DESIGN OF HVAC SYSTEMS FOR DEPRIVED COMMUNITY HOUSES IN YORKSHIRE AND THE HUMBER REGION IN THE UK

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ABSTRACT

The stock housing of England (UK) constitutes the oldest housing stocks in the world. Indeed, 63 per cent of all dwellings were built before 1960s and thus most of the people in the UK live in an old house or at least a house that is more than 50 years old. The most common dwelling types in the UK are the semi-detached and terraced houses, and particularly within deprived communities. In deprived communities, houses suffer from poor indoor conditions and building standards of energy performance. They always have the issue of having to be well heated in winter and have to burn more fuel as a consequence. Heating and ventilation are the biggest part of energy consumption in a house. In this study, an ongoing investigation is whether the current houses in deprived communities, in a situation of pre-refurbishment, are within the standards of the Chartered Institution of Building Services Engineers (CIBSE) recommendations in terms of heat, ventilation and possibly cooling. The methodology used is to model different kind and the most common dwellings, and to conduct dynamic computer simulations, for each one, in terms of energy consumption and performance analysis. As a result, this would help to highlight the current energy consumption, and to find out the weaknesses in terms of energy and comfort parameters such as indoor conditions of temperatures and relative humidity levels. In addition, further studies to investigate issues related to indoor air quality and ventilation aspects have been carried out. Furthermore, several design scenarios of a 'Heating, Ventilation and Air Conditioning' (HVAC) system, less energy-consuming and in accordance with the CIBSE guidelines in order to improve the indoor comfort of deprived community houses while reducing the energy consumption and the carbon footprint, has been presented in the study.

KEYWORDS

HVAC systems, airtightness, old dwellings, energy efficiency, housing retrofit, deprived communities.

INTRODUCTION

In deprived communities, houses suffer from poor standards of energy performance and they always have the issue of having to be well heated in winter and have to burn more fuel. The carbon footprint is higher than an equivalent energy efficient dwelling. One of the main consequences is that occupants fall in fuel poverty and may also experience health problems [2, 7]. In this study, the approach consists of analysing the current dwellings' situation, which is in pre-refurbishment stages. The analysis has been carried out using dynamic simulations with IES VE software [10] for different kind of dwellings that can be found in deprived communities. These dwellings are semi-detached or terraced houses. The computer models of the houses have been assigned with all fabric and constructions properties, defining the current thermal condition and ventilation. Moreover, the simulation studies would enable to find out the weaknesses in the current heating and ventilation systems, and see whether these fulfil the UK compliance and ratings. As a result, if the system consumes too much energy, an improvement of the system of heating and ventilation with a design of HVAC system less energy-consuming would be suggested.

The BIG Energy Upgrade (BEU) programme is a consortium programme in the Yorkshire and the Humber region in the UK. It is also known as the Energy Innovation for Deprived Communities (EIDC). The total investment is about £14.9 million which is partially funded by the European Regional Development Fund (ERDF) as this is a project part-financed by the European Union. This is a support for the region’s economic development through the Yorkshire and the Humber between 2007 and 2013 [13]. The aim of this innovative programme is to deliver energy efficiency and renewable energy measures in deprived houses. The measures are going to be applied to a minimum of ten thousand deprived communities across six local authorities within Yorkshire and the Humber region in the UK. In this study, case study houses have been selected from this programme.

HOUSING IN ENGLAND

The end of World War I social housing was built in mass scale. After the World War II, the need for mass housing was even greater especially after all damages due to the aircrafts bombarding. England has one of the oldest housing stocks in the world; 63% of all dwellings were built before 1965, 39% before the World War I and with 4% before 1851 [6] (see Figure 1).

