

Article

IDEAhaus: A Modular Approach to Climate Resilient UK Housing

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Abstract: This paper describes the result of a project to develop climate adaptation design strategies funded by the UK's Technology Strategy Board. The aim of the project was to look at the threats and opportunities presented by industrialized and house-building techniques in the light of predicted future increases in flooding and overheating due to anthropogenic climate change. The paper shows that the thermal performance of houses built to the current UK Building Regulations is not adequate to cope with changing weather patterns, and in light of this, develops a detailed design for a new house: one that is industrially produced and climatically resilient, but affordable. This detailed concept *IDEAhaus* of a modular house is not only flood-proof to a water depth of 750 mm, but also is designed to utilize passive cooling, which dramatically reduces the amount of overheating, both now and in the future.

Keywords: climate change adaptation; thermal comfort; passive cooling; flood resilience; industrialised housing; mass customization

1. Introduction

Recent research has shown that current UK housing, even that designed to the current Building Regulations is poorly suited to deal with the changing climate the UK is likely to experience over the next 50 years. This paper describes the design of a novel modular house, which aims to answer some of these short-comings and provide a cost-effective and reproducible solution to living within a changing climate.

Anthropogenic climate change is now an undeniable phenomenon [1] and already in the UK, models of future climates have been developed, allowing architects and designers to predict the thermal performance of designs using predicted weather data for a range of climate scenarios over the next 70 years [2]. The change in climate is not only to hotter drier summer conditions, but also to milder much wetter winters. These two changes create a new difficult scenario for the architects of housing where passive cooling needs to be factored into the design, along with flood resilience.

In addition, in the UK there is a great need for new affordable mass housing and indeed greater industrialization of the process that could bring better quality, speed and predictability to its delivery. However, in the UK, factory-made housing has not been able to provide the variety and flexibility necessary to respond adequately enough to differing site contexts and programmatic requirements. Therefore, rather than engage with modular solutions, UK house-builders have looked to use timber-framed solutions, to make a cost effective, high build quality solutions. This is not without its drawbacks: indeed much of the recently built, highly insulated, air tight, timber-framed housing is already suffering summer overheating. In addition it is also highly susceptible to flood damage. These are both risks that will be exacerbated in the future with climate change.

The Design for Future Climate projects are part of the UK Technology Strategy Board's vision to support UK industry to develop innovation in new technologies. Climate change resilience is a key area of that work, where solutions are seen as holistic and design based, rather than technological add-ons. The IDEAHaus project as part of the Design for Future Climate, focused on two main objectives: firstly to assess the performance of current newly-designed housing within future UK climate scenarios, and secondly to develop a design for a new house that was affordable and could be easily replicated, which could adapt in a better and more passive way to the changing future climate context.

As the case study, the project took a proposed social housing development in Liverpool UK. This development consisted mainly of semi-detached and terraced low-rise houses, which were typically three bedroomed. Once the energy and thermal performance of these houses had been modelled utilizing UK Met Office climate projections through the century up to 2080 [3], it became clear, that although these houses had been designed to current UK Building Regulations, the house type was unsuitable for the future climate change scenarios expected. The thermal analysis showed significant risks of overheating not only in the future, but also today, and also that the cooling demand for the house would exceed heating demand within 20–30 years. The houses had been designed to meet a scenario where heating in winter was the key driver, and had not considered issues of cooling.

Taking this performance data, the project developed designs for a building system for low-rise housing which would be more resilient to flood damage and better at resisting overheating through passive cooling techniques, such as shading, and the use of thermal mass and natural ventilation

strategies. The system was to be based around a limited number of components which could be assembled to provide different sized homes, with a modular service/circulation core and a range of cladding options. The design illustrated how spatial flexibility, in-built flood protection, combined with thermal improvements and future adaptability could be used to develop an affordable but resilient house type that could cope with future extreme weather scenarios.

2. Future Climate in the UK

Climate change forecasting is an uncertain science. In the UK, the Department of Environment, Food and Rural Affairs have produced a range of Climate Projection scenarios known as UKCP09 [4]. These cover a range of years (2030, 2050, 2080), emissions scenarios (low medium high) and probability (33, 50, 66 and 90 percentiles). The emission scenarios are based on future levels of carbon emissions, however it seems unlikely at present, that anything other than a high emissions scenario will be likely. The probabilities here are the likelihood of a certain climate being not exceeded, so the 90th percentile model is the most extreme with only a 1 in 10 chance being exceeded. Thus, this 90th percentile is a likely occurrence in one year in that decade. From these scenarios, the Prometheus Project at the University of Exeter [5] have projected climate as a year-long set of results that mimic the CIBSE dsy (design summer year) and try (test reference year) data. The scenarios are in the form of hourly data, in Energy Plus format (epw) and can be used in most energy modeling software.

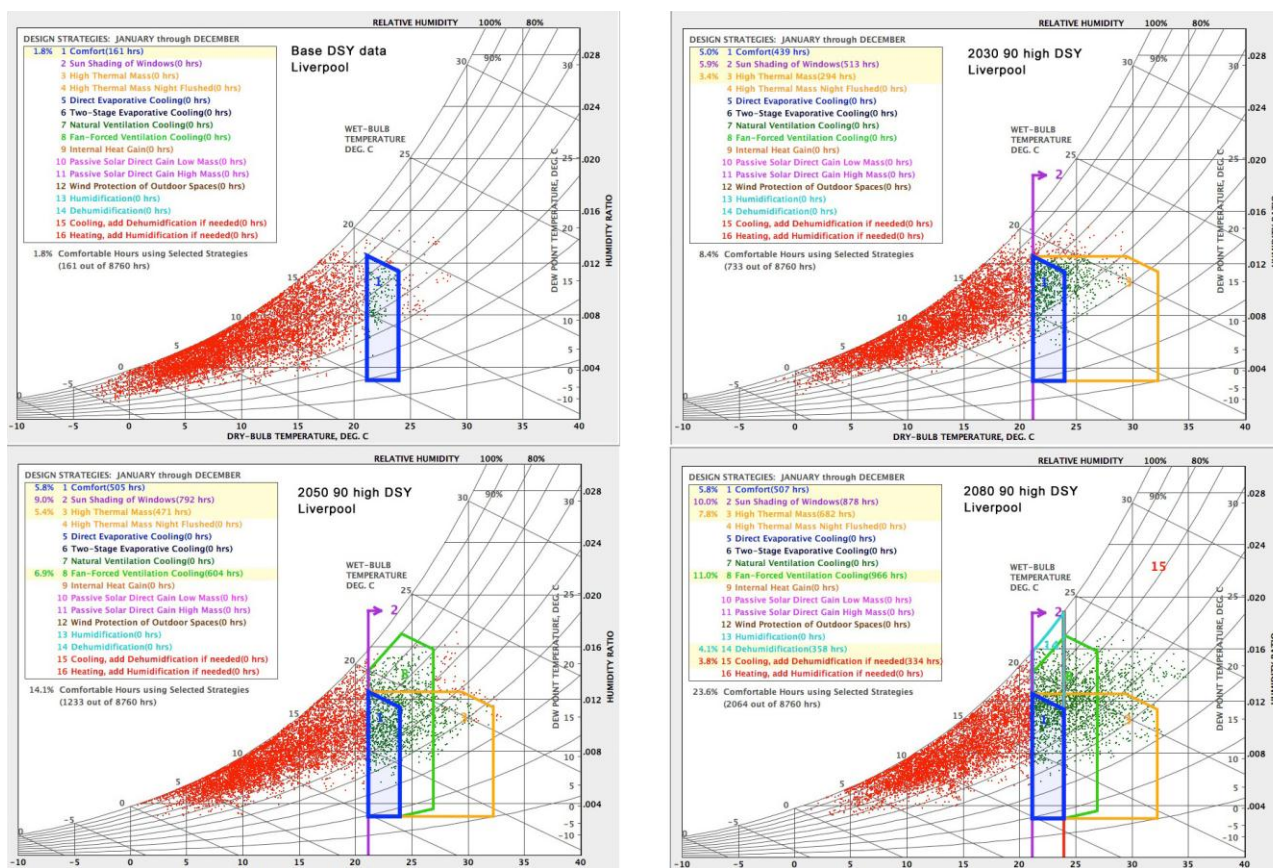
In general the anticipated pattern of change in the UK is toward hotter drier summers, milder wetter winters, stronger winds and more frequent, more extreme events such as heat-waves, storms and flooding. Climate change means that buildings will have to be, firstly more adaptable to cope with the changing climatic conditions, and secondly more resilient to cope with extreme events. Both these functions, will also have to happen within a changing energy and materials scenario, as oil diminishes and materials deplete. In addition, these two functional requirements, of adaption and resilience, are also not necessarily commensurate and create a complex design context, which can be difficult to negotiate.

