Sustainable design of terraced houses in Cardiff

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ABSTRACT
Global warming is no longer a threat, it has become a reality with significant effects on our communities, our health and our climate. Maintaining comfort in our homes will lead to a higher energy consumption for in-house cooling systems to counteract higher inside temperatures. Unfortunately, different ad-hoc cooling technologies will lead to higher CO_2 emissions. This research examines sustainable methods for commonly built residential houses in Cardiff. The building fabric is changed and the simulations indicate that the decrease of Window-to-Wall Ratio is the most effective, followed by a better insulation of building surfaces and adapting shadow devices.

Keywords
EnergyPlus simulation, sustainability future energy usage and comfort, adaptive comfort model, residential housing, Cardiff

INTRODUCTION
In recent years climate change has become an important issue for civil engineers, politicians, urban planners and scientists. Climate change will affect the way we live, because temperature and solar radiation will increase in the next century which in turn can lead to higher indoor temperatures [1]. Hence, the energy consumption for cooling will increase while heating energy needs will decrease [2]. This effect is related to the regions [3], [4]. In southern Britain the buildings will heat up more because the outside temperature will increase twice as much as in the northern part of Britain [5]. Besides the regional disparities, modern buildings (post-1990) will heat up more than older buildings (pre-1990) because of the cavity wall construction of more recent buildings [6]. Therefore, in new buildings the higher interior temperature will decrease the comfort of living. This is a crucial problem which can be solved by adapting mechanical ventilation, which however will lead to higher CO_2 emission, CO_2 being one of the greenhouse gasses that causes the climate change [7].

So other solutions than installing ad-hoc cooling technologies need to be found.
This is why the effect of climate change on recently built houses in Cardiff needs to be investigated. The objective of this research is to find solutions for Cardiff to maintain today's comfort, to reduce the energy use and to avoid a greater emission of greenhouse gasses like CO_2. In this research a standard residential house in Cardiff is modelled based on surveys, e.g. '2011 Census' or investigation of ten recently built houses. Today's and future's climate data are based on the UKCP09, a projection made by United Kingdom Climate Projections (UKCP). This data is converted into .epw files by the project PROMETHEUS, started at the University of Exeter. This file is needed as an input file for the simulation program EnergyPlus. EnergyPlus simulates the energy use and comfort in houses and is often used by engineers, architects and researchers to optimize the building design to decrease the energy and water use [8]. The input data file of the building is modelled and validated during this research. Finally, three changes of the building fabric are simulated to analyse the most effective way to achieve the objective. These three methods are a change of Window-to-Wall-Ratio, a better insulated building surface and the adaptation of shadowing devices.

CLIMATE CHANGE
Based on the literature, it is known that the Climate change is a complex process with effects on different nature parameters like wind, temperature, sea level, solar radiation and atmosphere. Generally, it is known that the sea level will continue to rise ($0.19\,\mathrm{m}$ in the period of 1901-2010), the ocean shows a linear trend of heating up and the temperature will increase all over the world [9]. Concerning Cardiff, studies from the UKCP identify different future scenarios. It seems that in the medium and high scenario of UKCP09 the mean temperature will increase in South England by about 4.2°C and 5.3°C by 2080 and the mean daily maximum summer temperature will increase by about 5.4°C and 6.8°C, respectively [5]. These scenarios are created and converted into .epw files by collecting climate data (UK09), adding probability factors, modelling a Design Summer Year (DSY) and a Test Reference Year (TRY) and finally validating it with climate data, investigated in 2002. The DSY is modelled to simulate the overheating risk and

the TRY to calculate future energy use. Later these .epw files will be used to model energy use and comfort.

TERRACED HOUSES IN CARDIFF

The '2011 Census' key statistics show that nearly all dwellings are unshared houses (99.9%) and 30.4% of it are terraced houses [10]. A terraced house is a house which shares two of its walls with the neighbouring houses, like a rowhouse [11]. The average household size is 2.3 people and the average number of bedrooms is 2.8 [10]. This means that commonly a couple lives in a terraced house with three rooms. Based on the investigation of ten houses, built in the last ten years in Cardiff, with three bedrooms, it appears that the terraced house has mostly three levels (80%). Figure 1 demonstrates the interior layout of a typical terraced house and in Table 1 the dimensions, size and floorarea are presented.

Figure 1: Floorplan of an average terraced house

This representative house is located in the north of Cardiff and its frontdoor is orientated in south west direction. But not every house looks exactly like this. Some have a separate dining room or a conservatory and still others use the pitched roof as a loft. However all the houses have commonly three bedrooms, a kitchen, a livingroom, and a bathroom. Most of these terraced houses are owner-occupied (59.1%) [10] which makes the adaptation of new systems easier, because they do not need the accordance of their landlord. Concerning the construction there are different underlying assumptions. The exterior walls are cavity walls insulated with mineral wool, the same insulation as in the roof. The interior walls are simple plasterboard walls made of gypsum. The floor is a solid concrete floor with an insulation layer above. All eight windows and the French door leading into the garden are double glazed. The window surface leads to a Window-to-Wall-Ratio (WWR) of 0.1. The conductivity (U-value) of the outside surfaces

