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To examine appropriate deep-retrofit practice using simulation results in an EU-funded urban regeneration project

Jia Michelle Cui[a]*, Anton Ianakiev[a], Miguel Á. García-Fuentes[b]

[a]*Nottingham Trent University, NG1 4FQ, Nottingham, UK*
[b]*CARTIF Technology Centre, 40151 Boecillo,Valladolid, Spain*

Abstract

This paper is based on a recently completed feasibility research – report of the Passivhaus standard retrofitting innovation activities – for the EU Horizon 2020 project REMOURBAN (REgeneration MOdel for accelerating the smart URBAN transformation). REMOURBAN is a major Future Cities demonstrator project supported by an investment of EU Lighthouse project scheme [1]. A block of terraced houses, which is one of the eight archetypes to be retrofitted at Nottingham demo site, will be cost-effectively retrofitted to a high energy-efficiency standard. Both static and dynamic simulation results play important roles in identifying appropriate retrofit standards and practice to achieve expected energy savings for such a major investment project. This paper aims to explore the building simulation effect on predicting the improvement potential in terms of energy savings under various refurbishment scenarios in the early project stage. The current feasibility study ushers the next project phases of implementation and real-time field monitoring, when detailed simulations are also expected to play important roles.

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Keywords: retrofit; EnerPHit / near Passivhaus district; static and dynamic simulation; cost-effectiveness

1. Introduction and project background

Retrofitting existing dwellings to the Passivhaus or a near Passivhaus standard has to consider the cost-effectiveness, especially for a project on the micro-urban scale. The EU Horizon 2020 project of REMOURBAN is a five-year project covering multiple smart city aspects such as energy, mobility, ICT, and citizen engagement. A terrace block of three-bed houses, one of the eight building archetypes at Nottingham demo site, is proposed for a deeper retrofit than the building envelope improvement to be adopted in the other seven archetypes. Energy performance, associated costs, and thermal comfort conditions are key factors in selecting the appropriate retrofit standards, which are used to certify the

* Corresponding author. Tel.: +44-115-848-2803; fax: NA.
E-mail address: michelle.cui@ntu.ac.uk

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effectiveness of the building components to be identified and the renewable energy solutions to be adopted. Dynamic simulation results using preliminary building information are required by the project committee to demonstrate the energy saving potentials if every archetype is retrofitted homogeneously to improve the building envelopes. Design Builder was selected by all three involved cities only for the cross comparison purposes, since neither the project nor this paper aims to compare the effectiveness of different dynamic building simulation tools. For the eight building archetypes, dynamic simulations were conducted for both pre-retrofit conditions and post-retrofit situations following the national standard for new building envelopes as in the Part L1B of UK Building Regulation. Proceeded by the building envelope improvement in seven archetypes, the deep retrofit is expected to take place in the third project year of 2017. Considering the relatively early project stage when producing this paper, the static simulation results, which were quoted in a recently completed feasibility study deliverable [2], using the Passive House Planning Package (PHPP) of Passivhaus Institute (PHI) are presented here to compare energy saving effects of several deep-refurbishment scenarios. Further dynamic simulations for the associated scenarios will be conducted in the project tendering stage following detailed building survey.

2. The houses for a deep retrofit

The West Walk building in Nottingham consists of nine terraced William Moss houses as shown in Figure 1. It was constructed in the 1960s with concrete raft foundations and load bearing precast concrete panels. Storey-height infill timber frame panels were fixed between the precast panels, and tiles hung on timber battens. Although the walls were originally specified with glass fiber insulation within the timber panels, it is assumed that this has either slumped or been affected by damp and its effectiveness has been reduced. The gable end walls were cladded in bricks, and the roof was covered in concrete tiles, with an asymmetrical section and copper cladding to a vertical element facing west.