The initial case-study was situated in Toxteth, Liverpool, UK. The current climate in Liverpool can be considered “mild maritime” with a January average of 6 °C and a July average of 13.5 °C. By plotting temperature and humidity data for the test years on a psychrometric chart, a bioclimatic analysis of the predicted future climate could be envisaged. Shown in Figure 1 are the charts for 2010, 2030, 2050, and 2080, for one year in ten using a high emissions scenario (the most likely). This shows a gradual change in summer from a mild maritime climate to a more Mediterranean one. This is significant as there is a drift of temperatures during this period, across the comfort zone, developing from a heating dominated operation, to a more cooling orientated one. In addition to this, quantitative analysis of the data showed there is also a predicted increase in extreme wet weather in winter, with over 20% more rain during the winter months.

The current data (2010) from the Chartered Institute of Building Services Engineers’ (CIBSE) Design Summer Year (DSY) demonstrates clearly the current position: there should be very little need for any environmental control in summer, other than solar control. However, as we move into the future, the situation begins to change: by 2030 there is a need for a coordinated cooling strategy—say increased thermal mass. Continuing into the mid-century period, analysis of the DSY data showed that by 2050 even with a medium emissions scenario, there was a 50% chance (*i.e.*, one year in two) that

the summer would be similar in temperature and humidity to that of a Northern Mediterranean city, such as Lyon, France. By 2080 the predicted weather had altered again: the data for 2080 with a high emission Scenario with a 90% chance of not being exceeded, gave a very different summer climate, one more similar to that currently experienced in Rome, Italy. In this scenario the increase in average summer temperatures would be an astounding 9 °C and the maximum temperature some 11 °C higher than experienced today.

Figure 1. Changing climate: bioclimatic charts: 2010–2080, Liverpool, UK.



3. Analysis of Baseline Scheme

Studies such as the UK Technology Strategy Board's Design for Future Climate [6] have shown that housing in the UK, even new housing is being designed and built with little or no consideration of the changing climate. In his book, Bill Gething [7] claims that we are now beyond climate mitigation in that the emissions already produced will cause unfettered climate change throughout the century, and thus we must now embark on a program of adaptation. This adaptation will have to engage with both new build and retrofit schemes, as much of the built environment of 2050 is already in existence. Retrofit ideas are already well documented, some involve fabric measures such as the addition of shading devices, or passive cooling techniques, whilst others involve the adaptation of the landscape in which the properties sit, to suit warmer and wetter conditions [8].

The IDEAhaus concerned itself with the new build market, particularly that for low cost housing suitable for rental. In this market in the UK, housing design is highly regulated, particularly with regards to spatial standards, life-cycle costings, and energy use. The energy use of the house is

modeled using an approved energy model known as the Standard Assessment Procedure (SAP) developed by the Building Research Establishment [9]. This model, originally based on a modified degree-day type calculation only really concerns itself with heating (and lighting), thus houses are adapted specifically for cold, not warm weather, that is for heating and not cooling.

By considering a housing scheme already designed as a baseline, the project aimed first to critique current practice and assess the performance of housing that met the criteria with respect to the climate that the houses will face in the foreseeable future. From this critique, a new modular house was designed with a customizable façade, which was designed with the future climate and weather in mind. One that was robust and energy efficient, but also comfortable for the occupants.

The baseline scheme for the project was an existing design for Plus Dane Housing Association that was proposed to be built in the near future. The site was located in Toxteth, Central Liverpool, UK (see Figure 2). This scheme was used to develop the base condition for comparative thermal and energy modeling, for different constructions within the same site layout. The layout of housing on the site adopted a diagonal solar orientation with houses facing SW, SE, NW and NE in square urban block arrangements.

Figure 2. Housing layout, Toxteth, Liverpool, UK.



A typical 3-bedroom 5-person, 2-story, semi-detached/end terraced house (Figure 3) with traditional elevations was selected. The construction specification was for a high performance closed panel timber frame system. The fabric, designed to current UK Building Regulations (REF), was therefore highly insulated (wall, floor and roof U -values at approximately $0.1 \text{ W/m}^2\text{K}$) and reasonably airtight ($5 \text{ m}^3/\text{h/m}^2$) but not so airtight that it required a whole house Mechanical Ventilation with Heat Recovery (MVHR) system: the house was naturally ventilated in both summer and winter.

Figure 3. Baseline 3-bed 5-person-house type.

Initially, detailed thermal modeling using 2010 climatic data was carried out with IES software for each orientation of the properties on site. However the different orientations of the house type made very little difference to the thermal modeling results with regard to internal temperatures and energy use. The most likely reason for this being that the front and rear elevations had similar proportions of glazing and that the diagonal solar aspect (SE/NW) of the layout tended to equalize the exposure to sunlight, so a property with a SE orientation was chosen for the further comparative analysis.

