The Deciduous House:
A design approach for energy efficient housing

FILBERT MUSAU[1]

[1]MEARU, Glasgow School of Art, Glasgow, Scotland, United Kingdom

ABSTRACT: The size of spaces has been associated with the levels of energy use in buildings. Empirical evidence shows that many home spaces remain unoccupied for significant lengths of time; and that a significant proportion of UK homes are under-occupied. This paper discusses the potential for saving space heating energy through a design approach for a house with a seasonally adaptive fabric. The approach explores the ways in which architectural design can save energy by resolving the tension between spaces in buildings that are tied in unchanging patterns by static furniture and/or equipment; and those tied in changing patterns by varying occupancy. The key features of the Deciduous House are: a rigid fabric to accommodate rigid elements such as services; and an adaptive fabric with capabilities to seasonally minimise the heated space during the heating season; change its glazing ratio and U-Values; and optimise solar energy when it is in useful supply. The research uses TAS simulation to assess the performance of different configurations of a three bedroom house. The results show potential savings averaging 25.45%, 24.6% and 25.5% during peak winter when the house is used by four, three and two householders respectively. This is in comparison with a conventional base case layout used by similar householders; and with similar U-values meeting the proposed 2013 UK building regulations requirements.
Keywords: space heating energy efficiency, household size, under-occupancy, deciduous house.

INTRODUCTION

The size of spaces has been associated with the levels of energy use in buildings. Conway and Roenich [1] list the costs involved in heating large as opposed to small spaces in temperate climates as a consideration in determining the size of spaces, among a variety of other considerations. For ventilation, if air were delivered per user, theoretically the volume of air (to be heated or cooled) would be the same whether the occupants are in a large or small space. In practice, however, it is more complicated and difficult to deliver air with such precision, especially if natural forces drive the supply air, and if occupancy is varied.

Empirical evidence shows that many home spaces remain unoccupied for significant lengths of time. In UK, the majority of people aged between 4 and 64 (80% of UK's population [2] go either to work or academic institutions regularly. The UK's average of 5.34 rooms per household and household size of 2.4 [2] imply that over 55% of the rooms remain unoccupied at any given time. This percentage is higher in a significant number of whole houses where the householders are single people; young couples without children; or old couples whose children have left home. The latter typically spend more time at home than employed householders. The number of these types of households is increasing significantly across the globe; while the delivery of suitable homes for them is slow; or not existent in the context of effective demand heating. There is also a significant increase in the number of children who split their time between two homes where parents live separately, but have shared parenting arrangements – resulting in under-occupied bedrooms in the homes of both parents. In addition, second homes and holiday homes remain unoccupied for long periods of time.

Unoccupied and under-occupied bedrooms, and second reception rooms in homes, in many cases, remain environmentally 'prepared' for occupation when there is at least a person at home – even where rooms are unlikely to be occupied. Under-occupancy in spaces without occupancy-linked controls results in avoidable energy waste [3]. Many householders turn off/down heating in under-occupied rooms and expect to make savings. However, many homes are not designed for sectional heating and the conduction of heat from heated rooms into the lower heated rooms through internal walls and doors, which are typically not insulated, reduces the potential savings. So does the escape of warm air through internal doors.

If we are going to minimise avoidable energy waste in the domestic sector, we must re-examine the way we design houses – in the context of energy performance, function, and aesthetics. Empirical evidence shows that the average size of domestic spaces *per capita* is very varied across different countries (Figure 1). The work presented in this paper is part of current research for a deciduous house, which seeks to answer the following important questions in the context of the changing household demographics:

(a) Could householders live in smaller home spaces during heating seasons; which could revert to conventional sized home spaces during nonheating seasons?
(b) If so, how could we design homes to facilitate this; how much energy could we save; and how might this vary across countries and economic brackets - from affordable to up-market housing?
(c) What size of space would be optimum per occupant in order to save space heating energy; and how much space should we provide for short stay guests/family members?

This paper focuses on the assessment of the potential for energy saving through different configurations of a proposed 'deciduous house' design approach, which would allow flexibility of the size of space we provide per householder in homes. The Thermal Analysis Software package (TAS) is used for the assessment.