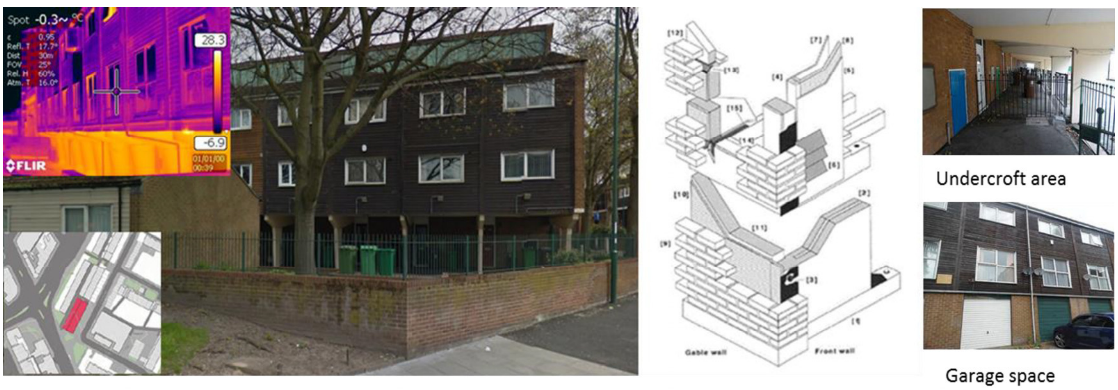


Fig.1. West Walk houses with the construction details of a typical William Moss house corner (Source for construction details: [3])

3. Research question and methodology

Multiple challenges reside in adapting an existing building to improve the energy performance. For example, the orientation of West Walk houses is fixed for the potential installation of roof PV panels. The building fabric components as provided are costly to adapt. Multiple areas are difficult to retrospectively make cold bridge free. Based on the industry-wise review of associated standards and practice in the UK and other European countries, the recently completed deliverable [2] recommended that the retrofitting interventions should aim for an energy performance close to the EnerPHit standard for the extra energy savings on top of the required normal retrofitting practice. The major difference in terms of energy performance between Passivhaus and EnerPHit standards resides in two aspects. Annual space heating requirement for treated floor area changes to 25kWh/m^{2}a from 15kWh/m^{2}a. The upper-limit for air infiltration test result under 50 Pascal changes to 1.0 air changes per hour (ac/hr) from 0.6 ac/hr [4].

An averaged post-retrofit energy use at 132.94 kWh/m^{2}a (with an extra 28.39 kWh/m^{2}a contribution from Renewable Energy Sources (RES)) were re-defined in a recently modified Building Energy Specification Table (BEST) across all eight building archetypes to achieve the overall 46.77 per cent of energy saving target at Nottingham demo site [5]. To strive for this ambitious target on average savings, one major research question for the West Walk retrofit at the current stage is how to secure extra energy saving margins from a deep-retrofit scenario that should be technically and economically effective. To identify a reasonable deep-retrofit scenario that has the heating requirement close to 25kWh/m^{2}a can also assist in justifying the normal retrofitting practice undertaken in the other seven archetypes at Nottingham demo site. Five retrofit scenarios with different improvement potentials in terms of energy savings are thus listed as in Table 1. The feasibility of each option is further analysed using PHPP static simulations results. The energy use outputs of dynamic simulation for the first retrofit scenario under national building regulation are tabulated in Table 2 to compare with the respective PHPP results.

4. Retrofit scenarios of West Walk houses

Table 1. Strategies to achieve an EnerPHit district in different Retrofit Scenarios

Components	Building regulation	EnerPHit + existing boiler	EnerPHit + Heat Pump	Zero Energy House	Energiesprong Zero Energy House
Building envelope	*ETICS 30mm walls	ETICS 100mm walls and 100mm roof	ETICS 100mm walls and 100mm roof	ETICS 100mm walls and 100mm roof	Prefab panel 100mm walls and 100mm roof
Form factor improvement	-	Additional room	Additional room	Additional room	Additional room
Windows	No change	Triple glazing window	Triple glazing window	Triple glazing window	Triple glazing window
Heating system	Existing boiler 9 kW	Existing boiler 9 kW	MVHR and Heat Pump** 4.25 kW	MVHR and Heat Pump** 4.25 kW	MVHR and Heat Pump** 4.25 kW
RES integration	-	-	-	Photovoltaics and energy storage	Photovoltaics and energy storage

