INVESTIGATING THE POTENTIAL IMPACT OF STAKEHOLDER PREFERENCES IN PASSIVHAUS DESIGN

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ABSTRACT

Low-energy buildings have a major role to play in achieving carbon emission reduction targets. The Passivhaus standard is driven by improved thermal comfort and has stringent targets for limiting energy consumption. Such constraints can be difficult to achieve with aesthetically pleasing results. In early stage building design, decisions are often made based on preferences, without assessing their impact on energy performance.

Multi-criteria decision-making provides a technique of evaluating competing criteria using a robust framework. However, existing research in building performance focusses on quantitative measures, leaving a research gap in the subjective area of design preferences.

This paper applies a modelling technique that incorporates user preferences, alongside quantitative building performance measures, by applying multi-criteria decision-making to a Passivhaus case study. Potential building forms are evaluated using dynamic simulation, then the impact of stakeholder preferences is assessed.

INTRODUCTION

Under the terms of the Climate Change Act, 2008, the UK government has a legal requirement to reduce CO_2 emissions by 80% by 2050, based on 1990 levels (HMSO, 2008). Until recently, the UK was the only country to have such legislation, however, the 2015 Climate Change talks in Paris (COP21) has seen international agreement on the aim of restricting global warming to a 2°C upper limit, with an aspiration towards 1.5°C (UNFCCC, 2015).

Worldwide, buildings are responsible for one third of greenhouse gas emissions and 40% of energy use (UNEP, 2016). The construction and operation of buildings is a major contributor to greenhouse gas (GHG) emissions, responsible for half of UK emissions (UKGBC, 2015). Under the European Performance of Buildings Directive (EPBD), all EU member states must ensure that all new buildings are "nearly zero-carbon" by the end of 2020, or 2018 for all publicly owned buildings (European Parliament, 2010).

Often, decisions made in the early stages of building design are driven by subjective preferences on aesthetics, without running any building performance simulation (BPS) (Negendahl, 2015).

Clearly, the adoption of low-energy building will be crucial to achieving our emissions reduction targets; indeed climate change could be viewed as an opportunity for the evolution of improved building design (Bergman et al, 2008). As the internationally recognised standard for low-energy construction, Passivhaus aims to promote improved thermal comfort and indoor air quality, whilst simultaneously reducing energy use to around one tenth of that of the average UK building stock (Cotterell and Dadeby, 2012). Choices on building form can have a significant impact on energy use and selecting a more 'spread-out' form may even make achieving the Passivhaus criteria impossible (Nikolaidou et al., 2015; Hopfe and McLeod, 2015). Hence, it is crucial that a technique is developed that considers stakeholders' preferences and illustrates the consequences of their decisions in the context of more quantitative measures.

Multi-criteria decision-making (MCDM) provides a method of balancing the trade-offs between competing criteria. The existing research in the application of MCDM to building performance focuses on quantitative criteria (Pombo et al, 2015; Wright et al, 2002). However, qualitative criteria have an influence over the decision making process (Hopfe et al, 2013). Focussing on the technical aspects of low-energy design will not in itself result in high performance buildings; other more subjective aspects of the design brief must also be addressed (Coley and Schukat, 2001). Kaklauskas et al (2012) consider that subjective criteria are an omission from existing models in the multi-criteria analysis of Passivhaus and illustrate how individual building components might be optimised by applying criteria weights using both qualitative and quantitative attributes.

The goal of this study is to investigate the potential of decision making protocols (Robinson et al, 2016) when using BPS. This paper will use an MCDM technique to derive a multi-stakeholder, multi-criteria decision-making model.

METHODOLOGY

An MCDM technique is used to combine the relative importance of multiple stakeholders, their building performance criteria and their subjective opinions on different building forms to derive a decision-making model. As this paper summarizes the results of an initial prototype, it should be noted that all input values addressing the stakeholder's opinion are assumed based on standard practice. The idea is to investigate the sensitivity of the role of stakeholder influence and to establish its impact on the resulting decision.

Case Study

A case study building is used to demonstrate the concept; the building under consideration is the Community Centre building in Findhorn, Scotland. Whilst the results will only be directly applicable to the specific building in question, the methodology is transferable.