Table 1 illustrates overheating in a typical SE facing double bedroom in the timber-framed designs. In the UK, CIBSE guidance recommends that internal temperatures should not exceed 25 °C for >5% of annual habitable hours and 28 °C for less than 1% of the hours [10]. This guidance is not currently applied to single dwelling-houses in the UK but is used in other residential buildings. The detailed modeling used 2010 CIBSE Design Summer Year (DSY) data and compared this with a “worst case scenario” that being the hottest summer in the decade around 2080. (This equates to 2080 DSY, with a high emissions scenario, 90th percentile projected weather set from the Prometheus database.) Findings showed that overheating in bedrooms (internal temperature above 28 °C) would occur for 6.6% of the time in 2010 rising to 50.5% of the time in 2080. If only the summer months of July and August are considered, this would equate to 28.4% of the time in 2010 and 74.6% in 2080. Peak internal temperatures experienced in the bedroom are 35 °C in 2010 and 39 °C in 2080. The conclusion inferred from this analysis is that the current house type is inadequate with respect to summer over-heating, as the internal overheating is already well above the CIBSE guidelines now, and becomes severe by 2080.

Table 1. Summary of internal overheating modeling (IES) on baseline house-type for SE facing bedroom in 2010 and 2080* Hi-emissions 90th percentile.

CIBSE	Guidelines	Period	Peak Temp	Int Temp	>25 °C	Int Temp	>28 °C
			(°C)	(h)	(% Time)	(h)	(% Time)
Timber-framed house	2010 DSY	annual	35	573	19.6	192	6.6
		July/August	35	310	62.5	141	28.4
	2080*	annual	39	2605	89.2	1474	50.5
		July/Aug	39	496	100.0	370	74.6
Masonry house brick/block	2010 DSY	annual	29	396	13.6	81	2.8
		July/Aug	29	286	57.7	42	8.5
	2080*	annual	33	1391	47.6	934	32.0
		July/Aug	33	496	100.0	262	52.8

Next, a similar analysis was performed on a similar house, that was designed utilizing what would be considered a “traditional” UK building method, namely a masonry construction of brick external skin and medium weight concrete block inner, with a wet plaster finish. This change of construction shows a significant reduction in overheating, with the house being above 28 °C for 2.8% of the time above in 2010, and 32.0% in 2080. Results for July and August show overheating for 8.5% of the time in 2010 and for 52.8% in 2080. Peak internal temperatures are also significantly reduced at 29 °C and 33 °C respectively, but these are still high.

Further energy modeling of the timber framed house was carried out using Sefaira Concept software [11]. This produced an energy consumption analysis based on the UK Government’s SAP analysis [12].

This analysis shows the energy footprint in kWh for the heating, hot water, lighting and power for the house (see Figure 4). It is clear that the space heating demand (red) reduces considerably to a minimal level by 2080. Hot water, lighting and appliances (yellow, orange and green) are constant. The modeling was then repeated with the addition of air-conditioning for comfort cooling; switching on at 25 °C (Figure 5).

This analysis shows that reduced demand for heating (yellow) that occurs in 2080 is counteracted by an increasing cooling demand (blue), and thus the overall energy demand for the house would actually increase over time. Further IES analysis shows that energy demand for cooling in the house could overtake its heating demand before 2040 in a 90th percentile year (Figure 6).

In fact, the “carbon crossover” rather than the energy crossing would, in practice, arrive even earlier, as cooling energy is generally more carbon intensive (with cooling being produced using electricity) than space heating (from gas central heating) in the typical UK situation. The team therefore concluded that if we are to design for future climate as well as the present, then summer performance will become more crucial and will need to be accommodated in today’s designs. In fact, the importance of winter performance and heat loss as a design strategy will diminish and more attention in the future will need to be paid to overheating and reducing the demand for cooling and summer energy use.

Figure 4. Energy analysis for 2010 and 2080 high emissions scenario 90th percentile energy analysis.

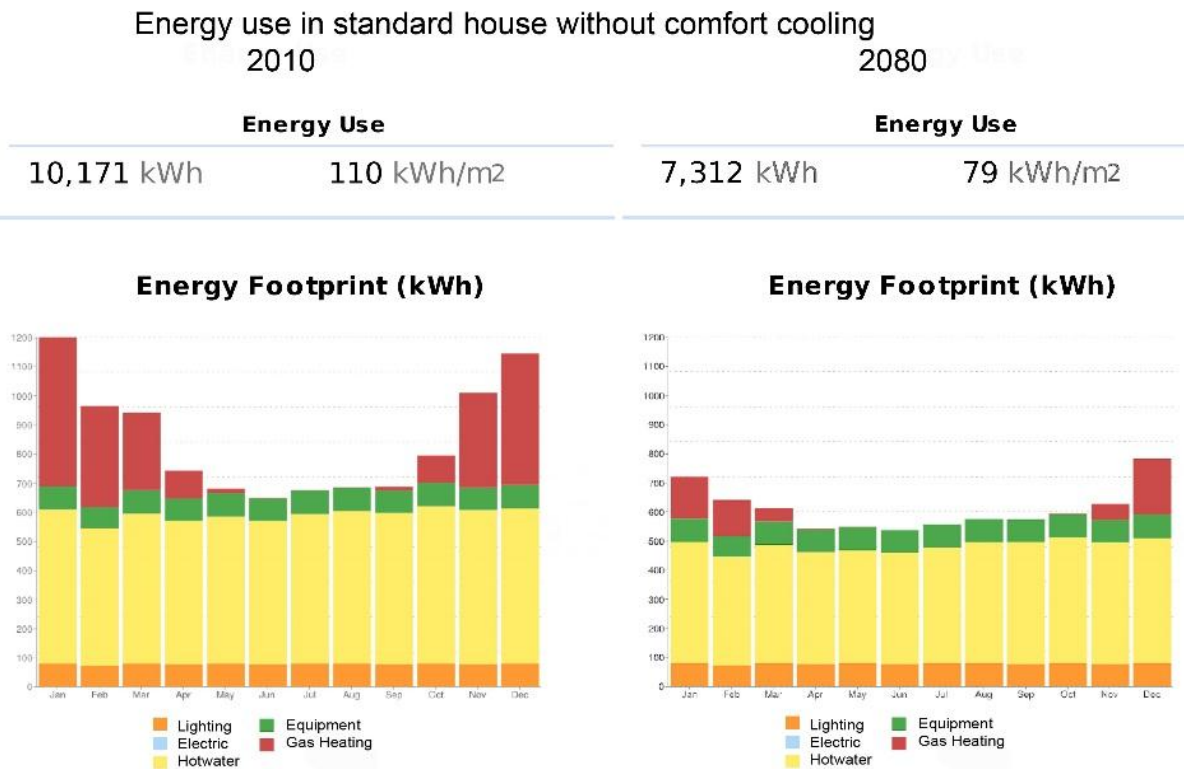


Figure 5. Energy analysis with air-conditioning at 25 °C set point for 2010 and 2080 high emissions scenario 90th percentile.

