final steps of the annual heat demand calculation, but also results. The process of developing such a system consisted of three main parts: 1) extending the IFC schema with an energy domain, 2) using the extension used to extract data from PHPP and 3) generating a tool based on the extended schema in the Java programming language.

IFC Energy Extension

There are many versions of the IFC schema, and the one extended in this project is the IFC 2x3 TC1. The first stage involved identifying key energy concepts from PHPP. The IFC already has a structural analysis domain, and the position and wording of its entities influenced the design of the energy extension. The IFC schema is available in both the EXPRESS and XML language. The XML version, IfcXML, is an XSD schema that is extensible without the need to edit the original schema. Figure 1 is an Express-G diagram of key concepts chosen to extend the IFC schema. The boxes represent entities in the IFC schema, and their attributes have been shown. Entities with a grey background are pre-existing, and the two dark grey entities are the main supertypes used. Entities from the structural domain, depicted as light grey, are included for comparison reasons. The extension concepts provide a mechanism to describe thermal items, activities and groups. The items include physical items, such as building elements and the ground. Examples of thermal activities include transmission and ventilation. The groups link activities to represent total heat loss, heat gain and the 'IfcEnergyAnalysisModel'. This last entity connects the type of analysis, building elements and thermal load groups. The items, activities and groups are further broken down into more specific concepts, and assigned attributes such as 'TotalLoad'. Other

elements that are in the extended schema include a heat recovery device and an energy resource. The 'IfcEnergyResource' defines boundary conditions for the simulations such as 'IfcAverageAirChangeRate'.

A new entity and relationship form part of the extension. The 'IfcDesignAlternative' entity contains information on alternative building elements and climates files. The new relationship 'IfcRelConnectsDesignAlternative' is a mechanism that enables alternative designs and their energy consumption to be linked to a base building model.

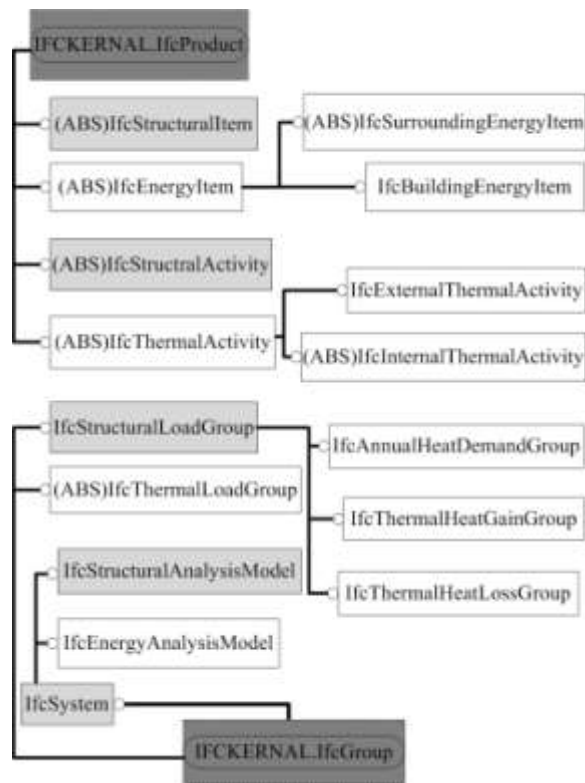


Figure 1 Express-G diagram of a selection of existing and proposed entities in the IFC schema

MsExcel XML Template

As the energy extension is in the format of a XSD schema, it can also facilitate the export of data from PHPP models into an XML document. To be compatible with MsExcel and inherently PHPP, the extension had to be simplified and unlinked from the IFC 2x3 TC1 schema. This process was necessary, as some XML tags used to describe the IFC schema are not compatible with Excel. The simplified schema was used to create a spreadsheet, called 'XML Template'. Concepts in the simplified schema were then mapped to cells in the XML Template. A macro was designed which loads data from PHPP models into this XML Template. The data in the mapped cells is now exportable to a XML document. The simplified extension was then reused to generate Java classes by software called Liquid XML Studio 2011. These classes contain algorithms that can read the exported XML documents from the XML Template.

These data are now accessible to the main PassivBIM Java tool.

