Challenges and opportunities to deep retrofitting of traditional fabric buildings to achieve nearly zero energy building (nzeb) standards.

Maria Lopez Zambrano[1], Paul Kenny[2], Jamie Goggins[1]
[1] MaREI Centre for Energy, Climate and Marine, Ryan Institute & School of Engineering, National University of Ireland Galway.
[2] Tipperary Energy Agency, Erasmus Smith House, Church Street, Cahir, Co. Tipperary, E21 HP66.
email: maria.lopezzambrano@nuigalway.ie, paul@tippenergy.ie, jamie.goggins@nuigalway.ie

ABSTRACT: Many of our traditional buildings are disappearing or in danger of being underutilised because they are not comfortable with modern-day living and do not meet our present-day needs. If a building does not have a use, inevitably it deteriorates and eventually becomes a ruin or gets demolished. It is essential to retrofit these buildings, which are part of our identity and can be compelling tourist attractions, even though most of them are not listed. Some owners want to apply for retrofitting schemes and grants, but they are discarded as candidates because there are no standard solutions to achieve low levels of consumption in these kinds of buildings. Besides, most of these buildings are built with traditional techniques such as local stone, historic brick, earth/mud walls, traditional plasters, and mortars. This project defines the mains challenges to retrofitting traditional fabric buildings. It plans a strategy using energy simulations tools, knowledge in nearly zero energy building (NZEB) retrofitting and restoration of heritage to help the market to retrofit these buildings without prejudice to the historical values and characteristics of the building. To approach this, we first defined what a traditional fabric building is and the building regulations framework regarding energy retrofit in these kinds of buildings. Establishing a comparison between the behaviour of regular buildings and those with traditional fabric walls, we explained how to perform analysis of these buildings in the Dwelling Energy Assessment Procedure (DEAP). Then, recommendations for design solutions to achieve NZEB standard are presented, which preserve and enhance the historical value of these buildings. The main findings in this research are that it is possible to retrofit buildings of historical importance with existing products in the Irish market.

KEYWORDS: NZEB, energy efficiency, traditional fabrics, energy retrofit, heritage.

1 INTRODUCTION

According to the 2016 census [1], residential buildings built in Ireland before 1919 represent at least 8 % of the total residential building stock, which rises to 15 % when we include residential buildings built up to the year 1946. From CSO census data, it can be seen that more than 13,000 buildings built before 1919 were lost in the ten years from 2006 to 2016, which represents more than 8% of the total stock from that era (Table 1). These figures reflect only occupied buildings, so the number is probably higher.

Table 1. Private households in Ireland by the period in which they were built, as a report from various Census data [1][2]

All private households	2006	2011	2016
All years	1,462,296	1,649,408	**1,697,665**
Before 1919	154,352	149,939	**141,200**

Historic buildings are not only an essential part of our culture; in the words of an expert group on cultural heritage in the EU [3], “the evidence demonstrates that relatively modest investment in cultural heritage can pay substantial dividends. These can be taken economically but also in terms of improving environmental sustainability and social cohesion”, and for that reason, it was included under the Horizon 2020 Work Programme 2014 for the Societal Challenge ‘Climate action, environment, resource efficiency and raw materials’. Retrofitting these kinds of buildings not only benefits the occupants in terms of comfort and increase asset value but also to the community as an essential attraction from a tourism point of view and the hospitality industry. Furthermore, of course, it contributes to the reduction in energy demand and CO_2 emissions.

1.1 *What is a traditional or historic fabric?*

According to the description by Arnold [4], traditional buildings include those built with solid masonry walls of brick and/or stone, often with a render finish, with single-glazed timber or metal windows and a timber-framed roof; usually clad with slate, but often with tiles, copper or lead. These were the dominant forms of building construction from medieval times until the second quarter of the twentieth century. Many traditionally built buildings are protected structures under the Planning and Development Acts[5] and, therefore, are identified as being of particular interest. However, many other traditionally built buildings do not have statutory protection, but may nonetheless be worthy of care in their repair and enhancement for contemporary living.