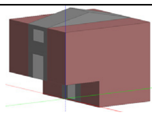
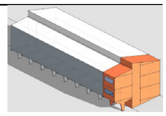
Note: *ETICS: External Thermal Insulation Composite System

** MVHR: Mechanical ventilation with heat recovery (MVHR) with integrated heat pump from Genvex® was quoted in [2])

4.1. Building regulation

The first evaluated scenario is the one that complies with the Part L in UK Building Regulation. No specific definitions on the efficiency improvement due to the window replacement in existing systems are provided in the Part L1B. All properties at Nottingham demo site have to be insulated to reach the minimum U-value at 0.3 W/m²K according to the Part L1B [6]. The preliminary information such as building materials and U-values in pre-retrofit situations were directly taken from the survey results in a Green Deal document pack provided by one project partner. The same system conditions, except for the improvement on External Thermal Insulation Composite System (ETICS), were considered for this scenario. Dynamic simulations were conducted using the target U-values at 0.3 W/m²K and the average temperatures recorded over the recent ten-year period in Nottingham to compare with the static PHPP simulation results under this building regulation scenario. The winter design day temperature used to simulate the coldest outdoor temperature was set at -3.6ºC. It is at this temperature that the heating demand is at its highest. PHPP was conducted using the software built-in weather data for the UK midland area. The whole building energy usage was averaged as in the Table 2.

Table 2. Design Builder and PHPP simulation results for the building envelope improvement under UK Building Regulation

Property type	Energy use per property using Design Builder dynamic simulation results (kWh/m²a)			Energy use per property using PHPP static simulation results (kWh/m²a)			
	Pre-retrofit	Post-retrofit			Pre-retrofit	Post-retrofit	
End Terrace	272.61	158.23		Average	266.74	191.5	
Mid Terrace	223.65	149.14					

The pre-retrofit energy use of the end-terrace house in the Design Builder results is approximately the same with the averaged energy usage per house in the PHPP simulation results as shown in Table 2. However, the post-refurbishment energy usage in the PHPP result is larger than that in Design Builder results for the first scenario. The overestimation in general given in the PHPP result is assumed to originate from multiple reasons, such as the weather profiles used in the tools, the essential difference between dynamic and static simulations, and the suitability of using PHPP within the UK context instead of the monitoring-validated situations in Germany. Regarding the applicability of PHPP in different geographical areas, an example was given in the case-study based research using PHPP and TRNSYS in Spain [7]. It was found out that although PHPP as a simplified and static simulation method cannot produce more precise assumption of the disaggregated energy demands than dynamic simulations, it is still a very powerful tool in the feasibility studies to quantify effectively the performance improvement of buildings. Similarly, PHPP is expected to be able to effectively compare the energy saving potentials and cost-effectiveness of different deep-retrofit scenarios as discussed below prior to the detailed dynamic simulation being conducted for a selected retrofitting proposal of the West Walk houses in the next project stage.

4.2. Deep-retrofit scenarios

The rest of four strategy scenarios in Table 1 are all based on the EnerPHit standard in terms of the fabric parameter limits. The major difference resides in the energy source profiles that range from keeping the existing boiler to achieving a zero energy house. Another difference is that, for all EnerPHit retrofit scenarios, extra rooms are expected to be claimed by converting the undercroft area and the garage space of the existing building shown in Figure 1. This will present two main benefits in terms of energy efficiency. The first one is related to the improvement of form factor by avoiding the high thermal loss through areas such as the exposed slab and the entrance walls. The second benefit is to avoid certain thermal bridges, such as the ones existing in the beams and columns in the front side. As shown in the thermographic image of Figure 1, heat was lost mainly through these areas. These two benefits have been clearly demonstrated by the following PHPP simulation results. Additional benefits such as the increase in property values can be also derived from this intervention. The floor area is thus increased to 100m² in the PHPP static simulations from the 82m² used in the initial Design Builder dynamic simulation. To achieve zero energy EnerPHit houses in the last two EnerPHit scenarios, the energy needed for space heating, DHW, lighting and appliances is expected be covered by the Photovoltaics (PV) microgeneration at 51,500 kWh/a, which requires an approximate installation capacity at 60 kWp. The monthly PV microgeneration profiles and the electricity end use breakdown are demonstrated in Figure 2.

