CCC 2018

Proceedings of the Creative Construction Conference (2018)
Edited by: Miroslaw J. Skibniewski & Miklos Hajdu
DOI 10.3311/CCC2018-117

Creative Construction Conference 2018, CCC 2018, 30 June - 3 July 2018, Ljubljana, Slovenia

# Heritage Building Information Modelling (HBIM) to make informed decisions when retrofitting. A case study

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**Abstract**

No-fines concrete (NFC) dwellings is a very common type of housing in the British urban landscape and other parts of the world. However, the fabric of these buildings can not be considered efficient anymore. Therefore, city councils and individuals aim to improve their energy efficiency. Unfortunately, accurate information about the thermal efficiency of this type of buildings is not available, as it happens with many other types of existing buildings. This work forms part of a British Council-funded Institutional Links project to create a Heritage Building Information Modeling (HBIM) web-portal to share key information about heritage building typologies. This paper presents the case study of NFC buildings.

For this purpose, three NFC dwellings (C1, C2, and C3) were monitored, gathering in-situ key information about the thermal performance of the fabric to create a HBIM model where to display the information. It was found that the original $U_{NFC}$ = 0.85 (±0.052) W/m$^2$K, could be reduced to 0.22 (±0.013) W/m$^2$K if 110mm of external wall insulation (EWI) was added. It was also found that the initial in-situ U-value (0.85 W/m$^2$K) was 50% lower than those assumed (1.71 W/m$^2$K). Based on these outputs, two Building Energy Models (BEM) were created and compared, using SAP. One included the traditional assumptions and the other model the actual in-situ data. Higher starting U-values resulted in predicting an unrealistic 27% heating consumption reduction in comparison to the actual 15.5% reduction if the in-situ measured thermal baseline was used.

In conclusion, the use of assumptions for the fabric of a building lead to inaccurate predictions, a performance gap will appear and expectations will be jeopardised. Only the use of actual data can help make optimal decisions. Therefore, the HBIM models will help future stakeholders to make informed decisions based on actual data when trying to improve the thermal performance of NFC buildings.



*Keywords: Building Performance Evaluation; No-fines concrete; Retrofitting; External wall insulation; Heating energy consumption*

## 1. Introduction

No-fines concrete (NFC) was a construction method for mass-production of low-rise dwellings at a low cost. Around 300,000 NFC houses were built in the UK between 1940s and 1980s [1]. Although this research is based in the UK, NFC was extensively used for housing in South Africa [2], the Middle East, West Africa and countries like Venezuela or Hungary [3]. Therefore, some of the findings will also have a global impact.

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The fabric of the NFC buildings can not be considered efficient anymore [4]. Uninsulated solid walls, like those made from NFC, contribute a large proportion of UK $CO_2$ emissions due to their poor thermal performance and jeopardise the level of comfort of their occupants [5]. The Council of a city in the South West of the UK carried out an ambitious large scale retrofit programme to improve the thermal performance and comfort adding external insulation to hundreds of its social houses. The target of the council was to reduce the $CO_2$ emissions of the city by 40% and energy use by 30% by 2020 against a 2005 baseline, and to improve the thermal performance of the exterior wall to match the requirements of current Building Regulations for new residential buildings. Therefore, the proposed over-cladding project aimed to reduce the heat loss through the walls below 0.25 kW/m$^2$ [6].

In order to decide what measures are optimal for the thermal improvement of existing buildings, it is necessary to know the actual heat loss of the original fabric, called thermal performance baseline [7]. However, there is a lack of information about the materials and thermal behavior of the fabric of existing buildings [8]. This is especially limited in the case of NFC homes. The aim of this study was to gather information about the original fabric of NFC buildings and quantify the heat loss reduction after adding EWI, to find if the targets were actually achieved.

This work forms part of a British Council-funded Institutional Links project to create a Heritage Building Information Modelling (HBIM) web-portal to share key information about NFC buildings, as a starting point to later cover other building typologies. Therefore, the information collected will be input within a HBIM model for rapid and user-friendly consultation and visualization. The HBIM model is expected to be of benefit to any stakeholder involved in implementing thermal improvements to NFC dwellings, especially homeowners, designers, consultants, and councils, since there is currently little accurate information.