As a summary, the historic traditional fabric is defined here as a masonry wall of stone, brick, earth/mud walls, traditional plasters and mortars built without cavity before 1945. The “historic” is the technique. For that reason, a building with a historic fabric may or may not be protected under the Planning and Development Acts.

1.2 *Building regulations framework*

In can be seen in Figure 1 that a dwelling with a traditional fabric that receives a deep retrofit is not obligated to comply with heritage regulations [5] if it is not listed, but must comply with Part L [6] of Irish building regulations and be assessed with a Building Energy Rating (BER). On the other hand, if the building is listed, it is mandatory to comply with the heritage regulations, but it is not mandatory to comply with Part L [6] of Irish building regulations.

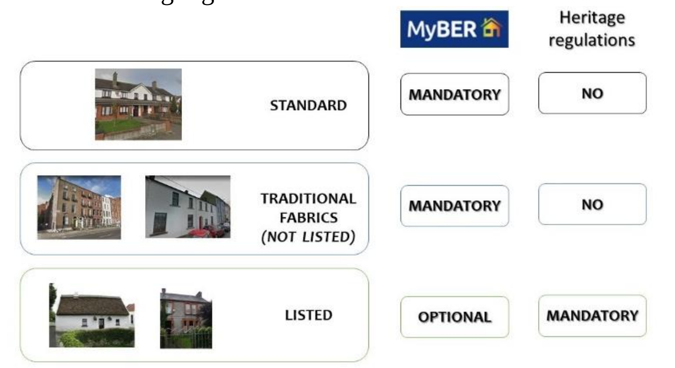

Figure 1. Compliance according to kind of building.

These situations have both advantages and disadvantages. In the latter case (listed), it is necessary to get approval from the heritage commission to go ahead with retrofitting; however, it is not necessary to complete the Domestic Energy Assessment Procedure (DEAP) to obtain a BER, so it is possible to use products that are not approved by the National Standards Authority of Ireland (NSAI). In the former case (not listed), it is a considerable benefit not to need to comply with heritage regulations when applying retrofitting solutions, but the principal problem is that this building must comply with the building regulations similar to a standard building. However, the characteristic of the fabric and the appropriate solutions are not the same, since there is a dearth of breathable products on the NSAI register. Besides, if we want to achieve the nearly zero energy building standard, we need to assess the BER by using DEAP.

This research aims to explain, in a general way, how a traditional or historic fabric building works, how we need to assess the BER to retrofit these buildings and gives some recommendations.

2 MATERIALS AND METHODS

Concerning building standards and guidelines, the behaviour of historic fabric of buildings is discussed in Section 3. Building physics and hygrothermal behaviour are considered by utilising case studies. The most critical challenges to perform condensation risk simulations of this kind of buildings are highlighted. In Section 4, a hypothetical case of study is used as an example of how to assess the BER using DEAP. Finally, some recommendations for specifying retrofitting solutions for traditional fabrics are given in Section 5.

As an illustrative propose, a hypothetical case study is used to help clarify the concepts developed in this work through the use of simulations. This case study has two variants – one of them is an actual end-terrace house located in Dublin city with hollow concrete blocks walls and the second variant is the same house, but with stone walls. Both of them are assumed to have the same features in terms of occupancy, schedules, windows, floors, roof, orientation and different wall U-values (Table 2). The principal features of the case of the study are gathered in Table 3.

We are going to consider that we upgrade the walls with a corkboard external insulation solutions of 100 mm of thickness and thermal conductivity of 0.040 W/mK for the DEAP assessment.