Table 1: Average household size and average size of new houses across the globe, m² [4, 5]

Country	House size (m^2)	Household Size	Space (m^2)/ Householder
Australia	214.6	2.6	82.5
USA	201.5	2.6	77.5
Denmark	137.0	2.2	62.3
Germany	109.2	2.2	49.6
France	112.5	2.5	45.0
Sweden	83.0	2.2	37.7
UK	76.0	2.4	31.7
Ireland	87.7	3.1	28.3

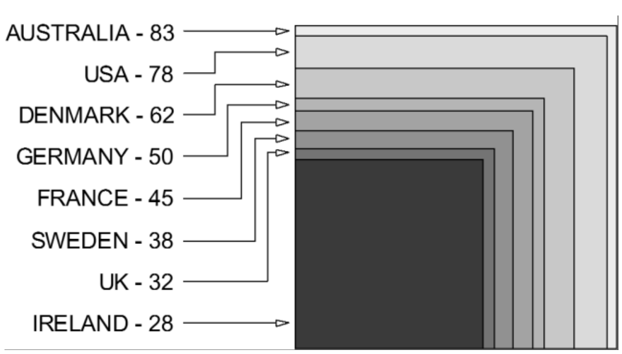


Figure 1: Average space (m²) per householder in new homes in different countries [author]

PROPOSAL FOR A DECIDUOUS HOUSE

The proposed design approach of the deciduous house explores the ways in which architectural design can save energy by resolving the tension between spaces in buildings that are tied in unchanging patterns by static furniture and/or equipment; and those tied in changing patterns by varying occupancy. The thesis is that there is potential for significant energy saving by developing homes that can shrink physically during the heating season and expand during the nonheating season (Figure 3). The design creates three major zones with features (Figures 3, 4, and 5) as follows:

1. A rigid fixed zone and fabric to accommodate rigid services and fixed fittings for auxiliary spaces - bathrooms and kitchen.
2. A rigid fixed zone and fabric to accommodate living spaces with fixed wardrobes and movable furniture.
3. A flexible and environmentally adaptable zone with a 'deciduous' fabric that will shrink during the heating season and expand during the nonheating season. This zone is environmentally and structurally more technical; and spatially adaptable to activity and temporal diversity. Although several types of the flexible fabric are feasible, two have been considered in this paper (Figures 4 and 5).
4. Integrated features to physically de-link unoccupied spaces during the heating season in terms of thermal and air exchange; and cut heating supply to them. This will include air seals and door closers for internal doors; and selected insulated internal walls, which will act as external walls of spaces when they have sectional occupancy and sectional heating.
5. Capabilities within the fabric to seasonally or diurnally change aspects such as the effective glazing ratio and U-Values as necessary (Figures 2 to 5).
6. Systems to collect solar energy during the nonheating season when it is in abundant supply, which can be stored for use during the heating season.

Note that the two rigid zones (1 and 2 above) contain all services and core functions. These aspects are inspired by the seasonal adaptations of deciduous plants and hibernating animals. In summer the leaves of deciduous plants capture sunlight to make food. As temperatures drop, they cut the supply of water to the leaves and seal off the area between the leaf stem and trunk; draw back some of the food in the leaves into the branches; lose the leaves to conserve water loss; and use the stored food the following spring. During winter, some hibernating animals, such as bears, reduce their need for food and partly live off the fat stored in their bodies.