Findhorn is distinctive in that it is a sustainable community and eco-village, where the opinions of the wider community are considered and a consensus is sought when making decisions. It has application beyond the individual community setting, given that the project aspires to achieving a highly energy-efficient building, following the Passivhaus standard.

Method

Four stakeholders are considered: the architect, the client, the community and the Passivhaus consultant. Whilst this is by no means a complete list of the project stakeholders, it provides a subset of interested parties with conflicting views and has been chosen to illustrate the process.

A subset of four quantitative criteria is considered:

a. The annual energy consumed for heating and cooling, normalised by floor area;
b. The number of occupied hours when under-heating was experienced, defined by a Predicted Mean Vote (PMV) of less than -0.5 on the Fanger scale;
c. The number of occupied hours when over-heating was experienced, defined by a PMV of greater than +0.5 on the Fanger scale;
d. The area of land required for the building.

The measures specified in b. and c. are chosen because the Fanger definition of thermal comfort is the basis of international standards, such as ASHRAE Standard 55 and ISO 7730. It specifies that a PMV in the range -0.5 to +0.5 covers the 90% confidence limit of when occupants experience thermal comfort, subject to:

1. A clothing level of 0.5 clo in summer and 1.0 clo in winter;
2. An occupant activity level is in the range 1.0 met to 1.3 met;
3. An indoor air speed of less than 0.20m/s

(La Roche, 2012).

The qualitative aspect of the building form is considered alongside the numerical measures.

The Analytic Hierarchy Process (AHP) was chosen as the MCDM technique to balance design form preference against numerical measures, following the approach used by Hopfe et al (2013). AHP follows a process of making pair-wise comparisons of alternative criteria, to determine their relative importance, using a scale of 1 to 9, as shown in Table 1 (Saaty, 1987). The resulting matrix is then used to compute the Eigenvector and normalised by the overall total to give weightings for each criterion (Saaty, 1987).

This paper introduces a Multi Stakeholder Decision Making Framework, which is illustrated in Figure 1 and can be summarised as follows:

1. *Analyse the relative importance of the performance criteria for each stakeholder*

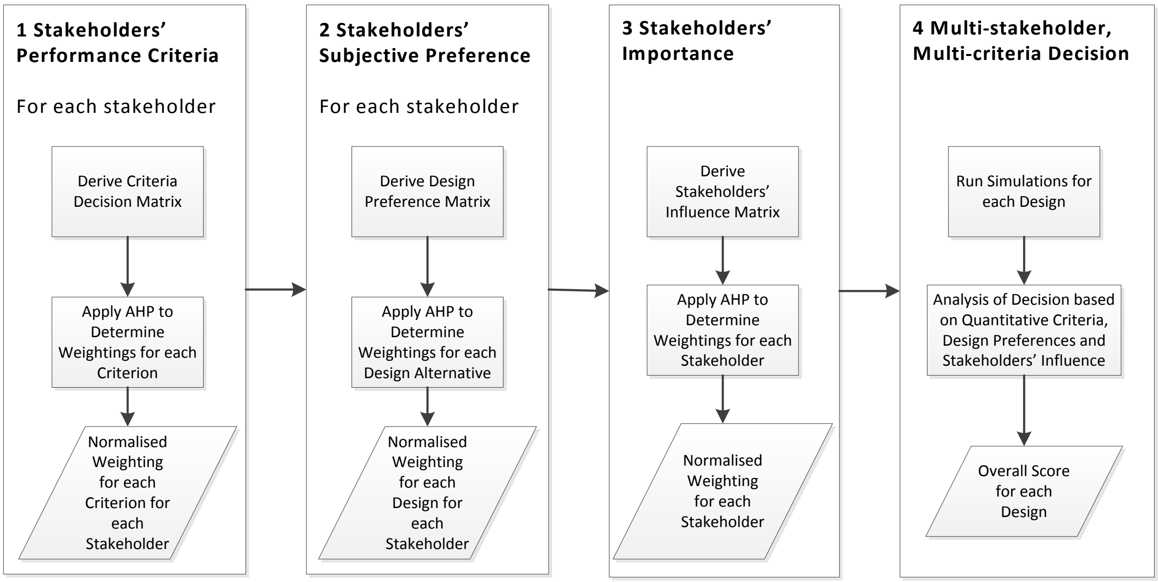
The opinions of the different stakeholders with regard to the relative importance of the performance criteria are estimated and AHP is applied to determine the weighting that each stakeholder attributes to each criterion (Saaty, 1987).