Table 2. U-values of the different envelope elements in the two cases of study

	Area (m^2)	Type 1 Concrete block U-value (W/m2K)	Type 2 Sandstone U-value (W/m^2K)
Walls baseline	102.67	1.53	2.1
Walls + cork 100mm	102.67	0.31	0.33
Floor	41.04	0.47	0.47
Roof	38.15	0.273	0.273
Windows	12.9	1.34	1.34
Doors	2	1.719	1.719

Table 3. Principal features of the case of study

Feature	**Value**
Total floor area [m2]	74
Dwelling volume [m3]	187
Ventilation method	Natural ventilation
Air permeability test in m3/hr/m2 (q50).	7.277
Effective air change rate [ac/h]	0.74
Type of Heating System	Central boiler
The efficiency of the primary heating system [%]	90.3

To evaluate the condensation analysis, we are going to use BuildDesk U version 3.4[7], the Type 2 case in this study and the insulation solutions in Table 4. The Welsh School of Architecture has independently reviewed BuildDesk U 3.4, Cardiff University as part of a European-funded project – Delivering Low Carbon Buildings Cymru.

Table 4. Insulation solutions features

Insulation	Thickness(mm)	Thermal conductivity(W/mK)
EPS	100	0.040
Mineral wool		
Cork		

3 HISTORIC FABRIC BEHAVIOUR

It is essential to understand the behaviour of the building from a holistic point of view. Historic buildings were designed to keep a balance, which means that all the elements have a function, and there is typically a connection between them. For example, to design solutions in a traditional building, regardless of whether it is protected or not, one of the most important things to consider is that solid masonry walls rely on their thickness to cope with atmospheric moisture, being sufficiently thick to ensure that drying takes place before moisture from rainwater passed through the wall to cause damp on the inner face. The breathable lime plaster allows the moisture in the walls to dry out to the external and internal air [4]. Because of this, breathable solutions are mandatory to ensure that the behaviour of the fabric is going to continue to perform in this way. However, also elements such as chimneys were linked with these effects, being ventilation elements, as well as heating the indoor space.

3.1 The thermal mass and traditional buildings

Thermal mass property is the ability to absorb, store and then release the heat with a determinate delay. If this thermal mass is high, the delay is higher too. Some retrofitting guides regarding historic buildings mark the importance of this characteristic, such as the Cornwall Council in the UK [8] that said that older buildings could save energy costs by absorbing and storing heat from solar gains and internal appliances and releasing it at a later stage. That will happen quicker with well insulated with lightweight materials compared to dense masonry walls.

The Irish guide for energy efficiency in traditional buildings[9] explains that a massive masonry wall and a well-insulated lightweight structure with the same U-value (rate of heat loss) have very different responses to internal space heating. It may well be suitable that a building should respond quickly to heat or cold, but in general, it is accepted that for traditional buildings, high thermal mass and relatively slow response time are advantageous. The thermal inertia is linked with the thermal delay (or lag) and temperature range reduction.

3.2 *Condensation risk and simulation methods.*

One aspect to take into account when we chose a retrofitting solution is condensation risk, which is not considered in the DEAP tool but included in the regulations is the condensation risk.

Appendix B of Part L of building regulations [6] establishes that condensation in buildings occurs whenever warm moist air meets surfaces that are at or below the dew point of that air. There are two main types: surface condensation and interstitial condensation. This document recommends assessing the likelihood of surface and interstitial condensation of a construction detail under IS EN ISO 13788:2012[14]. This standard contains recommended procedures for the assessment of the risk of (i) surface condensation and mould growth and (ii) interstitial condensation. Besides, reference is made to BR 497[15] for conventions for calculating linear thermal transmittance and temperature factors according to ISO 13788:2012.

These calculations were performed with BuildDesk 3.4 in the case of study type 2 (stone) for six cases (Figure 2): a stone wall with (a) 100 mm of external cork insulation, (b) 100 mm internal cork insulation, (c) 100 mm EPS external insulation, (d) 100 mm EPS internal insulation, (e) 100 mm rock wool external insulation and (f) 100 mm rock wool external insulation. All the insulation boards have the same thermal conductivity of 0.040 W/mK. Figure 2 shows the Glaser test to indicate top surface condensation, mould growth and bottom interstitial condensation. We can see that in all cases, the condensation surface and mould growth is not a problem, but interstitial condensation is a problem when the insulation is added to the interior of the walls. It is also possible to use BR 497 to calculate this in possible thermal points such as windows, corners, intersections with ground floor and ceilings.