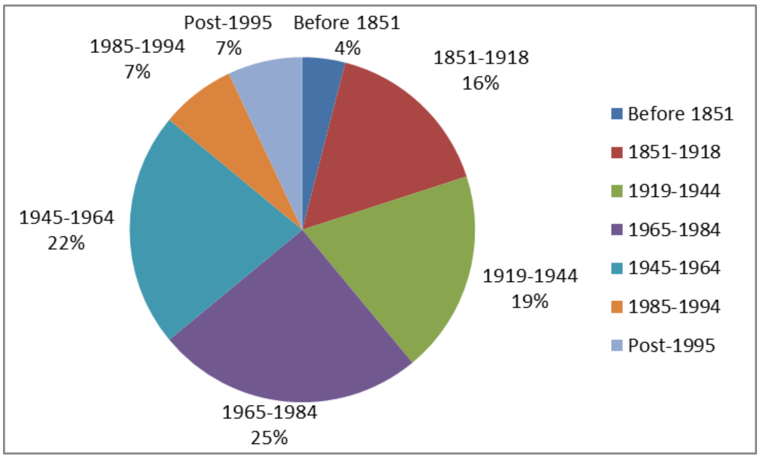
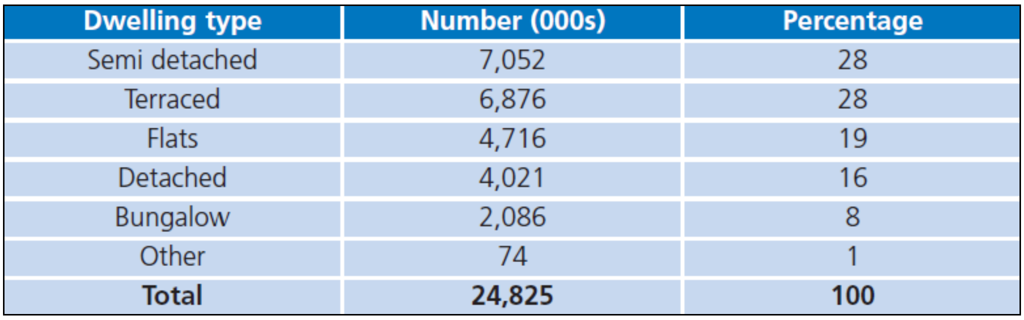


Figure 1. Age of the housing stock in England.

New houses that have been built after 1995 added only 7% to the existing housing stock. As a result, existing houses would require energy conservation and therefore most improvements can be and should be made by upgrading old houses. Accordingly, most of people living in the UK are in an old house or at least 50 years old house [6, 7, 8]. These houses are not energy-efficient even though improvements were made such as installing double glazing, new boilers or adding insulation, especially after the oil crisis in 1970s.

There are nearly 25 million of dwellings in England. One third of these dwellings are semi-detached houses and other third is terraced houses. In this study, a particular attention would be made to the latter type of dwellings and they represent 56% of the dwellings UK-wide (see Table 1). In Yorkshire and the Humber region, there are a total of 2,294,400 of dwellings [7].



Dwelling type	Number (000s)	Percentage
Semi detached	7,052	28
Terraced	6,876	28
Flats	4,716	19
Detached	4,021	16
Bungalow	2,086	8
Other	74	1
Total	**24,825**	**100**

Table 1. Roadmap to 60%: Eco-refurbishment of 1960s flats [7].

Terraced Houses

The terraced house is a very compact model for mixed use and very affordable house type. The population growth at the time of the Industrial Revolution was huge, and as a result, the migration of workers from the countryside to the cities had caused housing booms which enabled the creation of millions of houses. These houses were for middle-classes and poor communities. The terraced houses were small, especially in deprived areas. A lot terraced houses survived because of their flexibility and the popularity with the public (see Figure 2).

Figure 2. Front of a mid-terraced house in North East Lincolnshire (left) and an end-terraced house in Leeds (right).

The row of terraced houses is built, side by side with mid-terraced house in the middle row. The last house of the block is an end-terraced house and has normally three facades (see Figure 2).

Semi-detached Houses

A semi-detached house is a house built side-by-side with a party wall in between. It is a pair of houses with the layout of a mirror image. They have front, rear and any one side open spaces. This type of dwellings can be thought as being row housing and detached homes (see Figure 3).

Figure 3. Rear of a semi-detached house in Doncaster (left) and a single family detached house in Yorkshire (right).

The semi-detached house is the most common dwelling in England with 28% of the total housing stock which represents more than 7 million of houses [6, 7, 8] (see Table 1).

METHODOLOGY

In housing, it is very important to take an integrated design approach to make sure that insulation and HVAC would work optimally well together. Below are more details about the key aspects have been looked at in the study:

Insulation

One of the main action items, to be carried out, concerns insulation. A good insulation will slow down heat losses which will reduce the heat requirement to keep the internal temperature at an acceptable set point. The insulation of the loft space is a cheap and easy way to minimise the overall heat losses. Also, thermal bridges must be considered to avoid all condensation problems. Condensation occurs when warm air is in contact with a cold surface and this occurs often on single-glazed window. A lot of old houses had been constructed too draughty to avoid the moisture from rainfall and ventilated to the outside. The latter fact is one cause of heat losses [7, 8]. Condensation issues can build-up moisture which is damageable to the building fabric such as structural timbers used for the roof structure. An old house needs to breathe even if the insulation and the airtightness have been improved, to avoid all condensation issues. A controlled-ventilation is required in any house because moisture will always be created in bathroom, kitchen by occupants.