Table 1: Room sizes and floor area in m^2 and the volume of the rooms in brackets in m^3

Room	Size (m x m)	Area m^2	Volume m^3
Ground floor			
Kitchen	3.07 x 2.30	7.06	15.53
Livingroom	3.94 x 4.40	17.35	38.17
Entrance hall	1.10 x 3.07	3.38	7.44
Toilet	1.00 x 2.00	2.00	4.40
Staircase	1.00 x 2.15	2.15	5.61
Storage	0.85 x 0.85	0.72	1.59
First floor			
Bathroom	2.10 x 2.00	4.20	9.24
Bedroom 2	2.30 x 3.30	15.31	33.68
Bedroom 3	1.71 x 4.40	7.59	16.70
Landing & staircase	2.10 x 2.55	4.51	9.92
Storage	0.90 x 0.90	0.81	1.78
Second floor			
Ensuite	1.50 x 1.50	2.25	3.34
Bedroom 1	4.46 x 4.40	19.64	36.91
Staircase	1.00 x 3.85	3.85	4.62

is very important, because the house will mainly lose heat via its surfaces. The cavity wall, the insulated roof and the ground floor will have a U-value of $0.3\,\mathrm{W/m^2K}$, $0.5\,\mathrm{W/m^2K}$ and $0.12\,\mathrm{W/m^2K}$, respectively. The U-value is the reciprocal of the resistivity (1–3). For the U-value it applies that the lower the U-value, the better the insulation [12].

$$U = \frac{1}{R_{total}} \tag{1}$$

$$R_{total} = \sum R \tag{2}$$

$$R = \frac{b}{\lambda} \tag{3}$$

Concerning the adapted systems, there is a gas central heating installed which supplies the heating and the water installation in kitchen and bathroom with hot water. In general the hot water usage of a house with a floor area of $85m^2$ is 7.11GJ/year [13]. Furthermore, the ventilation in the house is based on natural ventilation, which means that in the morning, there will be a high ventilation rate because the windows are opened and during the rest of the day there will be no ventilation except of the infiltration. Infiltration cannot be avoided, but it is relatively low compared to the ventilation, which is expressed in Air Change Rate per Hour as it is seen in Table 2.

The ventilation and the usage of hot water are strongly dependent on the occupancy which can influence the energy use directly [14]. Based on '2011 Census' the standard newly built terraced house is mostly occupied by a couple which uses the other two bedrooms as a spare room and an office room. This couple is working over day so there will be no occupancy during the day except on the weekend days.

Table 2: Air Change Rate per hour for rooms in the terraced house

Room	ACH
Kitchen	1.06
Toilet	0.30
Livingroom	2.64
Entrance hall	0.51
Bedroom 2	2.22
Bedroom 3	1.14
Bathroom	0.63
Landing & Stairs	0.68
Bedroom 1	2.95
Ensuite	0.34

MODELLING ENERGY USE AND COMFORT

For the simulation the standard terraced house shown in Figure 1 can be simplified because such a detailed model is not necessary. Thus the third level is converted into an attic and the windows in the second floor become roof windows. Subsequently, the input data file (IDF) can be developed. For the model different assumptions are necessary, like the fact that the side walls, which connect the house with the next one, are created as an exterior wall with a common outside environment condition except of the sun and wind exposure. Furthermore, the central heating is modelled with the "Ideal Loads Air System". This system provides the house with the amount of heat water which it will need to maintain the defined interior comfort condition. However not every room will be heated with this system. Only the kitchen, livingroom, bathroom, spare room and bedroom will be heated. Under this condition the model is simulated in four moments of time (today, 2030, 2050, 2080).

Though this is not the only model. The aim is to find a sustainable design to reduce the energy use and maintain the comfort in the future. Therefore three designs are created which are tested in different simulation models. The first design contains a change of the building surface. The effect of an improved insulation is simulated in four different models: The walls, roof and windows are improved separately and as a whole. The wall is changed to a double cavity wall (U-value decreases from $0.271\,\mathrm{W/m^2K}$ to $0.155\,\mathrm{W/m^2K}$), the windows become E-low windows (U-value decreases from $1.957\,\mathrm{W/m^2K}$ to $0.832\,\mathrm{W/m^2K}$) and the roof is improved by an insulation layer which is $0.2\,\mathrm{m}$ thicker than before (U-value decreases from $0.192\,\mathrm{W/m^2K}$ to $0.139\,\mathrm{W/m^2K}$). The second design is a change of WWR. The WWR is originally 0.1 and it is changed to 0.19 and to 0.06. The last design deals with shadowing devices. On the one hand, an overhang of half a meter width is adapted above each window, except the garret windows, because the attic is not used so that the temperature will not matter. On the other hand, a balcony of $4.5\,\mathrm{m}$ by $3\,\mathrm{m}$ is adapted above the windows of the livingroom.

To evaluate these different designs and its efficiency, some criteria has to be defined: Firstly, the comfort will be described as the amount of uncomfortable hours and is based on the adaptive model from ASHRAE2010. Secondly, the limit of energy use is the today's usage, so that the future energy use should not be higher than today.