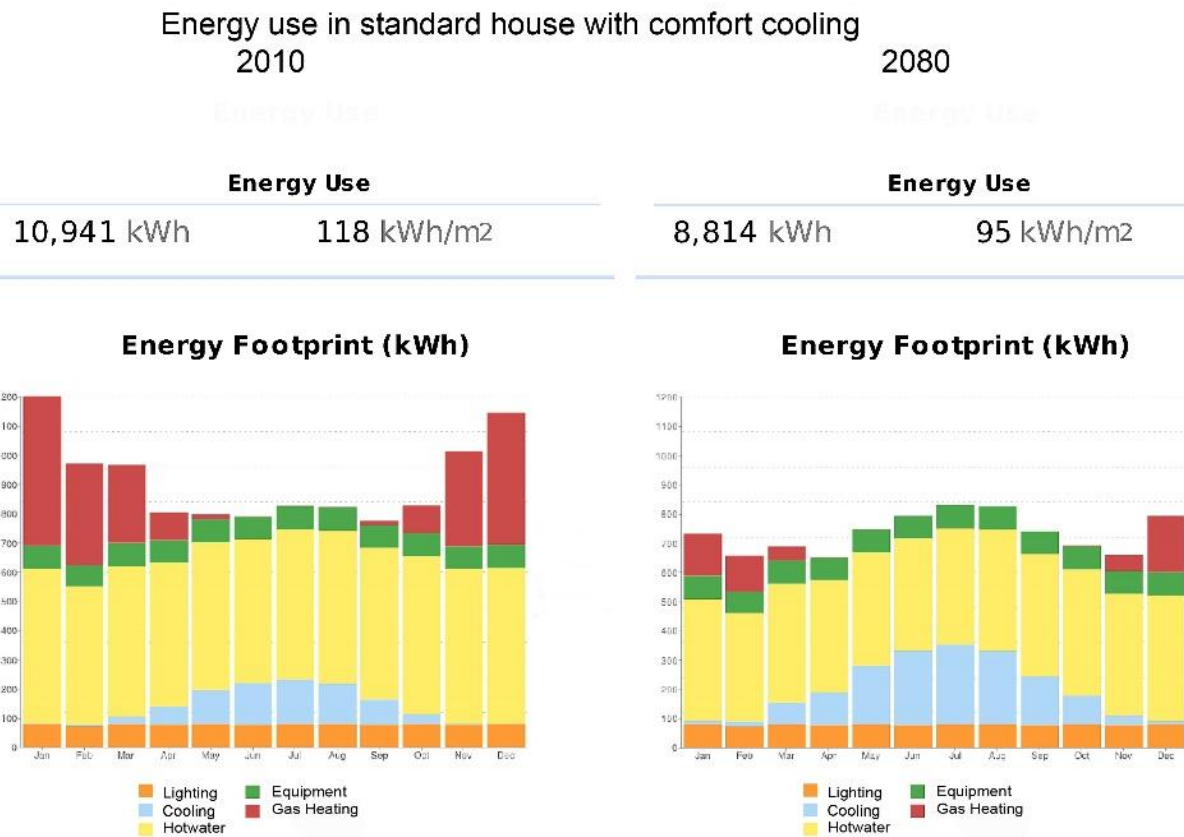
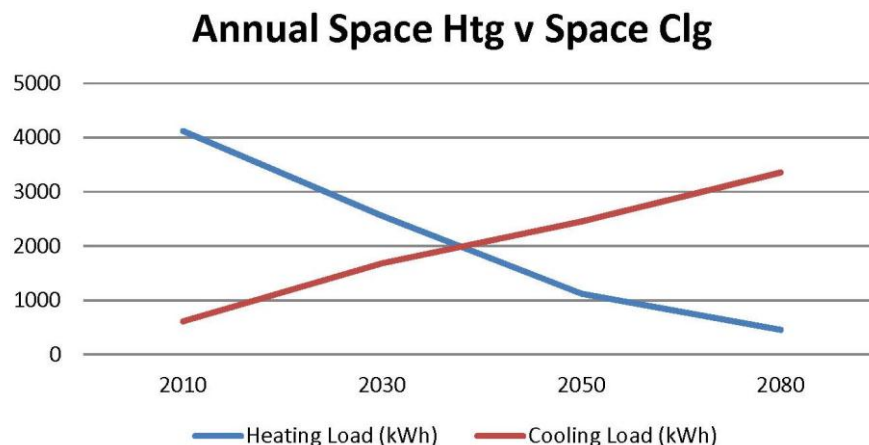


Figure 6. Timber frame—Space Heating *versus* Cooling energy demand in the house using high emission scenario 90th percentile projections.



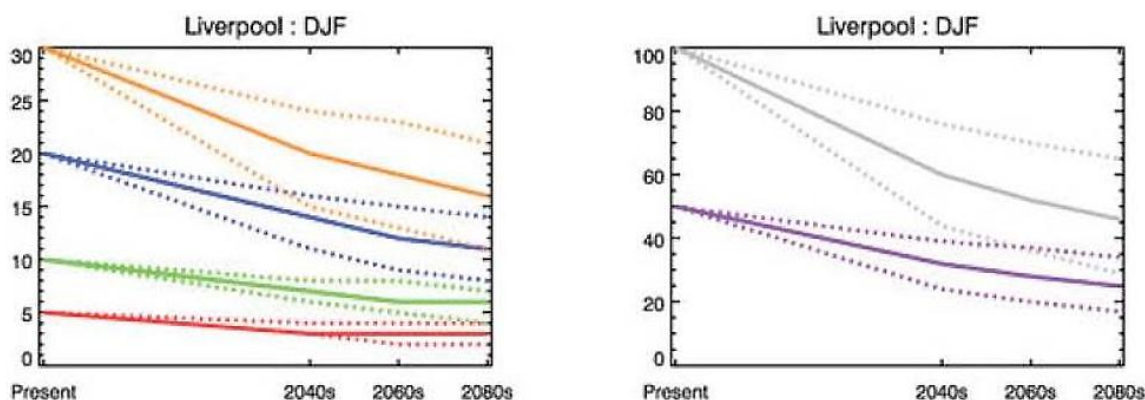
4. Climate Change Risk Assessment

A risk analysis of the effects of climate change on the housing development was performed. This emphasized two issues, firstly the likelihood of the risk, the number of impacts from the risk and the severity of these. Over 100 risks were identified, but only three had a likelihood and severity that made them serious enough to consider now for the future. These future serious risks were mainly concerned with extreme weather events or extended heat waves: the house of the future would have to cope high wind-speeds, high rainfall and flooding, and summertime overheating.

4.1. Flooding

Future flood return intervals are difficult to assess since they are based on historic data. In the UK, flood risk is predicted by creating “occurrence in a time period” data, so sites are given a clearance for a “once in 20 year flood”, or a “once in 50 year flood”, or a “once in 100 year flood” [13]. Climate change is affecting this analysis, as a site with a 1 in 30 year flood risk in 2010 will have a 1 in 16 year risk of flooding by 2080 (see Figure 7), and a current 100-year flood event is projected to become a 50-year event by 2080 within a widening probability band [14]. This can be seen clearly in Figure 7.

Figure 7. UK Met Office graphs showing changes in return period for winter rainfall events in Liverpool 2012–2080.



However, there is no new projected 100-year flood data for 2080. What is certain, however, is that the flood risk certainty is diminishing, and it is likely that most of the urban space in the UK will be at a much increased flood risk in the future. Flooding in the UK can be both fluvial and pluvial, but typically water depths are likely to be below 750 mm and the duration is likely to be no more than 2 weeks.