Appendix B also includes that IS EN 15026:2007[10] can be used to assess the risk of surface and interstitial condensation and mould growth. The transient models covered in this standard take account of heat and moisture storage, latent heat effects, and liquid and convective transport under realistic boundary and initial conditions. Reviewing the limitations of EN ISO13788:2012, we can see that it provides a more robust analysis of some structures than others. The results will be more reliable for lightweight, airtight structures that do not contain materials that store large amounts of water. They will be less reliable for other structures such as traditional fabrics that use their large thickness to not only store energy but also store moisture from the rain and the interior of the building. For these reasons, a calculation with a transient hygrothermal performance analysis by numerical simulation, instead of the steady-state condensation risk analysis by Glaser method, could be the most recommendable.

If we try to perform this analysis in software like WUFI[11], which is one of the most tested and reliable, we find some critical difficulties. The most important one is that we do not have traditional Irish materials tested in a laboratory to include in the software. To use materials from other countries, we do not have warranties that the calculations are correct. If in our case study, there is possible to test the materials of the building, then this is the preferred method.

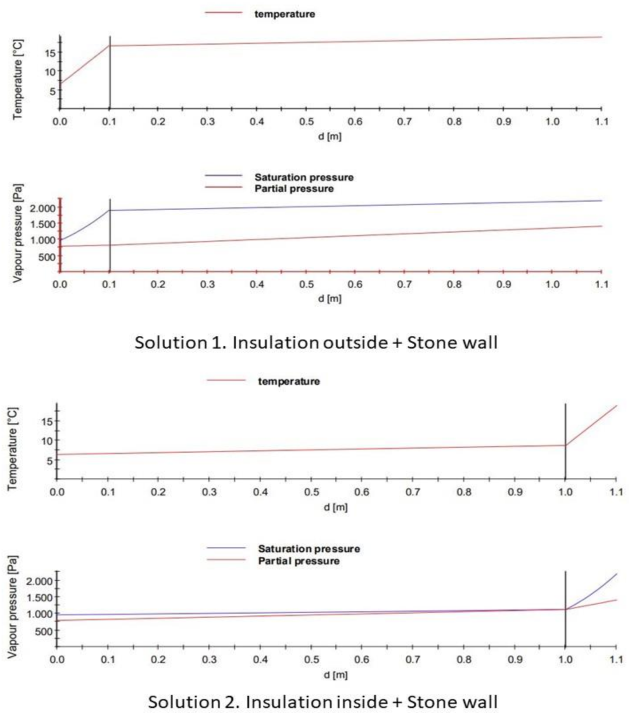

Figure 2. Glaser test results performed for the six examples in December for the Dublin location depending on the insulation position.

4 BUILDING ENERGY RATING

Domestic Energy Assessment Procedure (DEAP) is Ireland's official method for calculating and rating the energy performance of dwellings. If we want to perform a retrofitting, it is mandatory to do this assessment to get the Building Energy Rating (BER) of the building. For existing buildings, where major renovation is carried out, a primary energy performance of less than 125 kWh/m^2/yr (B2 BER) when calculated using DEAP typically activated is required under the following circumstances, where the work affects more significant than 25% surface area of the existing dwelling: external wall renovation (external or internal insulation), external wall and window renovation, external wall and roof renovation, external wall and floor renovation or new extension [6]. In comparison, for all new builds, Nearly Zero Energy Building (NZEB) is equivalent to a 25% improvement in energy performance on the 2011 Building Regulations (that is approximately less than 50 kWh/m^2/yr) [6]. As mentioned before, if a building is protected, it is exempt from needing a BER, but if a traditional fabric is not protected, it must comply with the Part L requirements of the Building Regulations [6].

The first step is to perform the certificate via DEAP software. Considering the example two cases of the study explain in subsection 2.1, the steps in DEAP are not very different for incorporating external cork insulation outside for both wall types. The 'dimensions' tab, windows (you can consider changing the shading for overhangs if it is applicable), light, ventilation and hot water are the same.