Heating

Historically houses were heated to a much more low temperature than today. People wore more layers of clothes. In 1970s, the average UK houses were heated to 12°C to reach 18°C in 2003 [4, 5, 7, 8]. In this study, the temperatures are going to be set in the simulation, according to the building recommendations by CIBSE.

Ventilation

The ventilation in old houses has always been a problem. The latter is due to uncontrolled air infiltration and heat escaping through openings such as windows, gaps around doors, or even due to building fabric that can be leaky such as in timber-framed [4, 5, 7, 8]. Usually, an airtightness test has to be performed to determine accurately where draughts are located. This test can target the improvements in the specific areas. An efficient draught-stripping is a good energy efficient measure especially in old houses. However, it should allow the evaporation of moisture and to dry out the traditional construction such as rain-soaked solid walls. There are two kinds of ventilation; controlled and uncontrolled. A good strategy of ventilation has to be thought in purpose of being energy efficient dwellings.

Energy Performances

Since the introduction of the home information packs to the UK's housing market, all dwelling transaction requires an Energy Performance Certificates (EPCs). The rating of energy efficiency is based on A to G scale (see Figure 4). This system is based on the legislation from the European Energy Performance of Building Directive (EPBD) [14]. EPCs gives information about the energy use and the typical energy costs as well as a recommendation with suggestions to reduce energy use and save money by making homes more energy efficient. All homes bought, sold or rented is required to have an EPC.

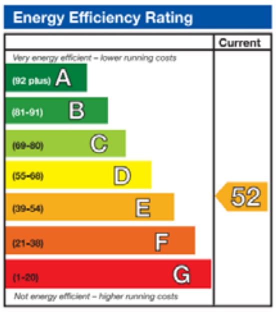


Figure 4. EPC rating for a house type [3]

BUILDING RECOMMENDATIONS

In the study, building recommendations would be mainly provided by the CIBSE guides and some by ASHRAE.

Thermal Comfort

The comfort is defined as the condition of mind that expresses satisfaction with environment [1, 4, 5]. The indoor environment should be designed and controlled to assure the comfort. There are differences in the perception of each one and the evaluation is subjective, what can bring dissatisfaction in buildings or dwellings. The main goal of the design is to minimise this dissatisfaction as much as possible. The environmental factors considered here in the study, include the thermal and indoor environment. There are a couple of parameters that affects the thermal comfort such as the air temperature, the mean radiant temperature, the humidity or still besides these factors there are personal factors as the metabolic heat production or the clothing [1, 4, 5]. The humidity has effect of warmth tough for sedentary people may become apparent if the operative temperature is above 26 to 28°C. The influence of humidity on warmth may be ignored if it is in the range between 40 and 70% [1]. In general, bathroom and kitchen may be prone to a high humidity due to evaporation from moisture and from poor ventilation.

Overheating

For some buildings, there are some risks of overheating, especially in summertime [4, 5, 11, 12]. There are limited recommendations to decide whether or not some cooling is required. The general summer indoor comfort temperature for non-air conditioned building is 25°C for the living areas and 23°C for the bedrooms [4, 5, 11, 12]. In some cases, sleep may be impaired if the temperature is above 24°C. The benchmark for the summer peak temperature is 28°C for living areas and 26°C for bedrooms. The overheating criterion is that if 1% of occupied hours have an operative temperature above 26°C for bedrooms or 28°C for living spaces, then some cooling system will be required. Even if there is no overheating in most of the dwellings selected for simulation studies, the effect of climate change can make domestic buildings prone to temperatures above 28°C.