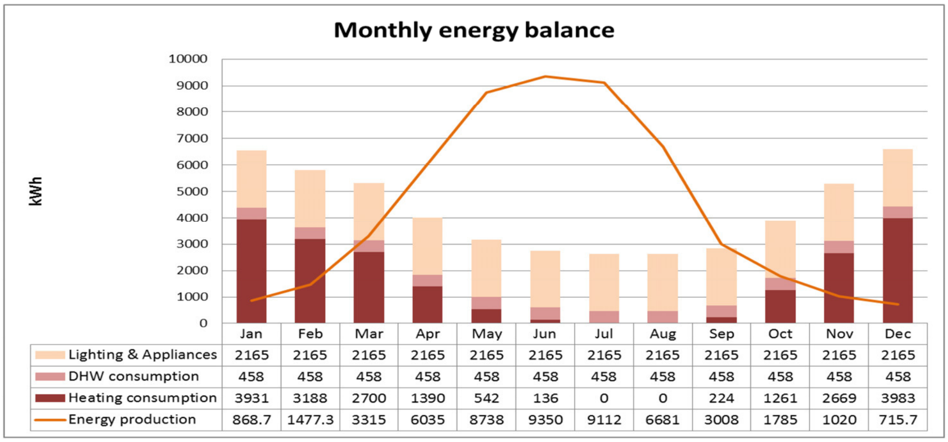


Fig.2. PHPP results of monthly energy balance for zero energy EnerPHit houses

The fourth deep-retrofit scenario differs from the first three ones by applying the Energiesprong approach. Energiesprong, or Energy Leap, is a Dutch initiative that has delivered 111,000 whole house retrofits in the Netherlands to net zero energy levels. The investment is financed by the guaranteed savings in energy cost. The requirements do not specify how the savings are achieved, and are not linked to a system or any supplier, as long as the delivery timetable can be made. Therefore, the design is very flexible [8]. The scheme started with housing associations, and has entered the private sector as it is rolled out further across Europe and into the UK that has been identified with a high implementation potential for this specific initiative. In social housing projects, an energy plan is set up for the tenants, who then pay the housing association as part of an energy plan, as opposed to paying an energy company for the energy demand. Some regulation barriers are still need to be overcome when implementing this model. In terms of technical aspects, Energiesprong offers a high-tech prefabrication solution to improve the building envelope to meet similar requirements to those stated by Passivhaus or EnerPHit standards. Currently, Energiesprong is in its early stages in the UK and no projects have been completed under its requirements yet. If selected and implemented at Nottingham demo site, Energiesprong will bring in not only technological but also financial innovations through the REMOURBAN project. Further analyses including financial modeling and technical simulations are expected to be conducted in the next project stage.

5. Feasibility analysis using PHPP

The PHPP simulation results are expected to assist in the decision making process of selecting an appropriate deep-retrofit scenario, which should also meet other requirements such as the investment and return in the next project stage regarding financial modelling. The annual energy use per house for all scenarios are demonstrated in Figure 3.