PassivBIM Java tool

The aim of this part of the PassivBIM system is twofold. Primarily, it is an example implementation of the extended schema, and it shows how building information and simulation results should be stored together. The secondary reason is to provide a prototype that would automate some of the steps necessary to define geometry for a PHPP model from an existing BIM model. In order to fulfil the first purpose, Liquid XML Studio converted the extended schema into Java classes. These form the skeleton of the tool. Part of the code generation process in Liquid XML Studio is also to provide classes that enable the reading and writing of XML documents that are consistent with the fully extended schema. Java packages from the Open IFC Tools (Open IFC Tools 2012) project are used to read IFC files, and store data. The Java tool was then developed further to be able to pre- and post-process the data, calculate the heat demand and to perform several tasks that can inform decision making. These tasks are just simple examples to highlight the potential of PassivBIM.

Figure 2 is a UML case diagram of how architects and Passive House designers would interact with the PassivBIM system. The first step is for an architect to create a Revit model of a building, and export an IFC file. Additional input is then entered by hand, or an XML document is selected. The latter reduces data repetition and redundancy. The calculation of areas relies on many rules in order to decide where the thermal boundaries are in a building. Examples of decisions include determining the orientation of building elements, deciding if specific wall areas need to include side areas of other walls as they join

but do not overlay in an IFC file and if the thermal boundary is in the ceiling or in the roof. Post-processing of the data then for example removes unwanted areas such as an overhang and adds areas such as the side thickness of a ground floor.

The next section describes in more detail the case studies used to create and test the main Java tool. Using BIM generated IFC files presented an opportunity to determine commonly exported geometrical representations of IFC entities such as an 'IfcWall'. This is important, as the tool is a proof of concept and does not currently need to handle all possible IFC representations. Two main studies validate the process of extracting geometry.

HANNOVER KRONSBURG, GERMANY

The first study is based on buildings from an estate in Hannover Kronsberg, Germany. They are certified as Passivhaus, and their performance is validated by measured results (Schnieders & Hermelink 2006). The aim of this study is to show that PassivBIM can process: 1) buildings in terraces that have party walls, 2) two buildings in a single IFC file, and 3) a middle and end terrace house to inform design decisions. The buildings all have the thermal boundary in the roof. The case study informed the development of algorithms that can deduce this location of the thermal boundary, and process representations of walls and roof slabs to give the correct roof and wall area, and remove overhang from the roof area. Figure 3 shows the south facades of part of the terraces. The buildings at the end and in the middle of the terrace are called 'Endhaus' and 'Mittelhaus' respectively, but in this paper they will be referred to as the end house and middle house.