Also, the ‘Fabric’ tab, the U-value and the area of the fabric are the same because DEAP considers internal measures. Nevertheless, there is a principal difference here when including the U-value, as two principal values are required for the U-value from the former wall and the transmittance from the insulation (in this example, it is corkboard). There are three options to include the total U-value: (i) defaults, (ii) certificate agrément NSAI [12], and (iii) other certificates.

(i) Defaults values: this means the values included in Table S3 in DEAP manual [13] for existing dwellings by year of construction. In the example in this paper, the value for stone buildings built before 1977 is equal to 2.1 W/m^{2}K. If we consider that the two dwellings were built before this date, the concrete block with drylining plasterboard is 1.53 W/m^{2}K.

Sustainable Energy Authority of Ireland (SEAI) in a consultation done with the motive of this paper said: "Regarding U-Value calculations on existing walls instead of using Defaults as listed in Table 3B for example. Yes, this can be acceptable if this can be fully substantiated, i.e. by an architect or equivalent engineer in a signed detailed report. The adjusted U-Value calculation must also be fully compliant if requested from SEAI or if the BER Cert is selected for audit. Note depending on the thermal conductivity of the actual product combined with the thickness of the actual existing wall no guarantee that the adjusted U-Value calculation would be less than 2.1Wm2k”. Table 3B must be Table S3B because there is no Table 3B in the DEAP manual.

(ii) Considering that traditional fabrics in most of the cases are old, were fixed with different materials and mainly handmade, this option is not possible. These fabrics are not a standard system or material so that the thickness could be variable in the same wall. For the insulation material, the product must accredited test data. When using certified data to determine thermal properties of building elements, acceptable data is available on Agrément Certificates from the NSAI or equivalent. In the case presented in this paper, this product is a CE marked material but is not included in the NSAI register.

(iii) Other certificates: This option is possible for insulation materials, where values determined following the appropriate harmonised European standard should be used. That complies of [13][14]:

a. Test certificates must relate to the actual product in question.
b. Installation instructions in the test certificate on which the stated performance depends must be adhered to.
c. Test certificates must be in English or be accompanied by a certified English translation. The translation can be from the accredited test house or a professional translator listed by the Irish Translators and Interpreters Association or international equivalent.
d. The relevant test performance standard must be stated on the test certificate.
e. The test laboratory must be accredited to test to the relevant standard.
f. Performance data on “CE marked” literature is acceptable provided that the literature refers to the relevant test performance standard.
g. A Declaration of Performance (DoP) as used for CE marked products is acceptable for DEAP assessments, provided the requirements included in [13] are met.
h. Self-declaration literature from a manufacturer referencing the Ecodesign directive, efficiency and relevant test performance standard where applicable in the DEAP guidance.

In cases where there is any doubt, the test certificate should be sent to the BER helpdesk for clarification. The BER Assessor’s Code of Practice details the type of data which must be collected and retained for BER assessments. Consequently, in the case study presented here, in theory with a marked CE in English must be sufficient, but this should be checked with the BER helpdesk.

With traditional fabrics, in most of the cases option (iii) is the most relevant, as currently there are not many products in NSAI that are breathable, which can be used for upgrading traditional fabrics. The answer from the BER helpdesk takes time, so sometimes the contractor prefers to avoid this step and search for another product with the NSAI certificate. Furthermore, when the building is applying for a retrofit grant, such as through the Better Energy Homes scheme [15], the installers must be included in the ‘NSAI Agrément Approval Scheme for Installers”[16], and they are obliged that all products used on a project must be listed on the certificate for the system being installed on that project. Use of products that do not appear on that particular certificate (e.g. brick slips, insulated/GRC oversills, dash) is not acceptable, which will void the warranty and may also result in the homeowner not receiving the full grant payment [17].