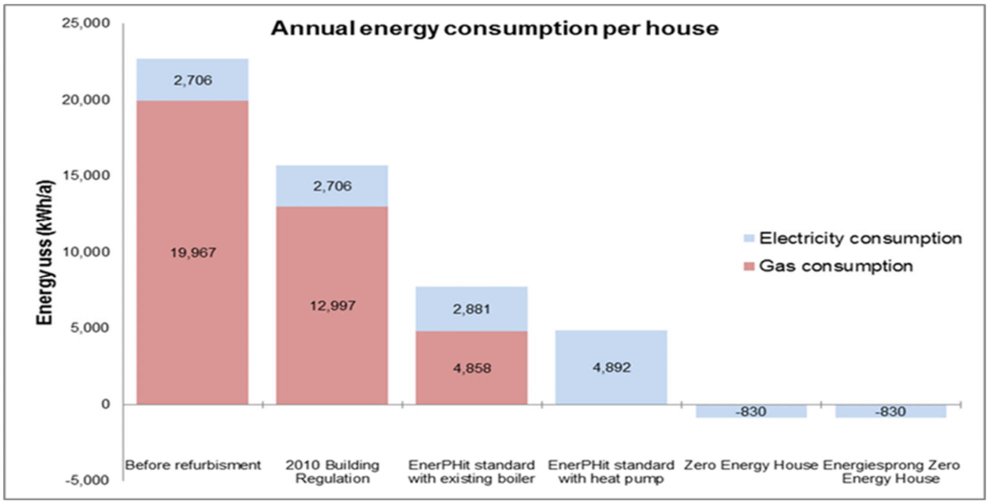


Fig.3. PHPP results of energy consumption for defined retrofit scenarios

Averaged by the mean floor area, the disaggregated heat energy balance is presented in Figure 4. In pre-retrofit situations, significant amount of heat is lost from external walls, followed by that from windows and ventilations. Heat gains largely rely on the gas-fueled space heating. The disaggregated heat energy balance, following the EnerPHit standard retrofit, shows that heat loss is expected to be significantly reduced, with only 11.14 kWh/m^{2}a of heat loss from the external walls. The improved air tightness can further reduce the space heating demand to 21.61 kWh/m^{2}a.

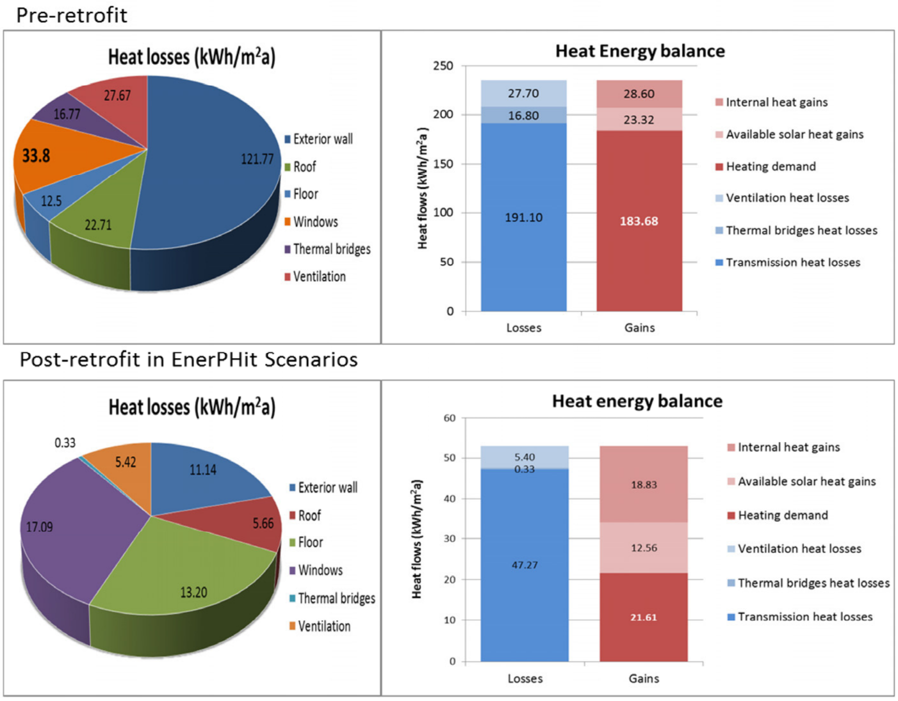


Fig.4. PHPP results of heat loss distribution and heat energy balance under pre-retrofit condition and EnerPHit retrofit scenarios

6. Discussion on the cost-effectiveness

Cost-effectiveness is a key aspect in selecting appropriate solutions for associated retrofit components. The building envelope insulation is exemplified in this section. The cost-effective selections of other building components such as windows and auxiliary plants follow the same principle.