2. *Quantify the relative preference of each stakeholder for each design form*

Three alternative designs are considered; their building form and external dimensions are shown in Figure 2. Design 1 is a single storey building, which is broadly favoured by the community; Design 2 is two-storey building with the same ratio of length to breadth; Design 3 is also a two-storey building, with a square footprint. Each design provides the same internal floor area and volume. The building forms were chosen to be dissimilar because research shows

Intensity of importance on an absolute scale	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement moderately favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Table 1: The Analytic Hierarchy Process Scale (Saaty, 1987)



that decision-makers are more certain of their decision when they perceive the alternatives to be significantly different to one another (Malhotra, 1982). The relative preference of the stakeholders for each of the three building forms are analysed, again by applying AHP to determine normalised preference weightings for each building form for each stakeholder (Hopfe et al, 2013).

3. *Derive the stakeholders' relative importance*

The relative importance of the stakeholders over the design decisions is analysed, again by applying AHP to derive normalised weightings for each stakeholder's influence.

4. *Incorporate simulation results into a multi-stakeholder, multi-criteria decision*

Building performance simulations are run to determine the values for the quantitative measures for each of the three design forms.

The results from the previous steps are then used to weight the results of building simulation and lead to a multi-stakeholder, multi-criteria decision.

The design specification for the building simulation is illustrated in Table 2. Each prospective building form is modelled with two zones because the initial requirement is to provide two functionally different areas, one to function as a café and the other as a shop; office space is to be included within each zone.

In the early stages of design, the internal layout will not yet have been finalised, so no room divisions are modelled. Furthermore, the construction of the building fabric has yet to be defined, so it is modelled in terms of its performance by specifying U-values, rather than considering the precise material constituents.

The designs were drawn and simulated using DesignBuilder software, which provides a user-friendly interface to EnergyPlus dynamic simulations. The choice of software tools was based on their widespread use in the research community (Nguyen et al, 2014). Furthermore, EnergyPlus is a validated tool that offers a wide range of heat transfer models and has a reputation for reliably forecasting energy performance (Jankovic, 2012).

The result of this process leads to decision, based on the preferences and influence of each stakeholder.

A sensitivity analysis was then performed to determine how sensitive the resulting decision is to variations in the relative influence of each stakeholder and to building form preference.

For all of the numeric measures considered, a low value indicates better performance. Hence, their