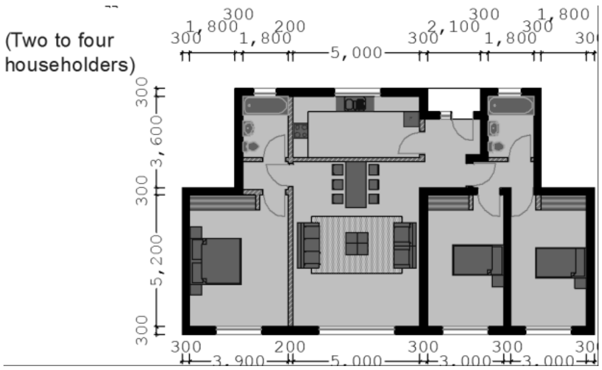


Figure 2: Floor plan of base case house

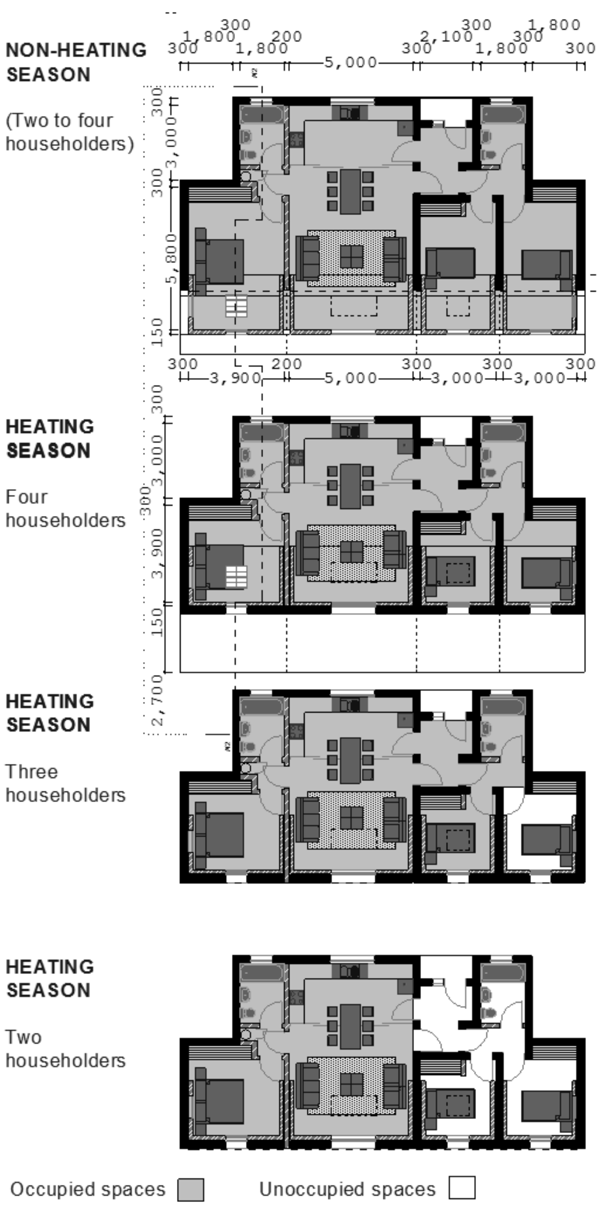


Figure 3: Floor plans of proposed deciduous house

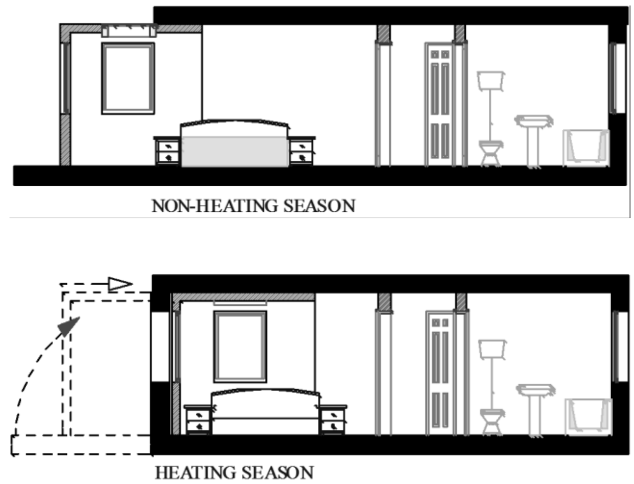


Figure 4: Option 1 - section of proposed deciduous house.

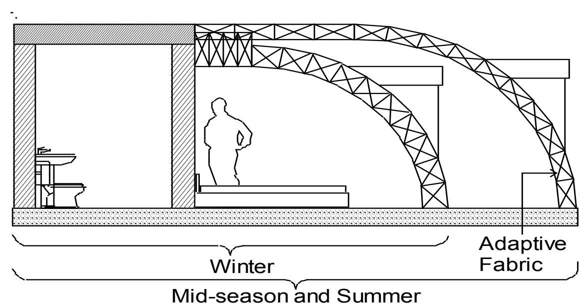


Figure 5: Option 2 - section of proposed deciduous house

The work is also inspired by a little expandable 'accordion' holiday house at the Swedish nature reserve of Glaskogen. It expands and contracts on demand, and is owned by Boris Zeisser and Maartje Lammers of the Dutch firm 24H-architecture in Rotterdam [6]. Expandable and shrinkable architecture has also been employed in airport boarding bridges; and emergency housing projects such as the 'Rapidly Deployable Inflatable Container housing' designed for New York City Office of Emergency Management by James Vira, and Jason Cadorette of Viraline, New York [7].