Carbon Dioxide

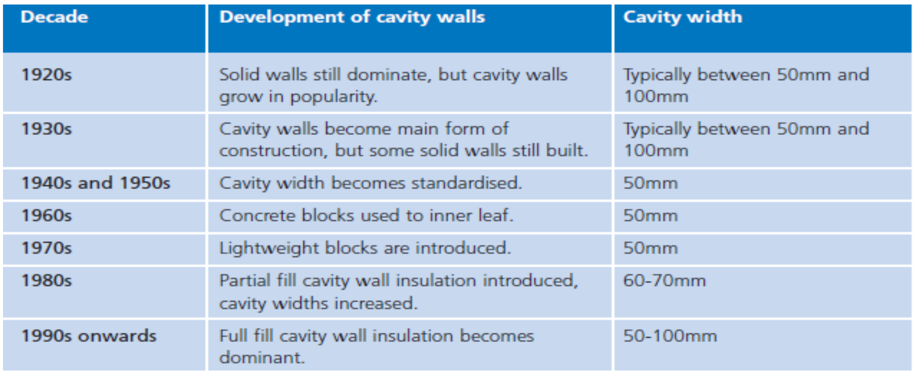
Carbon dioxide is a constituent that people exalt while breathing. It is measured to evaluate whether volumes of fresh outdoor air are being introduced into indoor air adequately. The outdoor level of CO_2 is usually from 300 ppm to 400 ppm. Usually, inside buildings, the CO_2 levels are greater than outside. The indoor CO_2 has to be below the guideline of 1,000 ppm otherwise some complains can be prevalent such as headaches, fatigue and irritation of eyes or throat [1]. If the recommendation is not met, the space should have better ventilation and in some case opt for a mechanical one.

CASE STUDIES

In this study, two case studies have been selected for the simulation analysis as representative of the UK existing housing stock and the typical dwelling of social housing.

Case Study 1: End-terraced House

This case study is in Leeds. It is a house with the ground floor and the first floor. It is fully double glazed. The house is a 40 years old dwelling which means that it has been built in 1970s. Accordingly with building surveys undertaken as part of BEU programme, there are 2 occupants who are a married couple and they are both smokers. The ventilation is made by opening one window at least and one kept open during nights. They have one pet and one cat. All this data would be useful to define the internal gains or the ventilation rate in the computer model constructed (see Figure 5). Again, it is assumed that the house is made with cavity wall as external walls and more information was provided from other sources (see Table 2) that for a 1970s house the cavity width is 50mm.



Decade	Development of cavity walls	Cavity width
1920s	Solid walls still dominate, but cavity walls grow in popularity.	Typically between 50mm and 100mm
1930s	Cavity walls become main form of construction, but some solid walls still built.	Typically between 50mm and 100mm
1940s and 1950s	Cavity width becomes standardised.	50mm
1960s	Concrete blocks used to inner leaf.	50mm
1970s	Lightweight blocks are introduced.	50mm
1980s	Partial fill cavity wall insulation introduced, cavity widths increased.	60-70mm
1990s onwards	Full fill cavity wall insulation becomes dominant.	50-100mm

Table 2. Cavity width by decades [8].

Figure 5. Case study of the end-terraced house in Leeds and the model built in IES VE.

Case Study 2: Mid-terraced House

The house is located in Leeds. It is a house with the ground floor and first floor. It is fully double glazed. The house is a 40 years old dwelling which means that it has been also built in 1970s. Again accordingly with building surveys, there are 2 occupants with one of them a smoker. The ventilation is made by opening one window at least and one kept open during nights. They have also 2 cats. All this data would be useful to define the internal gains or the ventilation rate in the computer model constructed (see Figure 6). As previously, it is assumed that the house is made with cavity wall as external walls with a thickness of 50mm.

Figure 6. Case study of the mid-terraced house in Leeds and the model built in IES VE.

RESULTS AND DISCUSSION

After several simulations with each scenario considered, a summary listing of the different scenarios have been presented (see Table 3). The scenario A and B are the cases without external insulation and with classic heating system. The situation C and D are the cases with external insulation and with classic heating system. The two last scenarios, E and F, are with alternative heating systems.

Case Study 1 & 2		Scenarios					
		A	B	C	D	E	F
External insulation		no	no	yes	yes	yes	yes
CIBSE recommendations		no	yes	no	yes	yes	yes
Heating system	**Central heating (boiler band A/radiators)**	yes	yes	yes	yes	no	no
	Central heating (boiler band A/underfloor heating)	no	no	no	no	yes	no
	Ground source heat pump (underfloor heating)	no	no	no	no	no	yes

Table 3. Summary of the different scenarios undertaken.