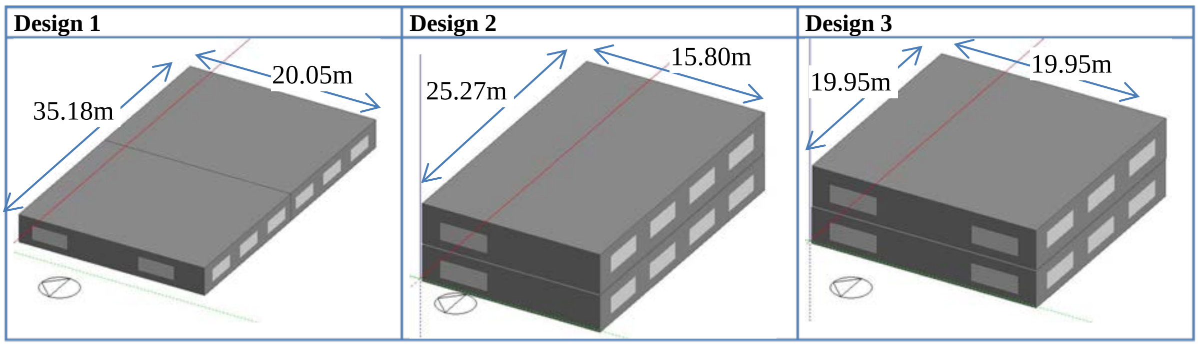


Figure 2: Alternative Design Forms

Table 2: Design Specification

	Parameter Type	Parameter	Value
Design			
Internal Floor Area			712 m^2
Internal Volume			2313m^3
Glazing	*Percentage of façade*	North-facing	10%
		East-facing	20%
		West-facing	20%
		South-facing	30%
Ventilation	*Volume of fresh air*	Per person	10 l/s per person[1]
Physical			
Building Fabric	*U-value*	External Walls	0.150 W/m^2K
		External Floor	0.085 W/m^2K
		Flat Roof	0.101 W/m^2K
	Thermal Mass		Low (timber-frame structure)
Glazing	*U-value*	Windows	0.780 W/m^2K
Infiltration			0.6 air-changes per hour at 50 Pascals
Ventilation	*MVHR*	Sensible Heat Recovery Effectiveness	90%
		Latent Heat Recovery Effectiveness	65%
Scenario			
Occupancy	*Occupancy Schedule*		09:00 to 21:00, weekdays
	Occupant Density		0.14 people / m^2 (assumed constant throughout occupied hours)
	Clothing Level	Summer Clothing Level	0.5 clo
		Winter Clothing Level	1.0 clo
Heating	*Heating Schedule*		08:00 to 21:00 weekdays (all other times: set back only)
		Temperature Set Point	20°C
		Temperature Set Back	12°C
Weather Data	*Design Builder*		Aberdeen Dyce Airport
Simulation	*Design Builder*	Timestep	10 per hour
Ventilation	*MVHR*	Usage profile	24 hours per day, 7 days per week
Equipment	*Internal Heat Gains*		8 W/m^2 (assumed constant throughout occupied hours)

value is subtracted from the worst case when deriving their weighting. For the subjective design preferences, a high value shows a stronger preference. The criteria are then combined into a single result, with the resulting total decision score, where a higher value indicates a better choice.
The values chosen for the pair-wise comparisons of the performance criteria, design preferences and stakeholder importance are based upon the views of stakeholders in the case study building design.

RESULTS

An analysis of the decision-making process in early stage design was completed by following the steps defined in the methodology:

1. *Analyse the relative importance of the performance criteria for each stakeholder*

The matrix in Table 3 shows the architect's relative preferences.

Table 3: Architect's Performance Criteria

Architect	**Energy Consumption**	**Under-heating Hours**	**Over-heating Hours**	**Building Form**	**Land Use**
Energy Consumption	1	1	1	1/5	1
Under-heating Hours	1	1	1	1/5	1
Over-heating Hours	1	1	1	1/5	1
Building Form	5	5	5	1	5
Land Use	1	1	1	1	1

The values chosen indicate that from the (anticipated) architect's perspective, 'Building Form' is very strongly more important than any other criteria.

[1] Requirement of UK Building Regulations (DCLG, 2013a)

The resulting normalised weightings are:

$$Architect \begin{pmatrix} Energy\ Consumption \\ Underheating\ Hours \\ Overheating\ Hours \\ Building\ Form \\ Land\ Use \end{pmatrix} = \begin{pmatrix} 0.111 \\ 0.111 \\ 0.111 \\ 0.556 \\ 0.111 \end{pmatrix} \quad (1)$$

Following the same process for the other stakeholders gives the initial results shown in Figure 3.

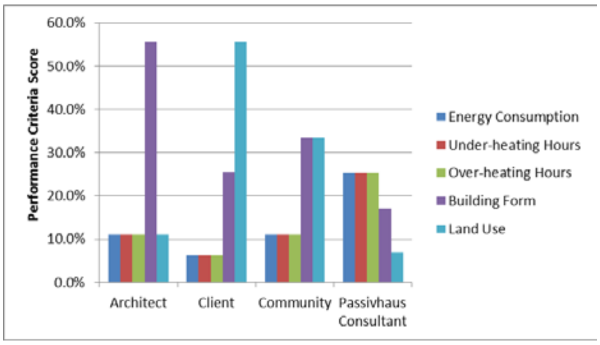


Figure 3: Stakeholders' Performance Criteria

The client criteria weightings show that building form and land use taking priority over energy consumption and thermal comfort measures. If the client was also the building occupant then the energy and comfort criteria may take greater priority. Similarly, the community attach importance to the building form and land use aspects.
For the Passivhaus Consultant, building form is interesting for its potential impact on energy consumption, under- and over-heating hours.