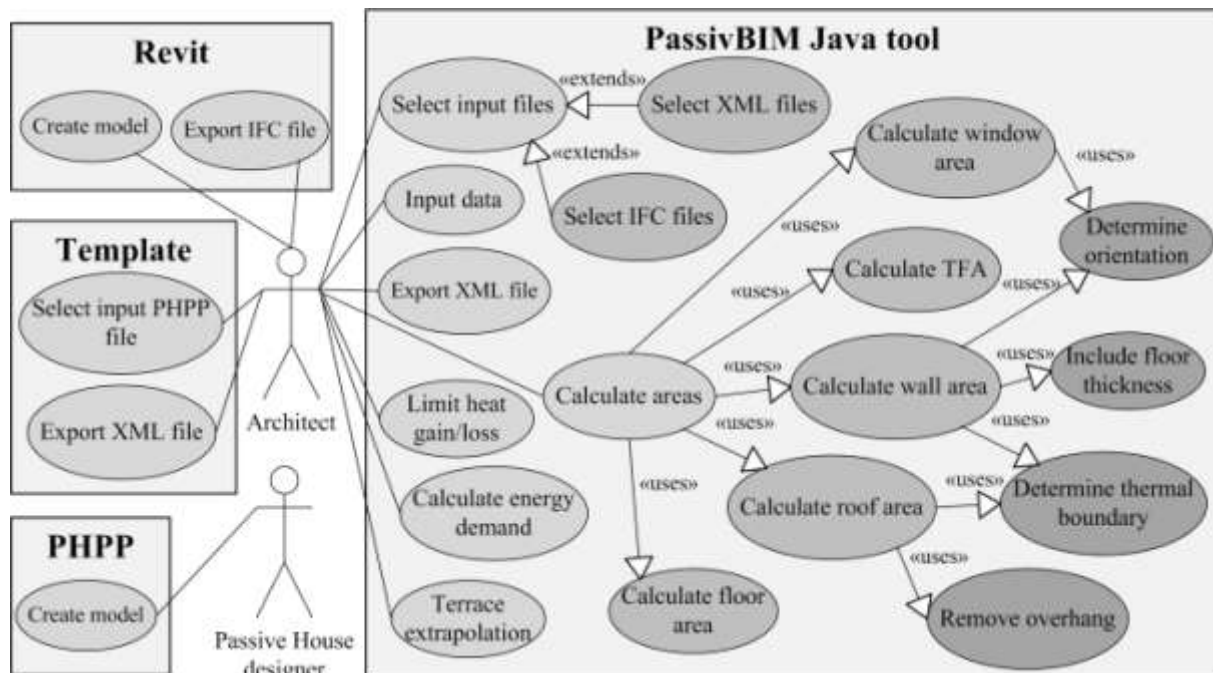


Figure 2 UML case diagram of the interaction between Architects, Passive House Designers and PassivBIM



Figure 3 South facades of the Hannover Terraces(Feist et al. 2001)

Middle house and end house data can be found in a report by Feist et al. (2001). They are both the ‘Jangster de Lux’ floor plan, but have different external walls. Non-geometrical data from the report was entered into PassivBIM by hand. Most building dimensions are available in floor plans, but some internal dimensions had to be extrapolated. A summary of the areas used is presented in Table 1.

Table 1
Area properties in (m²) of the case studies

BUILDING ELEMENTS	MIDDLE HOUSE (m ²)	END HOUSE (m ²)	LARCH HOUSE (m ²)
External door	0	0	2.37
Floor slab	71.76	76.99	63.88
North windows	8.60	8.60	4.07
East windows	0	0	4.39
South windows	11.40	11.40	28.07
West windows	0	0	0
Exterior Wall (Without windows/doors)	56.32	149.57	176.66
Treated Floor Area	120.61	120.61	86.69
Roof	78.25	83.96	63.88

The first part of the study involved IFC files representing the middle and end house terrace. All external walls must be labelled ‘external’ in Revit. The second part of the study used an IFC file of two end houses side by side, with their party walls in between. The end house model was created for both the left and right end of a terrace in Revit, and the two models were ‘linked’ and ‘exploded’ into a single file. Non-geometrical data is the same as for the end house, with the exception of the thermal bridge areas. This data is generally calculated using a dynamic thermal simulation, but as the buildings are identical, the areas were simply doubled. In the third part of the case study, PassivBIM is used to generate a graph that shows the average consumption of all the buildings in a range of terraces. This process starts with an end house and a middle house model. It then creates scenarios by composing them into terraces.

Figure 4 shows terraces with theoretical compositions of two, three and four buildings. This can be used to assess the impact of surface area to volume ratio on energy demand, which is one of the passive building design concepts (Sodha et al. 1986).

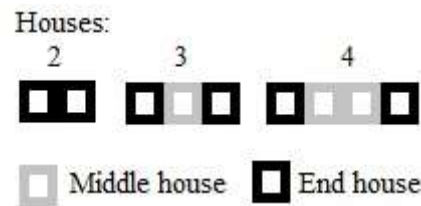


Figure 4 The composition of houses in a terrace

LARCH HOUSE, WALES

The second study is a building in Ebbw Vale, Wales, called the Larch House. Figure 5 shows a picture of this detached certified Passivhaus. It was completed in July 2010, but monitored data are not yet available. It is one of the first examples of a low cost Passivhaus and it is used as social housing (iPHA 2012). There are three main aims of using this case study. The geometrical extraction of the Java tool is further validated using a detached building model, which had the thermal boundary in the top floor. It informs the development of an algorithm that processes windows to calculate if reveals should be included in the TFA. Finally, validated models are used to show how design decisions could be informed. A specific example is annual heat demand is limited, and the effect on building element areas can be calculated. Geometrical data for the building originates from architectural plans so extrapolating internal dimensions is not necessary. Areas of its building elements appear in Table 1.



Figure 5 The Larch House case study (iPHA 2012)

Only one IFC file is necessary for this study, additional information about weather files and non-geometrical data comes from XML files. The initial model uses an Ebbw Vale climate file to validate the Larch House model against existing data. Two further models are set up for comparison, placing the same building under a ‘London CBD’ climate, and a future climate called ‘London CBD2080M50%’.

These climates were generated and validated in a study by McLeod et al. (2012). The future climate is for a median estimate of change, based on the medium emissions scenario and in the year 2080. It is interesting to note that the latitudes of the weather files are similar, with Ebbw Vale having a latitude of 51.76 N and London CBD having a latitude of 51.53 N.