This paper commences by reviewing available literature on the thermal performance of the fabric of NFC buildings. This is followed by the research methodology, findings, discussion and conclusions drawn from the research.

## 2. Literature Review

The aim of the literature review was to identify and describe relevant research conducted over the last few decades on the thermal performance of no-fines solid walls. Literature searches have been carried out in following databases for the period 1965-2017: Elsevier Science Direct, Research Gate; Construction Information Service; Iconda; Emerald; DOAJ, SpringerLink, JSTOR.

The research available consistently shows that the predicted savings of adding insulation to solid walls are typically, significantly greater than the actual energy savings achieved [8, 9, 10, 11]. One of the primary reasons is the inaccurate assumptions regarding the baseline performance of the building envelope and most importantly of the solid wall [8].

The thermal performance of a fabric is based on three key sets of information, its area and linear thermal transmittance and its air-tightness [12]. The thermal performance baseline based on standard values may differ to the baseline performance of the actual building under study, especially when default U-values are used [13]. They are a significant source of uncertainty [14, 15]. In situ measurements of the U-values and air permeability close this existing “performance gap” between measured and modelled data [16].

NFC is a mix of clean aggregate and Portland cement with no fine aggregates (sand or gravel) [17]. The result is an open textured cellular concrete that can have different levels of porosity depending on the level of compaction. The thermal properties and thickness of the layers of existing NFC walls are in general unknown. The literature reveals a standard wall, based on a NFC core of different thicknesses depending on the number of stories, usually finished externally with a layer of 15mm cement-sand pebbledash and a variety of interior finishes [17].

RdSAP is a simplification of the Standard Assessment Procedure (SAP), which is the regulatory tool used in the UK to assess the energy performance of new dwellings for compliance with Building Regulations. RdSAP is the building performance certification tool used in the UK for estimating the building performance of existing dwellings [8]. RdSAP allocates a generic safe estimate U-value and thickness for any NFC wall. For the buildings under study in this research, it assumes a thickness of 250mm and the same $U_{NFC}$ of 1.71 W/m$^2$K for any pre-cast concrete panel, steel framed, poured concrete or NFC wall built between 1967 and 1975 [18].

 DOI 10.3311/CCC2018-117

The process of transferring a real building to a computer model introduces uncertainties due to the simplifications made [19]. The assumptions made to fill the parameters to create a model not always match the actual building. For instance, the literature revealed that the U-value of the NFC wall can vary in a range from 0.94 W/m$^2$K [20] for the in-situ values to 1.71 W/m$^2$K [17] for the assumption used in RdSAP. This is due mainly to the differences of mixture, density and compaction (air voids) of the different types of concrete core specimens studied. In other words, the use of assumptions regarding $U_{NFC}$ could imply an uncertainty of up to 45% between in-situ U-values and assumed ones. Therefore, the thermal transmittance (U-values) of exterior walls represents a source of uncertainty when estimating the energy performance of dwellings [15].

This review demonstrated that the accurate determination of the thermal performance of NFC dwellings is not an easy task because of the number of factors adding uncertainty. The information to create accurate models is insufficient and is contained in separate documents. Because of this, generally, BEM models tend to be based on standard "average" assumptions and are created using tools such as RdSAP that over-simplify the model. A further investigation in-situ of the thermal transmittance of this type of walls and permeability of the fabric is required to provide paramount information for future retrofit projects [8, 21, 22,23].

**3. Methodology**

This research is reliant on a combination of quantitative data collection techniques for in-depth exploration from multiple perspectives. The quantitative research methods aim to collect numerical data to define the fabric of the NFC buildings studied (1). This data is used to create Building Energy Models (BEM) to explain and try to predict their pre and post-EWI thermal performance (2). Finally, these predictions based on assumptions are compared with predictions based on actual in-situ data collected to determine the existence of possible performance gaps (3).