2. *Quantify the relative preference of each stakeholder for each design form*

The matrix in Table 4 shows the architect's relative preferences for the three alternative building forms; the values chosen indicate an extreme importance for the building form of Design 2 when compared to that of Design 1; whereas, Design 3 is very strongly preferred over Design 1 and Design 2 is strongly preferred over Design 3.

Table 4: Architect's Building Form Preferences

Architect	**Design 1**	**Design 2**	**Design 3**
Design 1	1.00	0.11	0.14
Design 2	9.00	1.00	5.00
Design 3	7.00	0.20	1.00

The resulting normalised weightings are:

$$Architect \begin{pmatrix} Design\ 1 \\ Design\ 2 \\ Design\ 3 \end{pmatrix} = \begin{pmatrix} 0.045 \\ 0.737 \\ 0.219 \end{pmatrix} \quad (2)$$

which is consistent with the architect's objective of being able to incorporate a view of the sea into the building, which is only feasible if a two-storey building form is chosen.

Following the same process for the other stakeholders' building form preferences gives the results shown in Figure 4.

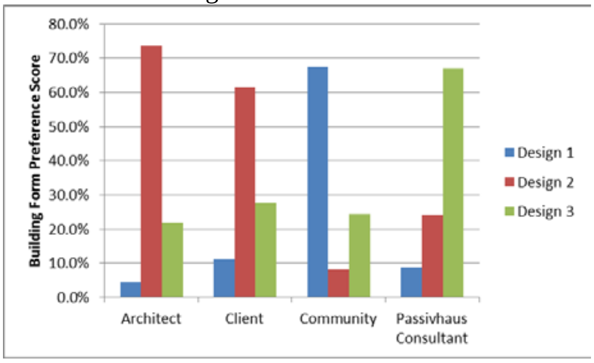


Figure 4: Stakeholders' Building Form Preferences

We assume that in the early stage design, the architect's preferences are closely aligned with those of the client. The community's design preferences show a preference for a single-storey building. The Passivhaus consultant's design preferences align with the ideal that a more compact building form makes the Passivhaus standard easier to achieve (Nikolaidou et al, 2015; Hopfe and McLeod, 2015).

3. *Derive the stakeholders' relative importance*

The matrix shown in Table 5 illustrates the relative importance of the stakeholders in early stage design; it must be noted that the balance of relative importance may shift in later design stages.

Table 5: Stakeholders' Relative Importance

	Architect	**Client**	**Community**	**Passivhaus Consultant**
Architect	1	1/5	1/3	3
Client	5	1	3	7
Community	3	1/3	1	5
Passivhaus Consultant	1/3	1/7	1/5	1

The resulting normalised weightings for the stakeholders' relative importance are:

$$\begin{pmatrix} Architect \\ Client \\ Community \\ Passivhaus\ Consultant \end{pmatrix} = \begin{pmatrix} 0.115 \\ 0.567 \\ 0.265 \\ 0.053 \end{pmatrix} \quad (3)$$

The client has the highest level of importance. In the context of Findhorn, we assign the community the next most significant role, followed by the architect and then the Passivhaus consultant.

4. *Incorporate simulation results into a multi-stakeholder, multi-criteria decision*

Each stakeholder's performance criteria (from step 1.) are weighted by the stakeholder's importance (from step 3.) to derive a single weighting for each criterion. The resulting performance criteria weightings are:

$$\begin{pmatrix} Energy\ Consumption \\ Underheating\ Hours \\ Overheating\ Hours \\ Building\ Form \\ Land\ Use \end{pmatrix} = \begin{pmatrix} 0.091 \\ 0.091 \\ 0.091 \\ 0.306 \\ 0.420 \end{pmatrix} \quad (4)$$

which indicates that Land Use and Building Form are the most important factors. Each stakeholder's building form preferences (from step 2.) are weighted by the stakeholder's importance (from step 3.) to derive a single preference measure for each design. The resulting design preferences are:

$$\begin{pmatrix} Design\ 1 \\ Design\ 2 \\ Design\ 3 \end{pmatrix} = \begin{pmatrix} 0.251 \\ 0.467 \\ 0.282 \end{pmatrix} \quad (5)$$

Building simulations were executed for each of the three alternative design forms, with all other aspects of the design specification kept constant, as described in Table 2. The results are illustrated in Table 6.