Case Study 1 - Scenario A vs. B

The scenario A is the house without any external insulation and with boiler band A. Accordingly with building surveys; the house was under heated and therefore not complying with the CIBSE recommendations. The house in the scenario A consumes yearly 10.6MWh just for the heating system. On the other hand, the scenario B is exactly the same with scenario A but with the only exception that here the house would comply with the CIBSE recommendations, which means more comfortable for the occupants. To have this thermal comfort, the energy consumption in this case is 11.4MWh, which also means more than 7.5% higher than the scenario A. Figure 7 shows this higher consumption of the scenario B except from May to August which corresponds to the switch off period of heating system. With this comparison, it can be said that, to have a comfortable indoor environment, it is needed to increase the energy consumption which means not always affordable, especially in deprived community housing.

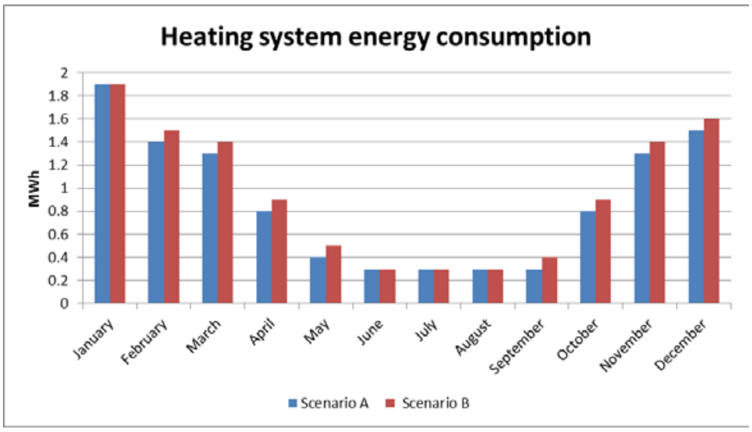


Figure 7. Energy consumption for the heating system, scenarios A and B.

Case Study 1 - Scenario A vs. C

The scenario C represents the same case that scenario A but with an energy saving action that consists in external insulation. Figure 8 shows that the energy consumption has decreased installing the insulation. The yearly consumption is about 9.7MWh, which represents a reduction of 8.5 % in comparison with the scenario A. As a result, it is not far off what was said about the insulation affect; it could reduce the heat losses by more than 10%.

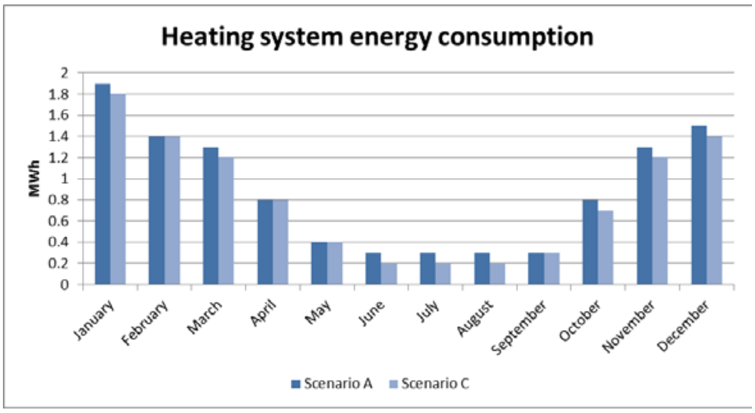


Figure 8. Energy consumption for the heating system, scenarios A and C.

Case Study 1 - Scenario D vs. F

The scenario D represents the case where the insulation is installed and that the CIBSE recommendations are complied with. The scenario F, is an alternative using the Ground Source Heat Pump (GSHP) with the underfloor heating. Figure 9 illustrated the big difference between the two scenarios, which is 67.6% on the yearly consumption.

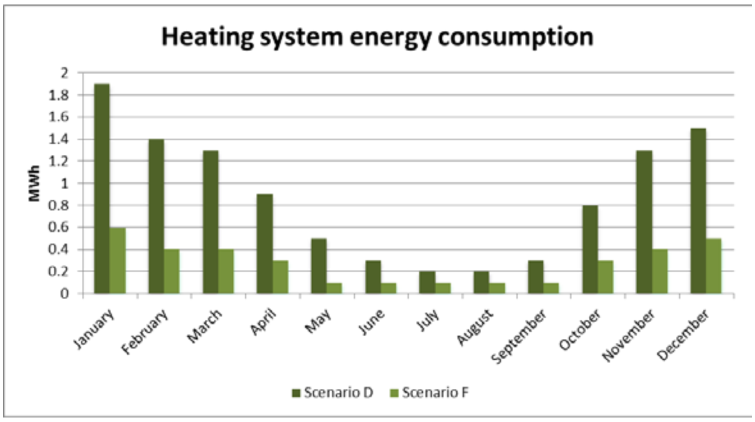


Figure 9. Energy consumption for the heating system, scenarios D and F.