A sample of three no-fines concrete (NFC) dwellings, two mid-terrace (CASE 1 and 2) and one end-terrace with an extra external wall (CASE 3), built in 1971 and with similar floor area and construction but different occupants were monitored.


Fig. 1. Three No-fines concrete dwellings. C1, C2 (mid-terrace), and C3 (end-terrace).

1. Several procedures were carried out according to corresponding standards and good practices to gather the following information before and after the insulation was installed:

- Dimensions, heating, hot water, lighting and ventilation systems and controls, by carrying out a visual survey.
- Thermal transmittance of the NFC walls by carrying out an in-situ heat-flux test in one of the properties (C2).
- Air leakage by carrying out an air permeability test in each property.

2. This data was used to create a Building Energy Model (BEM) using SAP, to determine the thermal baseline of the fabric of the NFC dwellings, and the impact of EWI on the heat loss of the fabric of this type of dwellings.

 DOI 10.3311/CCC2018-117

3. RdSAP is a regulatory tool designed to assess the building performance using default U-values and airtightness, the same standard occupancy, heating habits and weather location to enable fair comparisons between energy ratings of properties throughout the UK for compliance purposes [24]. This high level of simplification of the current model made Kelly et al. [25] to conclude that RdSAP is "grossly inaccurate". However, RdSAP is extensively used due to the lack of information on materials and thermal behaviour of the fabric of existing buildings. SAP also has limitations to include the actual occupancy, ventilation, heating patterns and weather data, but it allows to include the in-situ data of the fabric to determine the heat loss of the building [26] (Sierra et al. 2018). Therefore, the BEM models were created using SAP for comparison between assumed and actual in-situ heat loss values of the fabric.

**4. Results and Analysis**

The initial part of this section presents the thermal performance baseline of the fabric of the NFC dwellings, which was determined based on the data collected from the in-situ heat-flux test, airtightness test, and building survey before and after adding EWI. The second presents the results of the two BEM models and compares them.

A visual survey was carried out to produce dimensioned floorplans and to produce the specification of fabric and services. It was found that the dwellings were built featuring solid NFC walls, solid concrete slab ground floors and pitched trussed rafter roofs insulated with 100mm of rock-wool at ceiling level. Figure 2 shows a specimen taken from the wall of C2, which revealed that the solid NFC walls were formed by 15mm of pebbledash external render, and a core of 280mm of NFC, internally finished with a 15mm air layer followed by a 40mm paramount panel. 110mm EPS insulation boards ($\lambda = 0.032$ W/mK) were attached lately to the external walls and covered with 15mm of render.

Fig. 2. Sample of the NFC wall formed by 280mm NFC and 15mm thick external render

The accurate prediction of the reduction of the heat loss of a dwelling relies on a good estimate of the baseline of the thermal performance of the NFC fabric and most importantly of the U-value of the external walls to be insulated. The necessary key data was obtained carrying out an in-situ heat flux measurement to determine the amount of heat loss through a north-facing NFC wall of one of the case studies. The test was conducted over a two-week period before (November 2016) and after (March 2017) the insulation was added. This period is considered long enough to take into account the thermal inertia of the NFC wall and temperature stability on heat flux, allowing the result to converge [16, BSI, 2014).

It was found that the thermal transmittance measured in situ of the original NFC walls was $U_{NFC} = 0.85$ (±0.052) W/m$^2$K, some 50% better than the standard value used in RdSAP (1.70 W/m$^2$K). The post-EWI transmittance measured in situ was found to be $U_{NFC} = 0.22$ (±0.013) W/m$^2$K. Therefore, the target of the Council to reduce the heat loss through the walls below 0.25 W/m$^2$K was achieved. RdSAP, on the contrary, assumes in its calculations to determine the heat loss of the fabric a post-EWI thermal transmittance of 0.35 W/m$^2$K.