RESULTS AND DISCUSSION

The PassivBIM system has extracted geometry from both terraced and detached buildings. The process highlights some issues with both the Passivhaus standard and IFC exportation. To the standard rules to be fully automated, some need to be more rigorously defined. For example, the TFA calculation states that the reveal areas of full height windows can be included in the TFA. In reality, this window may be a couple of centimetres below or above the height of a floor, so a tolerance level needs to be agreed. In terms of IFC exportation, the value for the true north was not accurately exported. This should default to the positive direction of the y-axis, and you would expect the coordinate '(0, 1, 0)' to be exported. The coordinate actually exported was '(2, 0, 1)'. This was further tested with other rotations, to find that the first value in the coordinate was always '2', and if the second two values were used to represent 'x' and 'y' values, they gave the right direction.

Exported IFC files were also imported back into Revit to test IFC interoperability. Figure 6 shows a 3D view of a) the Larch house Revit model and b) the Larch house IFC file imported into Revit. Alongside some loss of information, the most noticeable problems are windows have lost transparency and the walls are not cut accurately. Another limitation arose when windows were inserted into a wall at the floor height on the second floor. The wall was exported using a representation that loses some parametric information. When these windows were at least 1mm above the floor, the walls were exported with the parametric information.

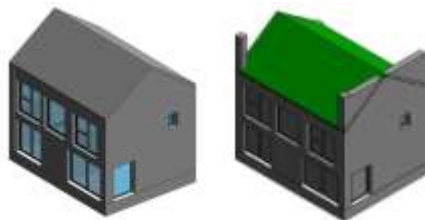


Figure 6 Larch house in Revit a) before export and b) after export to IFC and import to Revit

The sections below validate the Hannover Kronsberg and Larch House models against published data, and provide examples of informing design decisions.

Hannover Kronsberg, Germany

There is a high level of agreement between the simulated and published figures (Feist et al. 2001) of

the total heat demand for the middle and end house. PassivBIM calculated heat losses and gains are shown in Figure 7, normalised by their TFA. The percentage difference in heat demand between the middle and end house in the report and that calculated by PassivBIM is only 2.85% and 1.59% respectively.

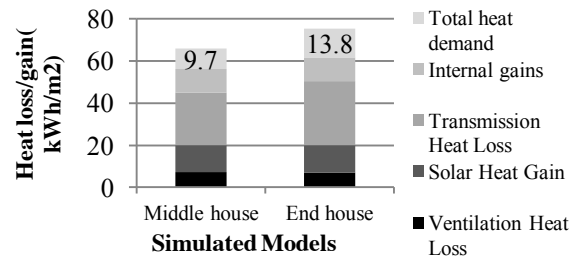


Figure 7 Heat transfer in Hannover buildings

As the middle house only has two external walls opposed to the three in an end house, it has a smaller heat demand. In a surface area to volume study, PassivBIM can predict to what point using more buildings in a terrace is effective. Figure 8 is an example of terraces created using the Hannover Kronsberg models. It shows that the effectiveness of terracing houses decreases at around 6 houses.

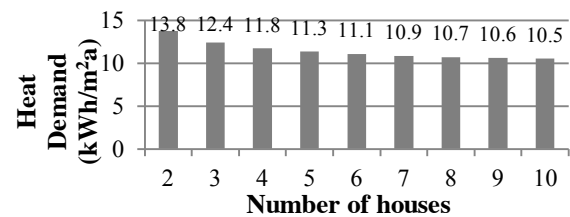


Figure 8 Annual heat demand in terraces

PassivBIM can also process data for a row of terraced buildings. Figure 9 shows the total heat demand for an end house that has not been normalised by the TFA, and two end houses in one IFC file.

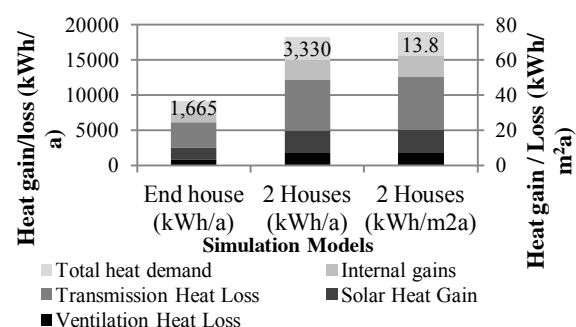


Figure 9 Heat transfer in Hannover buildings

Larch House, Wales

Overall, the Larch House heat demand is closer to published figures than the Hannover Kronsberg buildings. The heat losses and gains between a) a model with all data imported from PHPP and b) the same model overwritten with geometry from an IFC

file are shown in Figure 10. These models use the Ebbw Vale climate file.