As a result, the inclusion of the U-values in the fabric tab in the DEAP software is not something trivial. In the case study presented here, there are two options. In the case of the block concrete walls, we can opt to choose another material that has an Agrément Certificate from the NSAI (or equivalent) or follow the option (iii) and consult with the help desk. In the case of the stone wall, there is minimal choice but to make the consultancy (option iii). If we have permission from the DEAP helpdesk and we decide to include the value of the cork insulation, the final U-values are 0.33 W/m^{2}K (stone) and 0.32 W/m^{2}K (concrete block).

The next step is the ‘Heat Use’ tab in the DEAP software. In this section, all parameters remain the same except for the internal heat capacity. It is necessary to determine the thermal mass category following the process described in DEAP manual Appendix S10[13]; that is chosen from the five categories of the low, medium-low, medium, medium-high and high. To know the category of our building, we need to select the mass category of the elements of the house from Table 11a in the DEAP manual (See Table 5). The case of study 2 (highlight in green in Table 4) corresponds with “masonry externally insulated with dense plaster equivalent”, which is equivalent to the “Heavy” category. The case of study 1 (highlighted in orange in Table 4) is “masonry externally insulated wall with plasterboard on dabs”, which falls into the medium thermal mass category. The rest of the elements (in grey) to be considered are a ground floor, separating walls and internal partitions, which are the same in both buildings.

Then to assess the thermal mass category for the entire building, we need to check Table S10 of the DEAP manual. We can see in Table 6; the result is a medium-low thermal mass category for the house with the concrete block (yellow) and a medium thermal mass category for the house built in stone (green).

The rest of the tabs in DEAP are filled following the steps outlined in the DEAP manual. The results are included in Table 7. We can see how the building with traditional stone fabric, although the results do not differ much from concrete block buildings, performs worse in DEAP.

Table 5. Mass elements outlined in Table11a DEAP manual.

Element type	Description	Mass
Ground floor	Suspended timber floor	Light
Ground floor	Solid floor	Medium
Ground floor	Suspended steel frame floor	Light
Ground floor	Suspended beam and block floor	Medium
Ground floor	Suspended concrete beam floor	Medium
Ground floor	Suspended concrete plank floor	Medium
External wall	Timber/steel frame	Light
External wall	Masonry cavity fill with plasterboard on dabs	Medium
External wall	Masonry externally insulated with plasterboard on dabs	Medium
External wall	Masonry internally insulated	Light
External wall	Masonry cavity fill with dense plaster	Heavy
External wall	Masonry externally insulated with dense plaster	Heavy
External wall	Curtain walling	Light
External wall	Aerated concrete blockwork with plasterboard on dabs	Light
Separating wall	Masonry with plasterboard on dabs	Medium
Separating wall	Masonry with dense plaster	Heavy
Separating wall	Timber/steel frame	Light
Internal partition	Plasterboard on timber/steel stud	Light
Internal partition	Masonry with plasterboard on dabs	Medium
Internal partition	Masonry with dense plaster	Heavy

In summary, we can see that the DEAP gives us similar values for both cases. However, the significant difficulty is the U-value assessment of the baseline elements and to have a retrofit solution that complies with the requirements of SEAI.

5 DESIGN RETROFITTING SOLUTIONS

According to the information exposed in the previous sections to select a suitable insulation solution for a traditional fabric, we need to take into account several aspects.

There exists a lack of available laboratory test data for Irish traditional materials and fabrics that we can use as default values. Reasons for this include that each traditional building is handmade without a standard procedure and because not all stones, as an example, have the same characteristics. The best option in this cases is to test the materials, but in the majority of the cases, such as for small dwellings, the testing possibility is discarded, so we propose a simple approach to choose suitable solutions in retrofitting of traditional fabric buildings.

The first step is to define if we want the building to work as an "open-cell" construction or a "close cell" structure. An open cell fabric works like a sponge. The wall absorbs the moisture from the outside (e.g. from rain), inside (e.g. from cooking, breathing or baths) and/or from the ground. This kind of construction is defined as breathable, and it does not need to have impermeable layers to protect them; the building is a self-regulating body if it is well built.