In the construction of the proposed deciduous house, weight will be a limiting factor for the shrinkable and expandable structure to be robust and easily adjustable. It should have a high strength-weight ratio; high insulation value; and be affordable. Hemp is the insulation material currently under consideration. It is a durable renewable material; has a low U-value; and absorbs and distributes moisture allowing walls to breathe. It has high thermal resistance to weight ratio; and can be formed into flexible options of the proposed expandable fabric.

The following features will allow flexible glazing ratio and insulation levels of the flexible fabric during the heating season (Figures 2, 3, and 4): Each of the key rooms will have two windows on the flexible fabric. The rooms with duo aspect will have two side windows - one on each aspect. Rooms with a single aspect will have a side window and a roof window. During the heating season, one of the windows in each room; and the side walls, plus roof of the flexible fabric, will be tucked inside the highly insulated fabric of the nonflexible fabric (Figure 3). A portion of the floor fabric will flip up to highly insulate the remaining wall of the flexible fabric. The resultant configuration will make the entire fabric highly insulated; have smaller room spaces to light & heat; and less window area to loose heat through. The shrunken mode will capture a heating season experience and atmosphere.

ENERGY DEMAND SIMULATION

Table 2 shows the fabric characteristics used for the simulations. The internal gains used are: Lights = 10W/m^2, Occupants = 13.9 W/m^2, and Equipment = 13.8 W/m^2 based on good practice recommendations [8]. The house is occupied and heated at 6:00 to 8:00 hours in the morning and 17:00 to 22:00 hours in the evening. The internal temperatures used are averages of 21°C for the living room and 18°C for the rest of the dwelling during the occupied hours. This is in line with WHO recommendations. In unoccupied rooms, the temperature is allowed to fall below 18 ^{o}C, and set to a minimum temperature of 10 ^{o}C to provide protection for the building fabric and its contents. This is the typical recommended temperature but may be lower [9]. The ventilation rate is 10l/s/person. Trickle vents are scheduled to open during the occupied hours and they open in all rooms as long as the house is occupied. RH% is maintained at 40% lower limit, and 60% upper limit.

The weather data and location is that of Glasgow, Scotland – Latitude 55^{0}52’N and Longitude 04^{0}15’W in an open location without adjacent buildings. The coldest months in Scotland are typically January and February. The simulation is for January, Monday 15th to Friday, 19th; and for a number of scenarios as follows:

(a) Scenario 1: Base case fabric entirely fixed and with characteristics meeting the minimum U-values of the 2010 and 2013 building regulations [10] (Table 2); and used by four householders
(b) Scenario 2: Deciduous House fabric meeting the minimum U-values of the 2013 building regulations as shown in Table 2; and used by four householders
(c) Scenario 3: As (b) above; used by three householders
(d) Scenario 4: As (b) above; used by two householders

Table 2: U-values of construction elements [10, 11] of base case, expanded deciduous house, and shrunken deciduous house

Building element	U-Value (W/m^2 K)	
Base Case Fabric	2010 Regs.	2013 Regs.
Flat Roof	0.20	0.13
Ground floor	0.25	0.13
External insulated walls	0.30	0.15
Internal walls (not insulated)	0.36	0.36
Windows and roof lights	2.00	1.40
Doors	2.00	1.20
Deciduous House Fabric		2013 Regs
1. Fixed elements		
Roof		0.13
Ground floor		0.13
External walls		0.15
Internal walls (insulated)		0.15
Internal walls (not insulated)		0.36
Doors		1.40
Windows and roof lights		1.20
2. Flexible elements		
Expanded Roof		0.18
Expanded External walls		0.25
Expanded Ground floor		0.13
Shrunken or folded roofs		0.075
Shrunken or folded floor and south walls		0.070
Shrunken or folded east and west walls		0.075