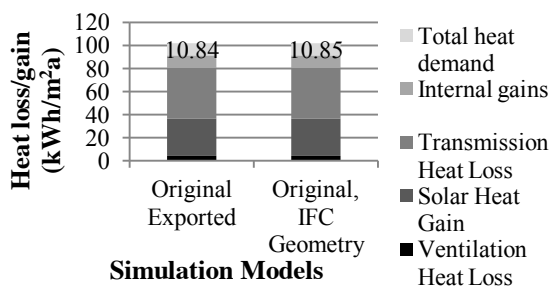


Figure 10 Heat transfer of Larch house with and without IFC geometry

The percentage difference in total heat demand in Figure 10 is only 0.1%, which further validates the PassivBIM geometry extraction. The heat demand for the Larch house in the Ebbw Vale climate is lower than in the study by McLeod et al. (2012). This could be due to PHPP having two methods for working out the annual heat demand. When planning a building, it may be useful to check how it could behave in a future climate or in an urban heat island. The effects of these two scenarios are presented in Figure 11.

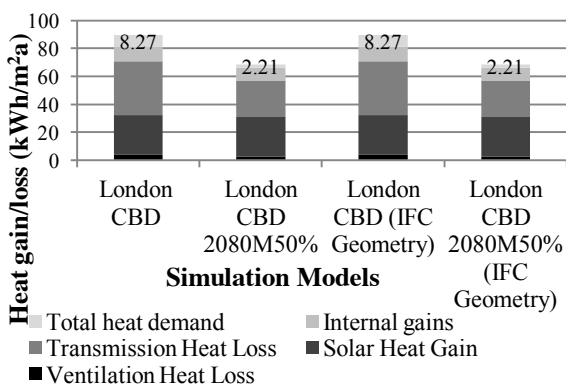


Figure 11 Future heat demand of the Larch house

The 'London CBD' and 'London CBD 2080M50%' models use only data extracted from PHPP. They are the basis of '(IFC Geometry)' models, but the geometry is overwritten. The percentage difference between the PassivBIM and published (McLeod et al. 2012) 'London CBD' and 'London CBD 2080M50%' models is 4.3% and 3.9% respectively. The climate files are the same as used in the report, so any error is associated with discrepancies in the PHPP models. It could also be due to different methods in calculating the annual heat demand. More importantly, the difference between models with and without IFC geometry is low. The percentage difference between the 'London CBD' and 'London CBD 2080M50%' with and without IFC geometry is 0.06% and 0.07% respectively. This is another validation of the PassivBIM geometry extraction process. Additionally, due to the 'IfcDesignAlternative' entity, a single IFC model can now hold results from Figures 10-11. Further processing could now be performed on the models to inform design decisions.

For example, as the heat demand is a steady state calculation, it can be reversed and used to calculate limits for building elements. For example, the annual heat demand can be set to 15kWh/m²a for the London 2080 model, and individual characteristics are calculated such as target wall area (440m²), wall U-value (0.23W/m²K), or window G-value (0.88).

CONCLUSION

This study describes an implementation of a methodology that extends the IFC schema with energy concepts. The resulting PassivBIM system can read both IFC and PHPP files and calculate the annual heat demand using the annual method. The extended schema allows both descriptive and behavioural data to be stored in the same place. This supports the concept of collaboration, as the data could be shared between team members of a project in order to make design decisions. The paper also includes some simple examples of how the data could be used to inform design decisions, on the subject of master planning and creating sustainable buildings for the future.

The process of extracting geometry is validated by both detached and terraced buildings, which further differentiated in the way they used the space under the roof. The error between a model using only PHPP data and one with IFC geometry remains below 0.1% for the Larch House models, and 2.9% for the Hannover Kronsberg models. When this geometry is used to calculate the annual heat demand for the Larch House case study, results differ to the published data by up to 4%. This is mainly caused by the difference in initial building models and not the geometry extraction. Future work would be to validate the tool with a wider range of models, which would include sloping and curved walls. The IFC exportation process also needs to be further developed. However, the process of automating data entry for PHPP shows good potential, and supports the aim of creating interoperable software and designing sustainable buildings.

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