Table 6. Thermal mass category defaults extract for the cases of study from Table S10 of the DEAP manual

	Type 1	Type 2
Number of light elements	1	1
Number of medium elements	3	2
Number of heavy elements	0	1
Thermal Mass Category	Medium-low	Medium

Table 7. DEAP results for the two cases of study.

	Case 1	Case 2
U-value walls	0.32	0.33
Heat loss coefficient [W/K]	158	159
Heat Use (gas consumption) kWh/year heating season	5048	5223
Primary energy per m^2	123	126
BER	B2	B3

The second option is the “close cell” fabric, which is most similar to current construction details. In this strategy, the building is protected from the internal and external sources of moisture by adding layers that prevent water from getting inside the wall. One of the main problems in the use of this strategy in historic fabrics is that it is challenging to guarantee that moisture will not go inside walls, such for example by capillarity from the ground floor.

Table 8. Examples of materials characteristics from the WUFI material database.

Material	Bulk density (kg/m^3)	Porosity [0-1] (-)	Specific Heat capacity (J/kg K)	Thermal conductivity (W/mK)	Water vapour diffusion μ (-)
Lime+ Gypsum	1571	0.39	850	0.82	9.61
Stucco	1600	0.3	850	0.7	7
Sandstone	2120	0.17	850	1.6	33
cork board	143	0.22	1900	0.0471	28.3
Isover Vario	83	0.12	1800	1	4000
EPS	14.8	0.99	1470	0.036	73.01
Cellulose	55	0.93	2544	0.0357	2
Mineral wool	65	0.95	850	0.032	1.1
PUR open	7.5	0.99	1470	0.037	2.38
PUR closed	39	0.99	1470	0.025	88.93

The second step is to look for the most suitable materials. We can use the materials included in Table 8 as an example. The materials with the capacity to store heat have a high bulk density typically, whereas the insulation used typically has low bulk density. Another valuable property is porosity, which is the measure of the voids in the material, where a value of zero indices all void whereas a value of unity indicates that there are no voids in the material. Porosity is very high in insulation materials such as PUR, EPS and mineral wool, but not in cork insulation panel. That indicates that corkboard can store more water than some other insulation products. Thermal conductivity is the ability of the material to conduct the heat, so for insulation, a lower value is always better. The water vapour diffusion resistance (μ) [18] is a measure of resistivity as a ratio of the resistivity of still air. It is a relative quantity and, hence, is expressed as just a number with no units. That is a property of the bulk material and is not dependent upon size, thickness or shape: the lower the μ value, the more 'breathable' the material.

According to the guide published by Historic England [19], if we follow an “open-cell” strategy, the insulation and protective finish installed externally must have low vapour resistance to retain the necessary 'breathability', and allow moisture to evaporate away harmlessly. A useful rule of thumb is that all layers of an insulated solid wall should become progressively more permeable from the interior to the exterior. While it is vital to protect external insulation from rain, this should not be done in any way that will trap moisture from within the fabric or from the ground within the solid wall material.

For an “open-cell” strategy, insulation materials such as cork, cellulose, mineral wool and PUR could be suitable. PUR has an open-cell has lower water vapour diffusion resistance of sandstone, so in theory, it could be suitable. Choosing a material only for thermal conductivity or the water vapour diffusion resistance properties could be an error. We must take into account other issues such as the reversibility of the solution, the compatibility of the material, avoid toxic materials, embodied carbon emissions, building regulations, forbidden materials, inter alia.

Another critical point is that adding the material outside to a wall is typically useful for avoiding thermal bridging and condensation, which could be a great ally to improve the energy consumption if a dwelling is regularly occupied. For discontinuous occupation or seasonal periods, adding the internal insulation could be beneficial. Thus, occupancy profiles should be considered when determining design solutions.

6 CONCLUSION

In this research, the principal challenges that can be found in retrofitting a traditional fabric building to be an NZEB are discussed. Some of them require testing of existing buildings to fill the dearth of reliable information to assess suitable U-values for traditional stone walls and for performing transient hygrothermal performance simulations. It is necessary to understand the behaviour of older buildings before selecting an intervention strategy and select insulation materials to retrofit these buildings that will maintain the breathability of their walls and the high thermal capacity contributing to stopping the trend of the demise of them in last years. It is time to include them in the retrofitting plans in urban and rural areas. They form part of the opportunity to cut emissions, achieve energy efficiencies and to have a positive impact on the economy and our heritage.