Case Study 1 - Scenario C vs. F

This is the most important comparison. The last situation of the house is represented by the scenario C with fabric refurbishment and an efficient boiler. Figure 10 shows that the energy consumption can be reduced considerably. The scenario C has a consumption of 9.7MWh and the scenario F is about 3.3MWh. This is a reduction of 66%, which would be a very energy-efficient alternative. The light energy consumption for all scenarios is 1.5MWh and 1.3MWh for the appliances. The heating ratio is almost equal to the sum of electrical goods and appliances together.

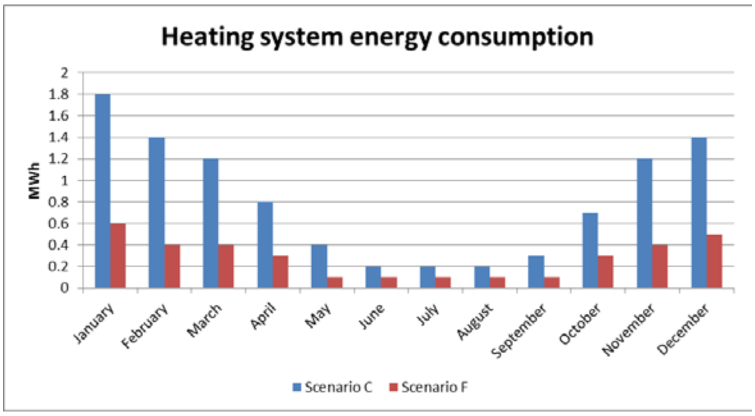


Figure 10. Energy consumption for the heating system, scenarios C and F.

The following figure illustrates the CO_2 emissions for the different scenarios. It can be noticed that for the scenario A, CO_2 emissions are about 2,165 kg CO_2 and that for the scenario C is about 2,324 kg CO_2, which represents an increase of 7.9%. There is a noticeable difference between the scenario A and F which is a reduction of 31% emitting 1,994 kg CO_2. The electrical goods and appliances emit 614.1 and 563.9 kg CO2. Although the reduction of energy between scenarios A and F were shown before which is about 66%, the reduction of CO_2 is reduced in proportion difference. The increase is that the GSHP uses electricity for the scenario F and gas for the boiler for the scenario A, and it is known that the production of electricity emits more CO_2 than gas (the emissions kg CO_2 per KWh is 0.198 for gas and 0.517 for electricity) [3].

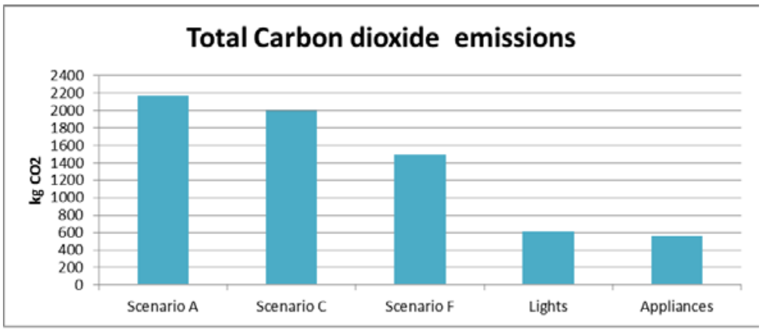


Figure 11. Total emissions of CO_2 for all scenarios.

Case Study 2 - Scenario A vs. B

The scenario A is the house without any external insulation and with the boiler band A. The house in the scenario A consumes yearly 9.6MWh. In the scenario B, the energy consumption in this case is 10.7MWh, which is more than 11.5% higher than the scenario A. Figure 12 shows this higher consumption of the scenario B expected. Also, the energy consumption is lower because it is a mid-terraced house whereas the case study 1 is an end-terraced house. Further analysis will show in terms of how the number of exposed walls affects the energy consumption.