RESULTS

The results of the simulations focus on these two criteria. Concerning the energy use it should be noticed that it is splitted in cooling, heating and total energy use. All results are given monthly and for every future year this research is focusing on. The Table 3 shows the future total energy use for winterdays.

Table 3: Total energy use in winterdays like january in MJ

Model	2014	2030	2050	2080
standard	68,793	58,654	49,607	49,554
Retrofitting				
Wall	68,451	58,319	49,271	49,276
Window	68,513	58,400	49,383	49,341
Roof	68,781	58,643	49,596	49,544
All	68,152	58,047	49,031	49,049
Change WWR				
lower WWR	56,229	48,084	40,659	40,384
higher WWR	67,253	49,670	48,965	48,474
shadowing devices				
Balcony	69,642	59,438	50,318	50,233
Overhang	69,625	59,422	50,299	50,216

ANALYSIS

Before having a look at the different designs the results of the standard building are noticeable. They show that the total energy usage will decline in future. This result is contrary to the one of other studies, but that is possible due to the usage of different methods, assumptions and technologies. Concerning the different designs none of the designs demonstrate a significant change of comfort in any moment of time. This is due to the fact that the amount of energy use will compensate a great change of comfort. Therefore the energy use is the main criteria to evaluate the designs. Before comparing the different designs, a look at the design variations is necessary. Concerning the first design, the better insulation of the building surface, the results make clear that for all points of time only a fully retrofitted exterior surface will lead to a significant reduction of enery use. This makes sense because the building will still lose heat through roof and windows if only the walls are improved. The results of the design of changing WWR detect that the smaller WWR is always more efficient than the larger one. This can be declared with the increase of solar radiation in future. A smaller window surface means that less solar radiation will enter the room to heat it up and the amount of heat loss through windows is smaller as well. Concerning the last design the study illustrates no significant change in reducing energy use, not today neither in the future. Only the overhangs reduce energy use slightly better than the balcony. It appears that the balcony even increases energy use, but this is due to the fact that the balcony is simulated as a shadowing device without other properties, e.g. like the capability of heat storage. Based on this analysis the best alternatives of every design can be compared with each other. In all four moments of time the results indicate the same ranking. Figure 2 demonstrates that the design of smaller WWR is the best to reduce energy use, followed by the retrofitting surface and the adaptation of overhangs.

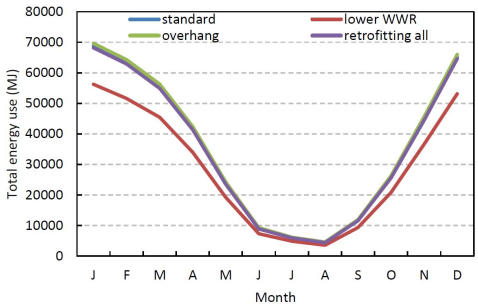

Figure 2: Total energy use in 2014

DISCUSSION

Some assumptions are underlying this research which contain different uncertainities. Concerning the building, for example, there is a trend in the UK to build more semi-detached and detached houses than terraced houses. So in 2050 or 2080 most buildings will not be terraced ones because the old houses from today might be demolished. Furthermore, there are great uncertainties concerning the future weather data, just because noone can forecast the climate. Another point of discussion are mistakes in the data base or the model. The model is validated by tests, but the data base of the climate is not controlled. Hence mistakes in the data base can affect the results of the simulation. Finally, there are many more parameters affecting the comfort and energy use. Accordingly the research needs to be broadened to get more established results.

CONCLUSION

Climate change leads to an increase of temperature and solar radiation. These effects influence in turn the comfort and energy use in residential buildings. The common residential building in Cardiff is a terraced house. The simulation of the terraced house shows that in the future heating energy will increase and in summer the interior comfort will decline. Therefore three methods are examined. From the simulation and the analysis a ranking of these methods is concluded. As a result it seems that the decrease of WWR is the most effective method, followed by the increase of WWR. The retrofitting of building surfaces is less effective than the change of WWR but more effective than adapting shadowing devices. A detailed ranking is shown in Table 4.

Table 4: Ranking of methods to reduce energy use and maintain comfort

Ranking of methods	
1	Decrease WWR
2	Increase WWR
3	Retrofit all external surfaces
4	Retrofit external walls
5	Retrofit windows
6	Retrofit roof
7	Adapt overhang
8	Adapt balcony

ROLE OF THE STUDENT

The Building Research Establishment (BRE) Trust Centre in Sustainable Engineering at the University of Cardiff does research on the sustainability of the existing building stock. Karin Ernst supported BRE on the field of 'Energy and sustainability' and 'Comfort, health and well-being' by modelling the energy usage and the comfort of a commonly built house in Cardiff. The results of the models might be of great value for the municipality. With this research it gets an idea what the change of energy use and comfort will mean for the population of Cardiff and what the municipality can do to improve it. Furthermore, the model can be used for further research by using the model like it is or by broadening it to analyse different fields of building sustainability. Finally she wrote a Bachelor Report of which this is the short paper.

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