Table 6: Building Simulation Results

Design	Annual Energy Consumption (kW/m^2)	Occupied Under-heating (hours)	Occupied Over-heating (hours)	Land Use (m^2)
1	8.40	2996	7	776
2	9.77	2914	23	398
3	9.62	2876	24	398

Allowing for the fact that for each of these criteria, it is desirable to have a low value, and normalising the result give a percentage, gives the results shown in Table 7.

Table 7: Multi-criteria Performance Scores

Percentage Scores	Energy Consumption	Under-heating	Over-heating	Design Preference	Land Use
Design 1	34.9%	33.0%	43.5%	25.1%	25.3%
Design 2	32.4%	33.4%	28.7%	46.7%	37.3%
Design 3	32.7%	33.6%	27.8%	28.2%	37.3%

The resulting overall decision score percentages are calculated by multiplying the values in Table 7 by the performance criteria weightings in equation (4) and summing them to give the resulting decision values:

$$\begin{pmatrix} Design\ 1 \\ Design\ 2 \\ Design\ 3 \end{pmatrix} = \begin{pmatrix} 28.5\% \\ 38.6\% \\ 32.9\% \end{pmatrix} \quad (6)$$

The results indicate that considering the preferences and stakeholders impact/ relative importance, Design 2 would be chosen which aligns with the opinion of the most important stakeholder in the early design stage: the client.

Impact of Decision Makers' – what if?

It must be noted that assigning a relative preference on the Saaty scale is a subjective judgement, so it is important to consider whether small changes influence the overall decision. Furthermore, stakeholders may modify their original view as the design process progresses and they gain more detailed information.

An exploratory study into the sensitivity of the model to variations in the choice of weightings was conducted, by considering four distinct scenarios, as described in Table 8.

Table 8: Sensitivity Analysis Scenarios

Scenario 1	Base case comparison for other scenarios
Scenario 2	Equal importance for each stakeholder
Scenario 3	Impact of greater community importance
Scenario 4	Impact of aesthetic preference change

Scenario 2 was chosen to investigate how the decision might change if one considered all stakeholders to be of equal importance. Whilst this scenario is unlikely to exist in reality, it is useful to consider against scenario 1 to illustrate to what extent the client's importance influences the result.
Scenario 3 was selected to show the impact of increased community influence over design decisions; such a situation arises when communities resist unwanted development (Davoudi, 2013). Scenario 4 examines the effect of changing client preferences for different building forms by revising the client preference to favour Design 3 over Design 2. Such a situation can occur as the design process progresses.
The comparative results of these scenarios are shown in Figure 5.

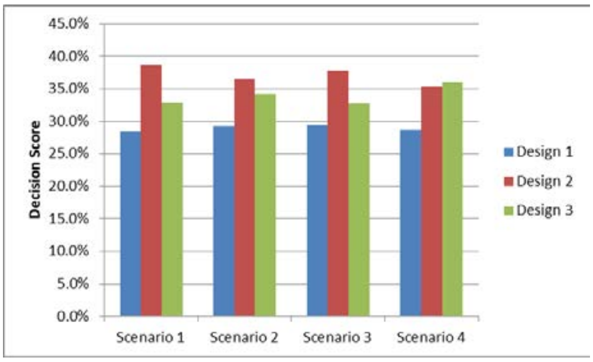


Figure 5: Sensitivity Analysis Results

Whilst it can be seen that changing the stakeholders' influence (in scenarios 2 and 3) did not change the final design in this instance, it did narrow the gap between the decision scores in this particular example.
However, changing the stakeholders' preferences for different building forms impacted the results sufficiently to reverse the order of designs 2 and 3 (scenario 4); in this instance, the client's relative

preference for design 3 over design 2 was increased by only two steps on Saaty's scale.

DISCUSSION

This paper illustrates a preliminary study into how subjective views on building form can be considered, alongside numeric measures of building performance as part of the design decision-making process, involving the opinions of multiple stakeholders. However, care must be taken in interpreting the results; the preliminary sensitivity analysis indicates that small changes in the preference of a key stakeholder can change the outcome sufficiently that a different decision is made.