Higher starting U-values result in predicting unrealistic higher energy savings. A calculation using SAP reveals that if the same 110mm ($\lambda = 0.032$ W/mK) of EWI are added to a wall of U = 1.70 W/m$^2$K ($U_{insulated} = 0.245$ W/m$^2$K), this produces a reduction of the heating from 111.55 to 81.43 kWh/m$^2$yr, a 27% reduction. If the same insulation is added to the actual wall of $U_{NFC} = 0.85$ (±0.052) W/m$^2$K ($U_{insulated} = 0.22$ (±0.013) W/m$^2$K), the heating drop is smaller, from 95.2 to 80.1 kWh/m$^2$yr, only a 15.5%. An inaccurate reduction of 27% of the heating consumption in comparison to a

15.5% reduction if the actual baseline is used. Therefore, the second target of the Council to reduce the energy use by 30% was not achieved, although RdSAP was predicts that it will come very close to it.

In addition, two air permeability tests were carried out, before and after the insulation was installed. The tests were conducted in accordance with BS EN 13829 [27] following the procedures set out in the Air Tightness Testing and Measurement Association [28]. It was determined that the fabric of these NFC dwellings had a high level of permeability, between 14.36 and 18.33 $m^3/hm^2$, depending on the case study, which was minimally reduced when the outer insulation was applied (13.92 to 17.56 $m^3/hm^2$). Far away from the air permeability limit of 10 $m^3/hm^2$ required by the current British Building Regulations.

Table 1 gathers the assumptions generally used when assessing existing buildings and the outputs of the visual survey and in-situ tests carried out. The data will be used to create two SAP models to compare the thermal performance of the NFC case study before and after retrofitting, depending on the data included.

Table 1. Building specification data used to create the SAP models using Case study 2.

| Parameter | CASE Study 2 in-situ | CASE Study 2 assumptions |
|---|---|---|
| External wall area | 55.56 $m^2$ | 55.56 $m^2$ |
| Total floor area ($m^2$) | 94.3$m^2$ | 94.3$m^2$ |
| 350mm External walls | $U_{NFC}$ = 0.85 $W/m^2K$ | $U_{NFC}$ = 1.71 $W/m^2K$ |
| 490mm (100mm EWI) | $U_{NFCwall}$= 0.22$W/m^2K$ | $U_{NFCwall}$= 0.35 $W/m^2K$ |
| Roof: 100mm insul. at joists | $U_{roof}$ = 0.40 $W/m^2K$ | $U_{roof}$ = 0.40 $W/m^2K$ |
| Ground floor (100mm slab) | $U_{floor}$ = 0.51 $W/m^2K$ | $U_{floor}$ = 0.51 $W/m^2K$ |
| Window areas ($m^2$) | 12.65 $m^2$ | 19 $m^2$ estimated by age & floor area |
| Double glazed windows | U = 2.0 $W/m^2K$ | U = 2.60 $W/m^2K$ |
| Infiltration uninsulated | 18.33 $m^3/hm^2$ | Unknown - Estimated based on age |
| Infiltration insulated | 17.56 $m^3/hm^2$ | Unknown - Estimated based on age |

The heat transfer coefficient (HTC) defines the thermal baseline of the fabric of NFC before and after EWI is added to the walls. It includes the heat loss through the external walls and other elements such as ground floor, roof windows etc., the heat loss due to thermal bridges and the heat loss due to infiltration. HTC defines the thermal quality of the fabric and is a key figure for predicting the amount of heating demand to achieve comfort within a dwelling. Figure 3 compares the wall heat loss (W/k), before and after the EWI is applied. The heat loss through external walls represents a 23% of the total heat loss of the entire fabric of C2, which was reduced a 15% after adding EWI. However, when assumptions are used for the fabric, the reduction in total heat loss due to EWI is predicted to be reduced by 27% for C2, since the heat loss from the walls was assumed to be 33% of the total heat loss of the fabric. Therefore, the impact of adding EWI on the total heat loss of the fabric was smaller than expected due to the use of inaccurate data.