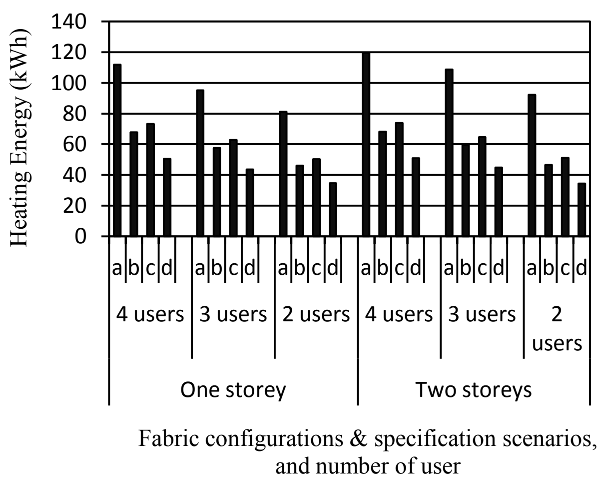
Table 3: Floor areas and space volumes of various rooms

	Base case & Expanded Deciduous		Shrunken Deciduous	
One storey	Area m^2	Vol. m^3	Area m^2	Vol. m^3
Bedroom 1	19.8	47.4	13.5	32.4
Bedroom 2	15.2	36.4	10.4	24.9
Bedroom 3	15.1	36.2	10.4	24.7
Bath 1	4.3	10.4	4.3	10.4
Bath 2	4.3	10.4	4.1	9.9
Passage 1	1.8	4.3	1.8	4.3
Passage 2	2.4	5.8	2.4	5.8
Hall	5.2	12.4	5.2	12.4
Living	32.5	78.0	24.5	58.8
Kitchen	12.0	28.8	12.0	28.8
Total	112.5	270.1	88.6	212.5
Two storeys				
Bedroom 1	19.8	47.4	13.5	32.4
Bedroom 2	15.2	36.5	10.3	24.8
Bedroom 3	15.1	36.3	10.4	24.9
Bath 1	4.3	10.4	4.3	10.4
Bath 2	4.3	10.4	4.3	10.4
Passage 1	1.8	4.3	1.8	4.3
Passage 2	2.4	5.8	2.4	5.8
Hall	5.2	13.9	5.2	13.4
Living	32.5	78.0	24.5	58.8
Kitchen	12.0	28.8	12.0	28.8
Total	112.6	271.7	88.7	213.9

A second set of simulations investigates the performance of similar scenarios of fabric and space use for the heating period; but with the one storey house reconfigured into a two storey house. The space areas and volumes are maintained similar in both the single storey and double storey configurations as shown in Table 3. The glazing ratio is maintained for all configurations: single storey, double storey, expanded, and shrunken. The area of glazing is therefore reduced in the shrunken configurations.

RESULTS AND DISCUSSION

The results of energy use for space heating in the different scenarios are shown in Figure 6. A sample breakdown of the heat gains and losses of the scenarios with four occupants across the three house configurations are shown in Figure 7. The heating attributed to the entrance halls is omitted in the analysis of the results since the volumes of the entrance halls of the single and double storey configurations are different. The results show that, for all base cases, there would be an average saving of 42% of heating energy by shifting minimum requirements for fabric U-values from the current (2010) UK regulations to the minimum values proposed for the 2013 regulations.



a. Base case with 2010 regulations U-values
b. Base case with 2013 regulations U-values
c. Deciduous (expanded) with 2013 regulations U-values
d. Deciduous (shrunken) with 2013 regulations U-values

Figure 6: Heating energy use (kWh) *during five days of peak winter - days 15 and 19 in January.*

The following discussions focus on comparisons between the base case with the 2013 U-values and the two configurations of the deciduous house; both also with 2013 U-values.

Overall, the heating energy use is generally similar in both the single and double storey house, except the scenario with three householders, which is slightly lower in the single storey configuration. For the one storey configuration, energy savings of the shrunken deciduous house compared with the respective base cases are 25.6%, 24.2%, and 24.9% respectively for the four, three, and two occupants. For the two storey configuration, the respective savings are 25.3%, 25%, and 26.1%. In all the scenarios, the expanded deciduous house results in slightly higher energy than the base case, although they are of similar configuration, areas and volumes. The breakdown (Figure 7) shows that this is due to higher solar gains in the base case configuration. This is linked to the slightly different window locations between the two house configurations.