The results for the early design stage indicate that the building form chosen by this method is Design 2. However, the results illustrate that a stakeholder's preference for a given building form may be based on preconceptions; for instance, the Passivhaus consultant's preference for the building form in Design 3, which was assumed in this study, is based upon the belief that it is the building with the best surface area to volume ratio (Hopfe and McLeod, 2015). It is important to consider that this view depends upon the assumption that the entire building fabric is equally well-insulated; the design specification used in this study included higher levels of thermal insulation in the floor and the roof, which meant that the heat losses are reduced in comparison to the walls. This aspect illustrates the trade-offs involved in increasing insulation levels to compensate for a more spread out building form in Passivhaus design. Moreover, this needs to be borne in mind when considering building forms for buildings designed to the current UK building regulations, which specify higher insulation levels for the roof and the floor than for the walls in new buildings (DCLG, 2013b). It would be instructive to feedback the findings from the initial decision making process and assess whether stakeholders might modify their preferences when given the relevant simulation results, as part of an iterative process.

Furthermore, stakeholders' preferences for different building forms must be seen in the wider context; there may be valid reasons for a stakeholder to prefer a single-storey building. For instance, a client may have reduced mobility, a planner may require a new building to blend in with the existing street scene (DCLG, 2012) or a community may wish to see a much-loved view preserved. Conversely, a commercial housing developer will be driven by the financial imperative of ensuring sufficient building density to maximise their profits, hence two or three storey properties may be preferred to achieve the same floor area in a smaller footprint, hence land use may be of greater concern.

Occupant behaviour can also be considered as a preference; for example, if the occupant has a strong liking for keeping windows closed at night, then that is incompatible with requiring night window opening as part of a strategy to prevent over-heating (Ridley et al, 2014).

Another interesting finding from the simulation results is that the thermal comfort measures indicate that there are a high proportion of the occupied hours when the occupants are likely to experience thermal discomfort due to under-heating. However, an air temperature of a minimum of 20°C is achieved during the majority of occupied hours. One of the key aspects of Passivhaus design is that good draught proofing and a lack of cold surfaces mean that thermal comfort can be achieved at lower air temperatures (Cotterell and Dadeby, 2012). These aspects are taken into account in the Fanger definition of thermal comfort; however the results shown here are inconsistent. Further research examining various methods of measuring thermal comfort is recommended. An alternative approach may be to consider over-heating hours as those with a temperature above 25°C, as defined by the Passivhaus standard (Hopfe and McLeod, 2015) and consider under-heating hours as those with an operative temperature below 20°C. Furthermore, the current method does not take into account the extent of the discomfort; it might be more useful to apply an integral PPD (percentage person dissatisfied) method, which takes into account by how much the threshold is exceeded.

CONCLUSION

This study provides valuable insights into how the views of multiple stakeholders, on many quantitative criteria, can be balanced against a qualitative aspect, by considering a subset of the participants in the early stage of building design. However, care must be taken; small changes in stakeholder preference can change the resulting decision. Also, there are notable areas for improvement. Firstly, the building design decision process is temporal in nature, with diverse stakeholders becoming involved at different points in time; this study has focussed upon the early stage of the design process. Future studies plan to address the subsequent design stages and the iterative nature of the building design process. The analysis of stakeholders' preferences needs to be expanded to incorporate behavioural preferences. Furthermore, the issue of how one assesses the extent of thermal comfort is worthy of more detailed research. Moreover, the sensitivity analysis undertaken in this study is rudimentary in nature; a more in depth study is planned. Finally, the issue of uncertainty in the simulation results is not considered here. It is intended that these aspects will be addressed in future research.

ACKNOWLEDGEMENT

Acknowledgement is given to Eco Design Partnership and to the Findhorn Community for the use of their project as a case study.

REFERENCES

Bergman, N., Whitmarsh, L. & Köhler, J. 2008, Transition to sustainable development in the UK housing sector: from case study to model implementation, Tyndall Centre for Climate Change Research.

Coley, D.A. & Schukat, S. 2002, "Low-energy design: combining computer-based optimisation and human judgement", Building and Environment, vol. 37, no. 12, pp. 1241-1247.