ACKNOWLEDGMENTS

This work was supported by SFI Industry Fellowship 18/IF/6349.

REFERENCES

[1] Central Statistics Office, E1004: Private Households in Permanent Housing Units 2011 to 2016 by Type of Private Accommodation, Aggregate Town or Rural Area, Persons per Household, Period in which Built and CensusYear, (2017). https://statbank.cso.ie/px/pxeirestat/Statire/SelectVarVal/Define.asp?maintable=E1004&PLanguage=0 (accessed March 31, 2020).

[2] Central Statistics Office, C0618: Private Dwellings in Permanent Housing Units by Regional Authority, Period in which Built, Aggregate Town or Rural Area and CensusYear, (2013). https://statbank.cso.ie/px/pxeirestat/Statire/SelectVarVal/Define.asp?maintable=C0618&PLanguage=0 (accessed March 31, 2020).

[3] Directorate-General for Research and Innovation (European Comision), Getting cultural heritage to work for Europe Report of the Horizon 2020 expert group on cultural heritage, (2015) 28. https://doi.org/10.2777/745666.

[4] P. Arnold, Thinking yourself warm: or how to approach heating traditional buildings., in Energy Effic. Hist. Houses, Dublin, Irish Georgian Society, Dublin, 2013: p. 19.

[5] Government of Ireland., Planning and development act, 2000. Irish Statute book., Dublin, Ireland, 2000.

[6] Department of Housing and Planning and Local Government, Conservation of Fuel, Part L - Conserv. Fuel Energy - Dwellings. (2019) 94. https://www.housing.gov.ie/sites/default/files/publications/files/tgd_l_dwellings_2019.pdf.

[7] BuildDesk limited, BuildDesk U 3.4, (2010). http://www.builddesk.co.uk/.

[8] A. Richards, P. Smith, Improving Energy Efficiency in Historic Cornish Buildings, Camborne (2016) 76.

[9] P. Arnold, Energy efficiency in traditional buildings, Government of Ireland, Dublin, 2010.

[10] EN 15026, Hygrothermal performance of building components and building elements - Assessment of moisture transfer by numerical simulation, Cen. 3 (2007) 0–90.

[11] Fraunhofer Institute for building physics, WUFI, (1995). https://wufi.de/en/.

[12] NSAI, NSAI. Agrément Certification, (2020). https://www.nsai.ie/certification/agrement-certification/ (accessed April 17, 2020).

[13] SEAI, Domestic Energy Assessment Procedure (DEAP) 4.2, (2019) 195. https://www.seai.ie/energy-in-business/ber-assessor-support/deap/.

[14] SEAI, Introduction to DEAP for Professionals, Dublin (2013)7–8. http://www.seai.ie/Your_Building/BER/BER_Assessors/Technical/DEAP/Introduction_to_DEAP_for_Professionals.pdf.

[15] Sustainable Energy Authority of Ireland, Better Energy Homes Programme, Dublin (2019) 17. https://www.seai.ie/publications/Homeowner-Application-Guide.pdf.

[16] NSAI, Agrément Registered Installers, Dublin (2020). https://www.nsai.ie/certification/agrement-certification/agrement-registered-installers/ (accessed April 17, 2020).

[17] NSAI, Technical update., Dublin (2016) 1–4. https://www.nsai.ie/download/certification/CWI-ETICS-Technical-Update-Issue-1.pdf (accessed May 19, 2020).

[18] KEIN mineral paints, Breathability & Moisture Vapour Permeability., Telford (2019) 0–4.

[19] Historic England, Energy Efficiency and Historic Buildings: Insulating Solid Walls, Historic England, London, 2016. https://doi.org/10.1108/ss.2011.11029caa.019.