4.2. Wind

Data on possible extreme wind events is difficult to obtain, and the hourly data from Prometheus does not accommodate storms, as it is based on a model year, which by its nature has non-extreme weather. The Prometheus model seems to predict general wind increases but not extreme gusts. It is likely that hurricane-force winds will be more common, and Liverpool has already seen gusts of over 150 km/h in the past five years [15]. Timber frame performs well in wind and simple improvements such as changing the size and frequency of fastenings for roof tiles can be easily made that have little effect on the overall design and cost, but greatly improve resilience to wind. These new safety factors should easily be incorporated into all housing.

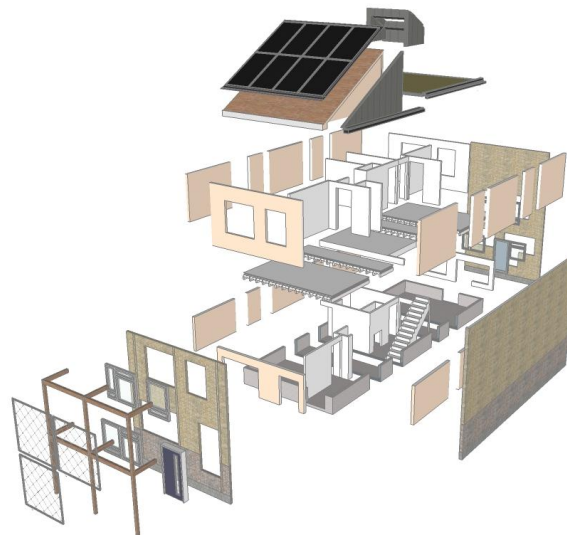
4.3. Overheating

Prolonged overheating presents a danger to health. Death rates amongst elderly people rise sharply above roughly 28 °C. In France for example, in 2003, 15,000 extra deaths of elderly people occurred due to an extended heat wave that lasted for only three-weeks, during which the daytime temperatures were only 4–5 °C above normal [16]. However, it appears that our own physiological response to the heat stress, rather than the maximum temperature experienced, is what causes death: thus an equivalent temperature in the UK could be more life threatening the same in Greece. This behavioral adaptation may affect the exact trigger temperature, but what is clear that once the temperature exceeds for some period a temperature of around 28 °C, mortality rates start to rise [17].

The other effect of overheating is that it raises the likelihood of carbon intensive cooling systems such as air conditioning being retrofitted to the property. Most of these systems use electrical means for chilling, which makes them very inefficient and costly to run, which in turn will increase household payments for occupiers, use precious resources, and indeed create a localized heat island effect which could exacerbate the problem.

5. IDEAHaus Concept

The final stage in the project was the design development of an idealized future housing product which could be mass produced, yet solve these future climatic issues. The design needed to be industrialized and cost effective, yet flexible in design and meet current spatial and energy standards without adaptation. The house would also have to be resilient to the risks inherent in the UK's future climate and resource scenario: it would therefore need to include passive design strategies for dealing with issues of flooding and overheating. Branded the IDEAHaus, this would be: Industrialized, Delightful, Efficient, and Adaptable (see Figures 8 and 9).

Figure 8. Exploded view highlighting component kit.**Figure 9.** Elevational options—brick, timber, render/panel.

5.1. Industrialized

The house would need to compete in the current market, in terms of price-point, quality and amenity. This lends itself to the development of an industrialized, product-based system:

- **Standardization**—mass production of regular core components for the superstructure;
- **Manufacturing quality**—enhanced quality achieved by production under factory conditions;
- **Predictable cost and delivery**—through repetitive design, specification and construction method;
- **Economies of scale**—through bulk purchasing power and availability of stock items.

5.2. Delightful

The house would need to be valued as a place to live, with excellent architectural features that enhance livability:

- **Spacious**—designs based on detailed furniture layouts and activity spaces, good ceiling heights and central light-well;

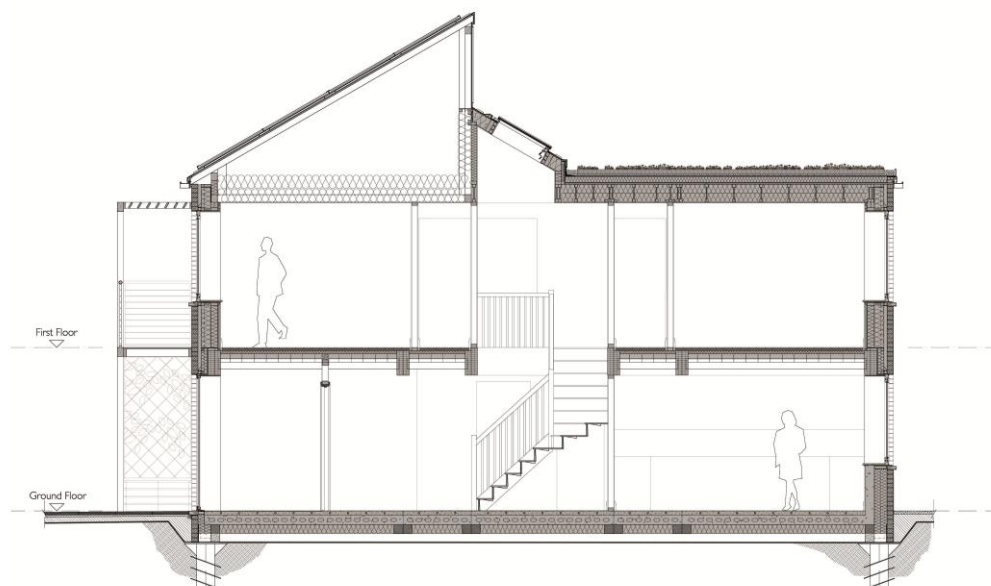
- **Individualized**—different possible room layouts, fenestration, cladding and finishing options;
- **Comfortable**—through use of thermal mass, good ventilation, shading options and radiant heating systems;
- **Quality**—high quality products with finishing options.

5.3. Efficient

The resource scenario for the rest of the century is uncertain to say the least. Peak oil production was reached in 2009 and we are now moving to a low-carbon economy [18]. Increasing differentials between rich and poor in the UK are already producing areas of “fuel poverty” where occupiers cannot afford to heat their homes adequately. It is likely that the necessity of mechanical cooling will exacerbate the problem. Fuel and therefore materials are likely to become more rather than less expensive in real terms. The house if it is to be successful as a model for social housing will need to be very low energy and resource efficient.

- **Passive design**—highly insulated fabric with thermal mass, good controllable natural ventilation and shading options (see Figure 10);
- **Renewable energy options**—ability to incorporate renewable energy systems;
- **Low impact materials**—sustainably sourced materials, engineered to minimize waste;
- **Fast construction**—predictable design time and quick to erect watertight shell construction.

Figure 10. Long section.