Cotterell, J. & Dadeby, A. 2012, The passivhaus handbook : a practical guide to constructing and retrofitting buildings for ultra-low energy performance, Green Books, Totnes.

Davoudi, S. 2011, "Localism and the Reform of the Planning System in England", Disp; disP, vol. 47, no. 4, pp. 92-94.

DCLG (Department for Communities and Local Government) 2012, National Planning Policy Framework. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/6077/2116950.pdf.

DCLG (Department for Communities and Local Government) 2013a, Building Regulations Part F, Available: http://www.planningportal.gov.uk/uploads/br/BR_PDF_AD_F_2013.pdf

DCLG (Department for Communities and Local Government) 2013b, Building Regulations Part L2A, Conservation of fuel and power in new buildings other than dwellings. Available: http://www.planningportal.gov.uk/uploads/br/BR_PDF_AD_L2A_2013.pdf

European Parliament 2010, Energy Performance in Buildings Directive 2010, Europe.

HMSO 2008, Climate Change Act 2008, UK.

Hopfe, C.J. & McLeod, R. 2015, The Passivhaus Designer's Manual: A Technical Guide to Low and Zero Energy Buildings, Routledge.

Hopfe, C.J., Emmerich, T.M. & Wright, J.A. 2014, "Pareto optimization and aggregation: A new approach with user criteria in BPS.", Computational Optimsation of Low-Energy Buildings , pp. 31.

Hopfe, C.J., Augenbroe, G.L.M. & Hensen, J.L.M. 2013, "Multi-criteria decision making under uncertainty in building performance assessment", Building and Environment, vol. 69, pp. 81-90.

Jankovic, L. 2012, Designing zero carbon buildings using dynamic simulation methods, Routledge, London.

Kaklauskas, A., Rute, J., Zavadskas, E.K., Daniunas, A., Pruskus, V., Bivainis, J., Gudauskas, R. & Plakys, V. 2012, "Passive House model for quantitative and qualitative analyses and its intelligent system", Energy and Buildings, vol. 50, pp. 7-18.

La Roche, P. 2012, Carbon-neutral architectural design, CRC, Boca Raton, Fla.; London.

Malhotra, N.K. 1982, "Information Load and Consumer Decision Making", Journal of Consumer Research, vol. 8, no. 4, pp. 419-430.

Negendahl, K. 2015, "Building performance simulation in the early design stage: An introduction to integrated dynamic models", Automation in Construction, vol. 54, pp. 39-53.

Nguyen, A., Reiter, S. & Rigo, P. 2014, "A review on simulation-based optimization methods applied to building performance analysis", Applied Energy, vol. 113, pp. 1043-1058.

Nikolaidou, E., Wright, J.A. & Hopfe, C.J. 2015, "Early and detailed design stage modelling using Passivhaus design; what is the difference in predicted building performance?", BS2015, 14th Conference of International Building Performance Simulation Association, December 7-9.

Pombo, O., Rivela, B. & Neila, J. "The challenge of sustainable building renovation: assessment of current criteria and future outlook", Journal of Cleaner Production.

Ridley, I., Bere, J., Clarke, A., Schwartz, Y. & Farr, A. 2014, "The side by side in use monitored performance of two passive and low carbon Welsh houses", Energy and Buildings, vol. 82, pp. 13-26.

Robinson, E., Hopfe, C.J. & Wright, J.A. 2016, "Stakeholder Decision Making in Passivhaus Design", SimAUD 2016, Symposium on Simulation and Architecture in Urban Design.

Saaty, R.W. 1987, "The analytic hierarchy process—what it is and how it is used", Mathematical Modelling, vol. 9, no. 3–5, pp. 161-176.

UKGBC. 2015, , Why we do it. Available: http://www.ukgbc.org/about-us/why-we-do-it

UNEP (Nations Environment Programme) 2016, , Sustainable Building and Climate Initiative. Available: http://www.unep.org/sbci/AboutSBCI/Background.asp

UNFCCC (United Nations Framework Convention on Climate Change) 2015, *Adoption of the Paris Agreement.*

Wright, J.A., Loosemore, H.A. & Farmani, R. 2002, "Optimization of building thermal design and control by multi-criterion genetic algorithm", Energy and Buildings, vol. 34, no. 9, pp. 959-972.