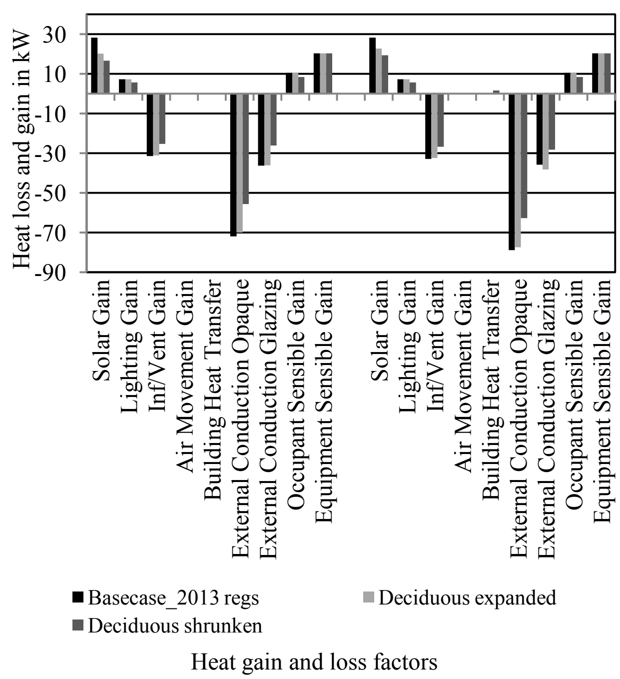


Figure 7: Breakdown of heat losses and gains (kW) for the base case house, deciduous house expanded, and deciduous house shrunken – all with the 2013 building regulations U-values and four householders. This is for peak winter – five week days 15 and 19 in January. The breakdown to the left is of the single storey and that to the right is of the two storeys house form.

The flexible walls and roofs in the expanded mode are specified with less insulation to reduce insulation costs, since very high insulation values are not needed in this mode; which is designed for use during the nonheating season. The results show that lower insulation of these elements does not result in significantly different conduction heat loss in the winter simulation. However, for the two storey house, the higher surface area of walls and the less roof areas result in slightly higher net conduction losses of the opaque elements than the single storey. This is a result of the lower insulation of walls than that of roofs as recommended in the building regulations (Table 2).

CONCLUSION

This work sought to investigate the energy impact of demand control of space utilisation and/or seasonal reduction of the space occupied in homes during the heating season. The results have demonstrated that homes can potentially save significant heating energy if they are designed to adapt thermo-physically, in terms of variable insulation levels and glazing ratios, to seasonal changes of the ambient environment; and adapt spatially to allow sectional use or use of smaller spaces based on changes in space needs and demographics. For a three bedroom house, the results show potential savings of space heating energy averaging 25.45%, 24.6% and 25.5% during a peak winter week when the house is used by four, three and two householders respectively. This is in comparison with a conventional base case layout used by similar numbers of householders respectively; and with similar U-values based on the proposed 2013 UK building regulations requirements. Further research is needed to investigate the degrees to which householders could reduce their need for space in homes during the heating season. The existing differences in the sizes of newly built homes across different countries suggest that significant energy use per capita could be saved by building smaller homes in countries where home sizes are significantly above global averages; and household sizes are growing smaller.

REFERENCES

1. Conway C. and Roenich, R. (1994). *Understanding Architecture, an Introduction to Architecture and Architectural History*. London: Routledge.
2. UK national statistics, [Online], Available online: www.statisticsauthority.gov.uk [10 October 2012]
3. C. J. Ashford, (1997). 'Avoidable waste/base energy budgeting'. Watford: Building Research Establishment.
4. Alan F.; Evans W. and Hartwich O. M. (2005). Policy Exchange 2005; Unaffordable Housing, US Census Bureau ABS, Statistics NZ, CommSec.
5. Economic Commission for Europe Statistical Division, (2001). Trends in Europe and North America 2001, UN Economic Commission for Europe, NY.
6. Broome B. (2007). The incredible shrinking house: 24H-architecture's Dragspelhuset expands and contracts on demand. *Architectural Record*.
7. Katie Gerfen (2009). Rapidly Deployable Inflatable Containers: Disaster Sites Worldwide. *Architect – the magazine of the American Institute of Architects.*
8. CIBSE Guide F (1998). *Energy Efficiency in Buildings*. London: CIBSE.
9. CIBSE Guide H (1999). *Building Control Systems*. Oxford: Butterworth-Heinemann.
10. HM Government, (2010). Building regulations 2010: Conservation of fuel and power in new dwellings, Approved Document Part L1A, NBS, RIBA Enterprises Ltd., London.
11. Department for Communities and Local Government (2007). Building Regulations: Energy efficiency requirements for new dwellings - A forward look at what standards may be in 2010 and 2013, Bressenden Place, London.