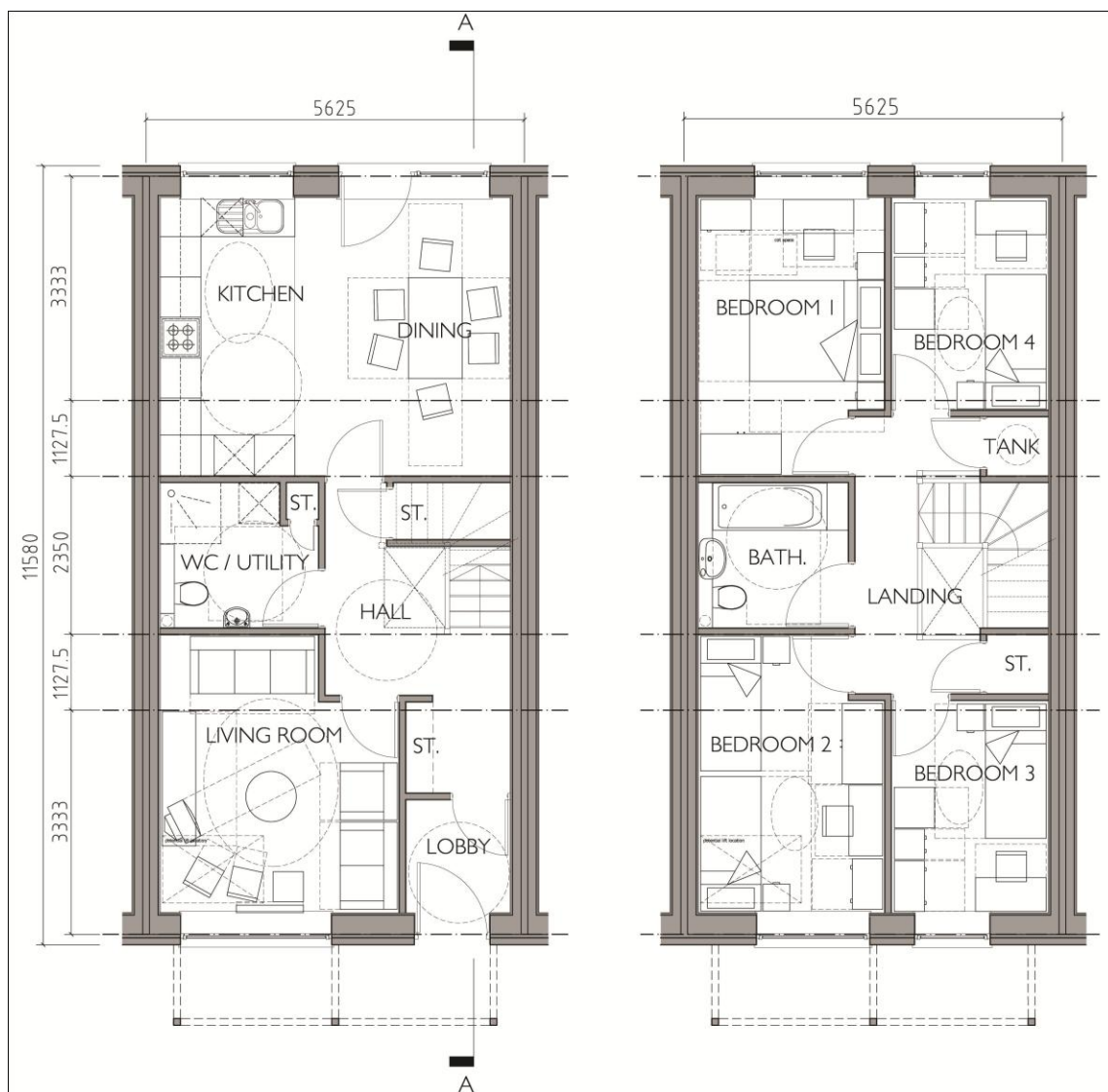
5.4. Adaptable

The market for social housing is difficult, due to the cost of available land in the UK, which is one of the most densely populated countries in Europe. Typically, social housing is forced to the margins, occupying space that has low value for development, in that it is awkward to occupy, in danger of flooding, or it is brownfield, with a complex history of industrial occupation. In order to maximize density on these sorts of sites, the product must be spatially adaptable to occupy the site effectively. In

addition, the range of occupiers for this sort of house is wide in the UK, and there is a need for 2, 3 4, or 5 bedroomed properties, often on 2 or 3 floors. Lifetime Homes is a UK standard that promotes flexibility for house designs so that they are adaptable for the needs of aged or disabled persons.

- **Flexible layout**—designed to the UK’s Lifetime Homes generous space and accessibility standards (see Figure 11);
- **Climate resilient**—flood resilient and overheating resistant construction;
- **Additive features**—construction allows for exo-structure options and vertical extension;
- **Upgradable performance**—allowing for replaceable cladding, solar panels and services.

Figure 11. Four bed six person house floor plans.



6. IDEAhAUS Detailed Construction

The idea of mass customization is that of “*producing goods and services to meet individual customer’s needs with near mass production efficiency*” [19]. This has been described as combining the customization of bespoke tailoring with the efficiency of the production line. Following the philosophy

of mass customization, the construction of the IDEAHaus is considered as a three-part system consisting of Core construction, Additive components, Adaptable services.

The house construction is made of five elements, three that constitute the core:

- **Floor and foundations:** the development of a flood resilient ground system including foundations, ground floor and lower walls [Core];
- **Volumetric central services area:** this factory assembled unit contains stairs, bathrooms and services [Core];
- **Cassette based upper systems:** This is a series of insulated and structural panels that complete the interior of the house [Core];
- **Customizable external cladding system:** This allows for aesthetic contextual adaption, or possibly climatic adaptation through retrofit [Additive];
- **Utility components:** This is a series of components that enhance the utility of the house, such as photovoltaics or solar domestic hot water systems [Adaptive].

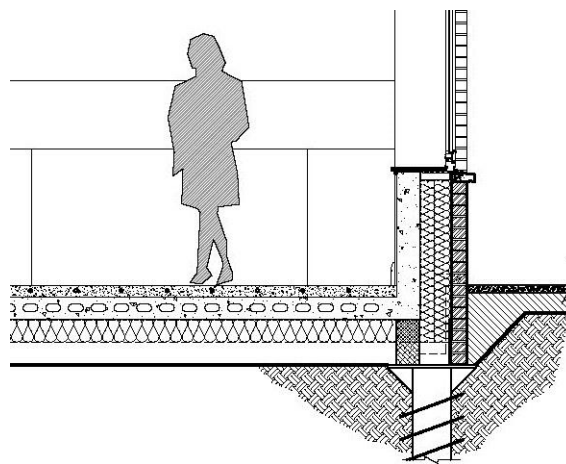
6.1. Core Construction

This part of the system is the spatial construct that defines the house as a living space. This consists of the foundations and ground floor, the wall, upper floor and roof constructions and the service pods for kitchen and bathroom.