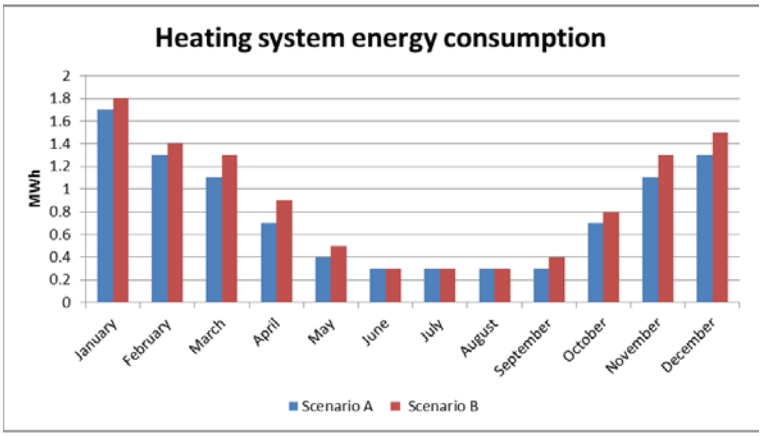


Figure 12. Energy consumption for the heating system, scenarios A and B.

Case Study 2 - Scenario A vs. C

The scenario C represents the same case that scenario A but with external insulation boards. Figure 13 shows that the energy consumption has decreased with the installation of the insulation and the yearly consumption is about 9MWh, which represents a reduction of 6.3% in comparison with the scenario A. In this case, the installation of external insulation limits the energy consumption to be reduced because only 2 facades would benefit from the insulation.

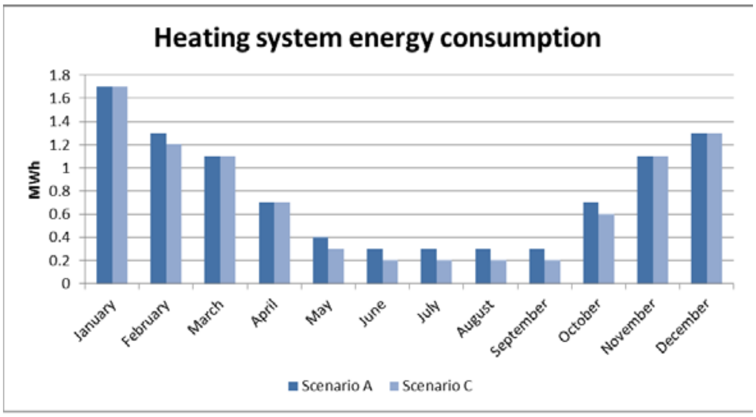


Figure 13. Energy consumption for the heating system, scenarios A and C.

Case Study 2 - Scenario C vs. F

With this comparison, the use of a GSHP enables the energy consumption to be reduced considerably as shown in Figure 14. The energy consumption for the scenario F is about 3.1MWh which is a reduction of 65.6%.

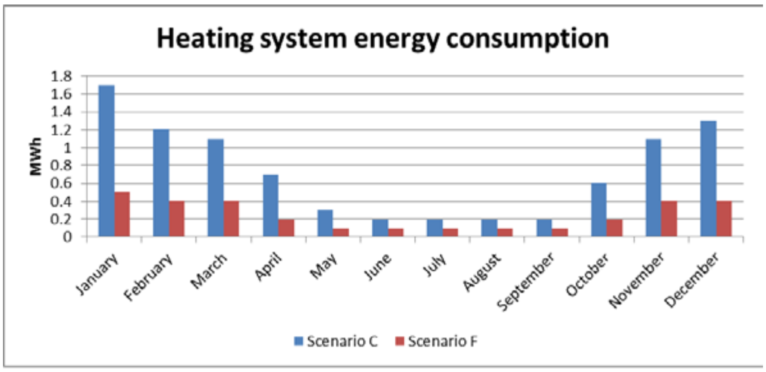


Figure 14. Energy consumption for the heating system, scenarios C and F.

The following figure illustrates the yearly consumption of energy dedicated to the heating, lighting and appliances. It can be seen that measures of retrofitting can be taken such as insulation or double glazing of windows but only the change in the system can bring a considerable reduction of energy (see Figure 15).

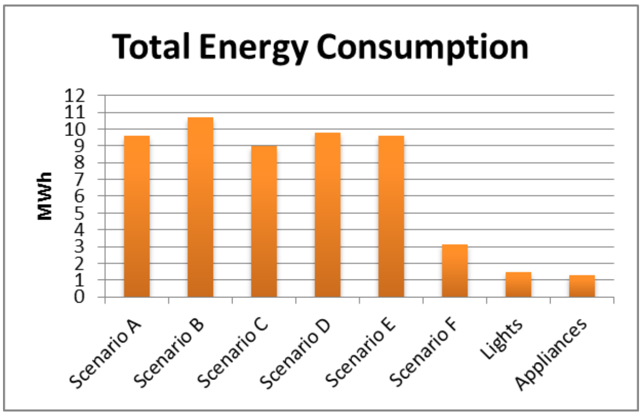


Figure 15. Total energy consumption for all scenarios.