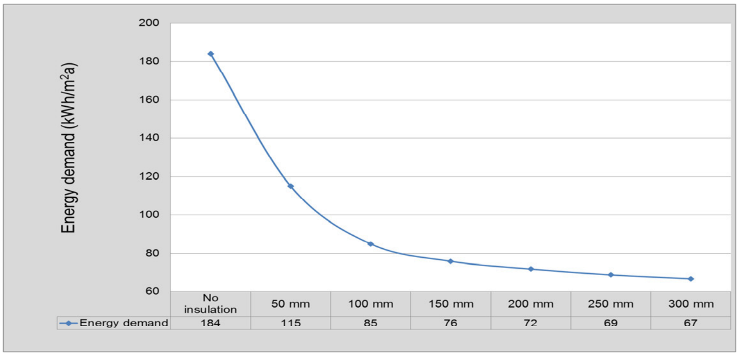


Fig.5. PHPP results of energy demand reduction corresponding to insulation levels for EnerPHit retrofit scenarios

As shown in Figure 5, there is a specific point where the demand reduction becomes almost linear. The effectiveness of increasing the insulation beyond this turning point has a low impact on energy demand reduction. The cost relating to the improvement on building envelope insulation after this turning point is thus not financially sustainable in terms of the cost and benefit. For this particular case, the most cost-effective insulation level is equivalent to adding 100mm of external insulation (with a U-Value lower than 0.4 W/m^2K) to the building envelope. This is the reason to choose the 100mm as the ETICS parameters for walls and roof in deep-retrofit scenarios in the previous Table 1. Other alternative materials with higher thermal performance features can be also considered to reduce the energy demand with a cost-effective thickness in the next project stage for a specific deep-retrofit proposal.

7. Conclusion

Appropriate deep-retrofit scenarios need to be examined for the West Walk nine houses presented in this paper. This is one of eight archetypes at Nottingham demo site in the EU Horizon2020 REMOURBAN project over the five-year period from 2015 to 2019. The aim of a recently completed deep-retrofit feasibility study, on which this paper is based, is to define the deep-retrofit standard and practice using simplified but effective simulation methods. The paper starts with the comparison between the Design Builder dynamic simulation results and the PHPP static simulation output for the retrofit scenario that complies with the UK building regulation. After pointing out the limitations of PHPP simulations, the paper dwells on the use of PHPP simulations in four EnerPHit-based refurbishment scenarios. The final decision on selecting any of the four EnerPHit retrofit scenarios will depend on multiple factors including the financial modelling results in the next project stage.

Considering the early project stage when producing this paper, PHPP simulations can effectively assist in examining the defined deep-retrofit scenarios. Detailed dynamic simulation will be performed again during the project tendering stage to verify the detailed design. It is expected that simulations will be re-run during the building project commissioning and operational stages when the real-time monitoring data are acquired from the established ICT platform by then. Therefore, simulation will be fully used over the entire project period, from the planning, design, and commissioning to the ultimate operation and maintenance.

Acknowledgments

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Biography

Dr. Jia (Michelle) Cui is a Research Fellow in Energy Efficient Buildings in the Sustainable Built Environment. She is working with Dr. Anton Ianakiev and Mr. Miguel Á. García-Fuentes in the REMOURBAN project (www.remourban.eu), which is a major Future Cities demonstrator project supported by an EU Horizon 2020 investment of EU Lighthouse project scheme. Dr Cui's current research interests include but not limit to: building performance evaluation and assessment, supervisory control and data acquisition (SCADA) for intelligent buildings, energy efficiency and sustainability in built environment; computational intelligence, occupancy-related built environment; renewable energy and district heating.