6.1.1. Foundations

Helical steel screw piles are proposed to suit virtually any site conditions (e.g., urban housing on filled brownfield sites) with minimal disruption and preparation. They can reduce site excavation and minimize cost of landfill taxes. They allow large shading trees to be located closer to buildings without root damage to foundations (see Figure 12).

Figure 12. Ground floor to external wall detail, highlighting flood resilient floor slab upstand.



6.1.2. Ground Floor

The floor is made of a series of large precast concrete units with flood-resilient, up-stand edges, with a bonded damp membrane and closed cell insulation to the outer faces giving an effective damp-proof

course some 750 mm above floor level (to repel flood water) and a high thermal mass. The units span between pile caps on insulated blocks with a reinforced up-stand edge beam. Units are designed to a standard house width of 5.6 m to suit 2, 3 and 4 bedroom house types. The modular floor allows a standard position for front and rear doors within two large 3.3 m length elements. In the center of the plan a 2.4 m floor unit is designed to suit a WC/utility and stairwell and if necessary 1.1 m infill units can be used to extend the floor depth of the house to suit the number of bedrooms required.

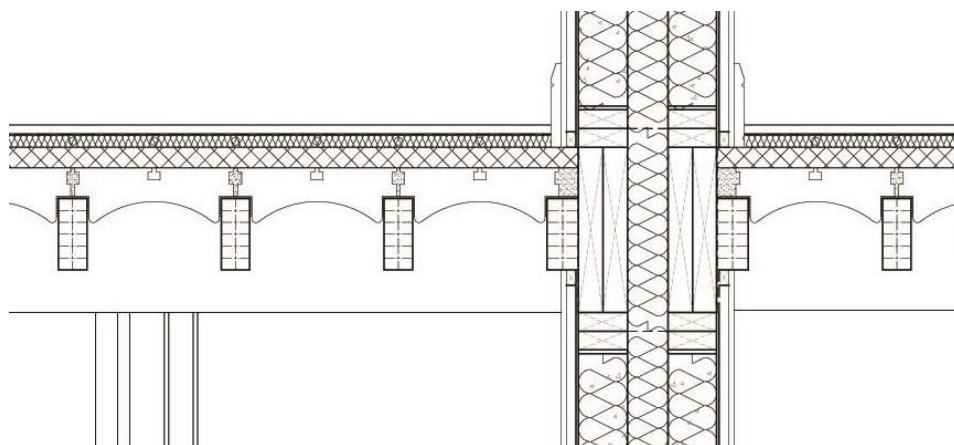
6.1.3. Wall Cassettes

The walls were manufactured with pre-insulated timber frame wall cassettes with 120 mm pre-cast “Hemcrete” insulation and 200 mm of hemp fiber insulation quilt [20]. The hemcrete product provides excellent thermal mass and has phase-change properties which enhance its cooling performance. The cassette has a breathable construction that enhances humidity control in the house. Window openings can be individually designed and the proposals shown are set out to suit standard brick dimensions, for ease of external cladding.

6.1.4. Upper Floor Cassettes

The upper floors are manufactured using open panel cassettes. Over the main living spaces these comprise exposed engineered timber edge beams and joists, which are then in-filled on site with hollow clay blocks based on the Ibstock “Coolvault” system [21]. This provides exposed thermal mass in the house, seen as a self-finished vaulted ceiling to ground floor rooms and a timber boarded finish above (see Figure 13). The central area around bathrooms and stairs are closed panel with plasterboard ceilings to allow space for services distribution.

Figure 13. Party wall/upper floor detail.



6.1.5. Central Volumetrics

The highly serviced central area with bathrooms, stairs and main heating system is standardized for all the house types. This would be manufactured off-site and be of volumetric construction. These could even be stock items. Finishes and fittings could be completed to standard or customized to

individual order. The upper volume has a pre-assembled roof cassette to match the main flat roofs. This can be rotated to suit solar orientation.

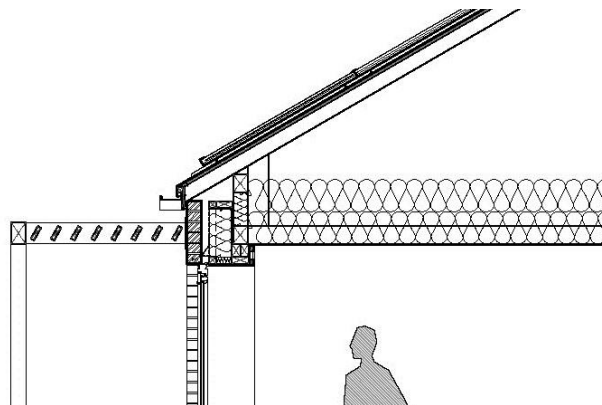
6.1.6. Roof

The roof can be rotated during construction to maximize solar collection. The roof is proposed with a 30 degree pitch for optimum solar collection potential. This can be pre-assembled (on or off-site) in trussed rafter and purlins spanning between party walls. It is constructed with a plywood boarded finish to provide racking and allow for different cladding options, such as photovoltaics.

6.2. Additive Components

These components offer the first part of mass customization. Changes to external components can affect both the aesthetics of the house as well as its thermal performance. Loggias or shades can be added to the external walls or green roof systems above to help with environmental control. The choice of external cladding can also help with planning issues re conservation (see Figure 14).

Figure 14. Eaves detail.



6.2.1. External Cladding

The proposal shows cavity wall brickwork cladding and zinc clad roofs with solar panels over the pitched roof, however, other finishes, such as brick or a rain-screen are equally viable.

6.2.2. Green Roof/Roof Garden

The North-facing flat roofs lend themselves to a green roof/garden finish to aid in bio-diversity, rainwater attenuation and cooling micro-climate through evapo-transpiration.

6.2.3. Fit Out

The layouts shown are based on highly specified UK social housing standards. This gives the flexibility to vary room sizes and shapes or adapt to a more open plan depending on the overall size of house.

6.2.4. Exo-Structure and Components

A grid of thermally broken fixing points is built into the façade for an optional 1.2 m deep timber framed exo-structure with a range of porches, shading devices, balconies, trelliswork, *etc.* (Figure 15).

Figure 15. Exo-structure variations.



6.2.5. Extra floors

The structural system will support additional floors with a second staircase added for vertical extension. Roof cassettes can be demounted and reused.

6.3. Adaptive Services

These components change to performance of the house from an operational viewpoint. There is a choice of renewable systems that can be added at the design stage or retrofitted at a later date.

6.3.1. PV-Thermal

Hybrid PV-T panels which produce both electricity and hot water are proposed to the south facing roof combining solar hot water collectors under photovoltaic cells. PV-T's can give a 40% greater energy yield for equivalent areas of roof than separate panel systems. A large hot water tank is provided at first floor level.

6.3.2. Under-Floor Heating and Cooling

Both the ground floor and the first floor are shown with under-floor heating pipework for comfortable radiant heat at low temperatures which also allows the use of a ground to water heat pump. This pipework could also be used for summer cooling if necessary, to disperse heat from the structure. There is space in the service module for a gas-fired boiler if specified to provide heating and hot water in combination with the renewable energy sources.