It can be seen that for the scenario A, the CO_2 emissions are about 1,959.9 kg CO_2 and that for the scenario C about 1,849.1 kg CO_2, which represents an increase of 5.7%. There is also a noticeable difference between the scenario A and F which is a reduction of 28.8% emitting 1,395.9 kg CO_2. Although the reduction of energy between A and F as shown before is about 66%, the reduction of CO_2 is reduced in proportion different.

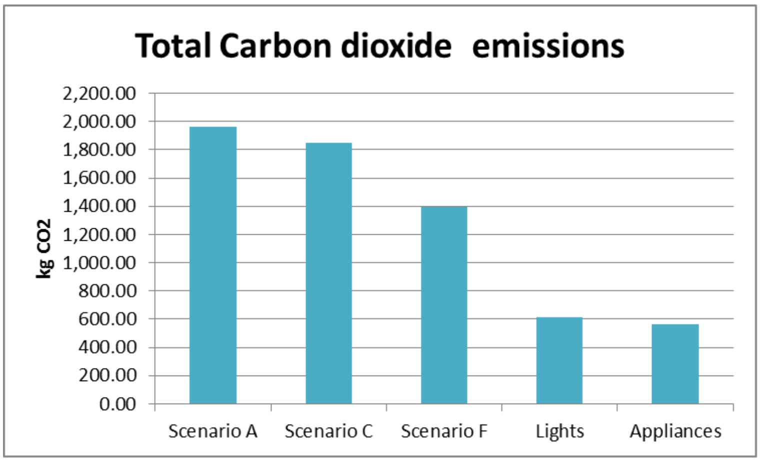


Figure 16. Total emissions of CO_2 for all scenarios.

In a perspective to reach the goals of the UK government about reducing by 80% the carbon footprint by 2050, some renewable sources should be considered to provide the electricity to run GSHPs. This is going to have a big impact on the CO_2 emissions and to evolve in the direction of producing low carbon houses.

CONCLUSION

After several simulation studies, it was possible to reduce the energy consumption dedicated to the heating. This reduction of energy can be performed complying with the building recommendations by CIBSE and ASHRAE. This way, the comfort of the indoor environment is improved which would bring more benefit to the occupants. In both case studies, it can be seen that to comply with the recommendations, more energy had to be used, about 7.5% in the case study 1 and 11% in the case study 2. This increase is not negligent and it would be a significant increase in the running costs as well which needs to be considered.

For the BEU (EIDC) project, there are some measures that can be taken and has been taken such as installing a new boiler or adding some insulation to the external walls, but the reduction still remains as low as around 10%. The significant reduction of energy consumption and CO_2 emission has to come from the system of heating. The best alternative found, for the houses in deprived communities, is to use a ground source heat pump (GSHP) as a source of heat in combination with the underfloor heating system. In both case studies, the energy reduction was more than 65% which is a very huge reduction. This percentage can even be higher, because in the simulation, the COP (Coefficient of Performance) implemented was the minimal value of 2.5. Usually, the GSHP is operating with a COP of 4 more or less. This was important to show that even in the worst case situation; a very big energy saving percentage can be achieved.

In the selected houses, natural ventilation was enough to avoid overheating during the summertime where the CIBSE criterion of overheating has been complied with. However, the prediction of future climate analyst asserting that houses in the UK and generally in Europe would more and more prone to be overheated; this should be taken in account for any further analysis including computer simulations. Therefore, with the choice of a GSHP, a reversible mode, it would be possible to have a cooling system for the houses. The GSHP can be applied at wide-scale as it is a realistic solution. On the other hand in this study, the running costs were not considered to see if this was economically beneficial, however this alternative of using a GSHP is feasible as the technology is already very well developed.

Finally, the energy reductions are still possible to be achieved by complying with all building recommendations. This is also synonym of a reduction of the energy bills to have affordable warmth. It would be in the same way, the solution to achieve the goal of UK government's that is aiming to reduce the CO_2 emission by 80% by 2050.

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