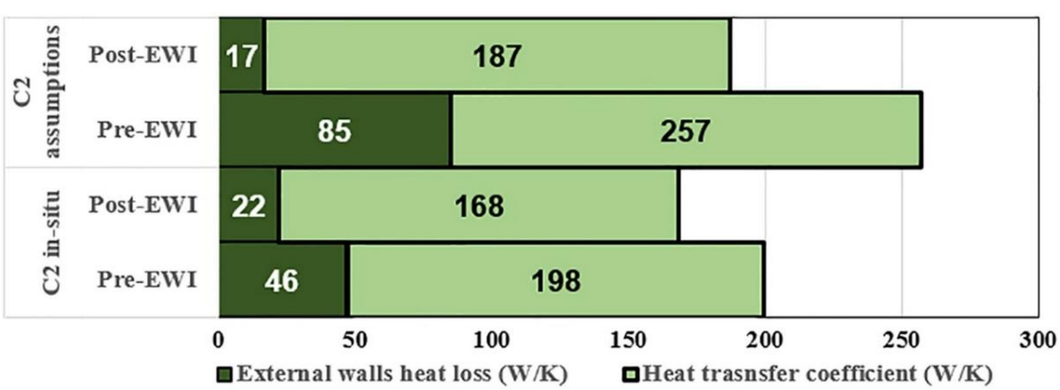


Fig. 3. Comparison between HTC based on assumptions and in-situ data

## 5. Conclusions and recommendations for future research

The aim of this study was to gather information about the fabric of NFC buildings and quantify the fabric heat loss reduction after adding EWI to cover the literature gap offering reliable information.

The thermal transmittance of the studied NFC wall was found to be $U_{NFC}$ = 0.85 (±0.052) W/m$^2$K, some 50% better than the standard value used in RdSAP (1.70 W/m$^2$K) to determine targets. When the EWI was added the transmittance was reduced to $U_{NFC}$ = 0.22 (±0.013) W/m$^2$K. Therefore, the target of the Council to reduce the heat loss through the walls below 0.25 W/m$^2$K, was achieved. It was also determined that the fabric of the studied NFC dwellings had a high level of permeability, between 14.36 and 18.33 m$^3$/hm$^2$, which was minimally reduced when the outer insulation was applied (13.92 to 17.56 m$^3$/hm$^2$). Therefore, after being retrofitted, the dwellings comply with the requirements of current British Building Regulations for walls to keeping the heat loss through them below 0.25 kW/m$^2$, but not with the air permeability limit of 10 m$^3$/hm$^2$.

A comparison between assumed and actual in-situ heat loss values of the fabric (HTC), demonstrated that the impact of adding EWI on the total heat loss of the fabric was smaller than expected due to the use of inaccurate data. Higher starting U-values resulted in predicting an unrealistic 27% reduction of the fabric heat loss in comparison to the actual 15% reduction if the in-situ measured thermal baseline was used. HTC is a key figure for predicting the amount of heating demand and energy saving targets. An inaccurate reduction of 27% of the heating consumption is predicted in comparison to a 15.5% reduction if the actual baseline is used.

The accurate prediction of the reduction of the heat loss of a dwelling relies on a good estimate of the baseline of the thermal performance of its fabric and most importantly of the U-value of the external walls to be insulated. The use of assumptions for the fabric of a building lead to inaccurate predictions, a performance gap will appear and expectations will be jeopardised. Only the use of actual data can help make optimal decisions. Therefore, the in-situ data gathered in this paper will help future stakeholders to make informed decisions based on actual data when trying to improve the thermal performance of NFC buildings.

A Heritage Building Information Modelling (HBIM) web-portal was created to share this key information about NFC buildings, as a starting point to later cover other building typologies. The HBIM portal will act as a template for similar case studies, for rapid and user-friendly consultation and visualization of the results of each study. A BIM model was created in Revit Autodesk, based on the data gathered during the visual survey. Then, structured object attributes were added allowing queries about the specifications, and key in-situ thermal performance data such as U-values and permeability of the NFC dwellings, in order to reduce fragmentation and lack of the information.

## 6. Acknowledgements

This work forms part of a project for which financial support was provided by the British Council-funded Institutional Links.

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