6.3.3. Ventilation

The design has focused on a natural ventilation strategy rather than whole house MVHR. Window patterns open top and bottom to enhance single sided ventilation airflow in rooms and the rooflight increases the options for stack effect ventilation during warm periods. Windows can be securely restrained re high winds and insect blinds can be added in the reveals. Opening sizes shown allow a night-time purge ventilation rate of 6 air changes/hour at a modest air speed of 0.5 m/s. Individual extract fans with heat recovery are proposed for kitchens and bathrooms.

6.3.4. Services Distribution

The external and party walls are dry-lined above 750 mm to allow a service zone for cables and pipework this protects services from flood damage, and the plasterboard from the same. Wiring for the ground floor lighting runs in the top of the “coolvault” units and drops through the ceiling where required.

7. Performance Modeling of the IDEAHaus Design

Thermal modeling with particular focus on overheating was carried out on the IDEAHaus using IES, again utilizing hourly weather data from Prometheus for today and 2080. The results are summarized in Table 2.

Table 2. Summary of internal overheating modeling (IES) on IDEAHaus SE facing bedroom, for 2010 and 2080* Hi-emissions 90th percentile dataset.

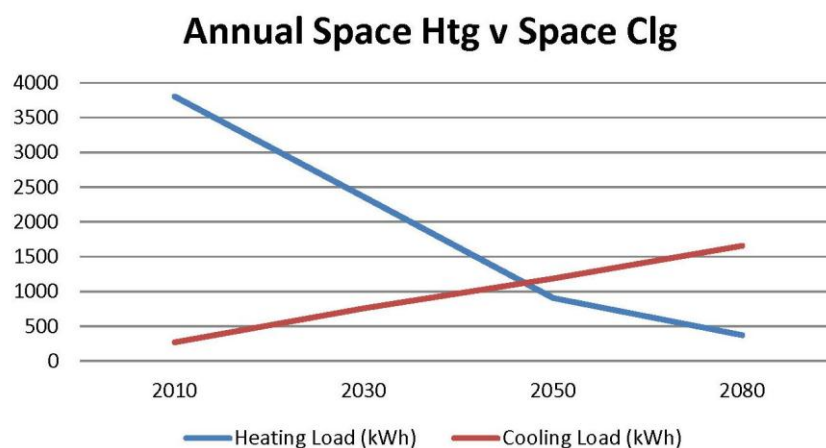
House	Climatic dataset	Period	Peak Internal Temp	Temp above	25 °C	Temp above	28 °C
			(°C)	(h)	(% Time)	(h)	(% Time)
CIBSE Guidelines					5		1
IDEAhaus	2010 DSY	annual	28	41	1.4	5	0.2
		July/August		34	6.9	5	1.0
	2080*	annual	34	990	33.9	352	12.1
		July/August		496	100.0	200	40.3

The performance of the house, without active cooling appears to be excellent. The findings show the IDEAHaus proposal reduces the overheating problem significantly more than even the brick/block option. ISO 7730 recommends several ways of assessing thermal comfort in occupied buildings. The researchers chose method A as described in Annex H, long-term evaluation of the general thermal comfort conditions: “Calculate the number or percentage of hours during the hours the building is occupied, the PMV or the operative temperature is outside a specified range” [22]. The reason this more simple method was chosen, is that it is the most reasonable due to the compound error that is always present in future casting utilizing data that has been derived from theoretical climate modeling. In addition, it is difficult to assess future comfort exactly, as there will likely be a physical and behavioral adaption over time to the changing climate, which makes people’s reaction in the future difficult to assess [23].

The results thus show, annual habitable hours with internal temperatures above 28 °C are 0.2% of the time in 2010 and 12.1% in 2080. In the summer months of July and August, overheating was also reduced to just 1.0% of the time in 2010 and 40.3% in 2080. This reduction is a 76% improvement over the existing timber framed design for 2080. This considerable improvement is related not only to the availability of thermal mass in the house, not only in the floor and walls, but also in the ceiling, compared to the masonry and timber framed designs. In addition, the breathable Hemcrete has phase-change properties due to its moisture content, that also helps prevent overheating [24]. The improved ventilation utilizing the openable roof lights above the stairwell, also helps cool the house, by increasing ventilation rate using the considerable stack effect of the high-level opening.

IES analysis of the IDEAHaus heating and cooling demand shows a lower demand than the timber frame baseline house which equates to a halving of the energy requirement for heating and cooling in 2080. The adoption of the IDEAHaus construction also changes the crossover point between heating and cooling demand to around 2050 (about 10 years later than the standard house). This is shown in Figure 16. The building was designed to be more resilient to climate change with respect to comfort, rather than economics. The team realize however that the cost-effectiveness of the solution needs to be understood. This not only includes the additional cost of manufacture, but also the future energy savings described above. A further assessment of the financial investment will be needed, to take the house into the production and deployment phase. It is intended to extend this work in the prototyping stage to produce an accurate cost model of the building after value engineering, which will allow the team to further assess the IDEAHaus as a cost-effective solution through a life cycle cost assessment.

Figure 16. IDEAHaus—Space Heating *versus* Cooling energy demand—Hi-emission, 90th percentile projections.



8. Conclusions

Future climate will challenge contemporary house design in the UK. Firstly there is a need to recognize that overheating is already an issue in highly insulated, lightweight construction and cooling for comfort is already becoming an issue. This will become a serious issue within 20 years, when more energy will be spent cooling a timber-framed house than heating it. Secondly that extreme winter weather will become the norm in the near future and new houses need to be designed to withstand higher wind speeds, possibly up to Category Five Hurricane, and be able to resist possible flood damage.

8.1. Passive Cooling

There is a need for cooling demand to be recognized in housing design in the UK. Appropriate passive cooling strategies can provide more comfortable and energy efficient houses. In the UK, although climate change will be extreme by the end of the century, passive cooling techniques involving strategic use of thermal mass and night time ventilation, will mitigate much of the change. With careful design, such as in the IDEAhause, thermal mass can be incorporated into lightweight structures, and improve the performance of the dwelling.

8.2. Flooding

Flooding is a serious and increased risk during this century in the UK [25] Timber frame structures are very susceptible to damage from floods, but can be made flood resistant if adequately protected. The IDEAhause utilizes a concrete basin-type ground floor with closed cell insulation and doorway protection to give protection against water ingress to a depth of 750 mm.

8.3. Modular Construction

The use of a hybrid open system of modular construction gives new flexibility that suits the demands of the UK housing market (see Figure 17). The use of mass-customization and customizable façade cladding can provide an industrialized but attractive choice of products, and this, an adaptable construction, can allow for change over time, which can mitigate for future uncertainty.

The IDEAhause is one blue-print for a more adaptable UK house, than can withstand the rapid climate change expected in the twenty-first century.

Figure 17. Typical IDEAhause.



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Author Contributions

The co-authors both contributed equally to this research project and the writing and review of this article.

Conflicts of Interest

The authors declare no conflict of interest.

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