Proceedings of 7th Windsor Conference: ***The changing context of comfort in an unpredictable world*** Cumberland Lodge, Windsor, UK, 12-15 April 2012. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

Adapting REALL building design for comfort in a changing climate

Sue Roaf[1] and Gary Clark[1]

[1] School of Built Environment, Riccarton Campus, Heriot Watt University, Edinburgh, EH14 4AS, Contact email: s.roaf@hw.ac.uk

1. Introduction

The need to understand how buildings and people interact to provide comfort is important, not just to those involved in thermal comfort research or standards, but also to those who design and occupy buildings. The comfort approach that informs a building design, the ways in which the building is used, and how it is adapted by, and for, its occupants, all have a significant impact on the amount of energy consumed in that building and the greenhouse gases it generates (Nicol et. al, 2012).

The overwhelming trend towards the use of air-conditioned buildings is reflected in the scale of the consequent US energy consumption patterns. In 2010 around 40% of all energy in the US and 76 per cent of electricity[1] was used in buildings (DOE 2011). About 40% of primary energy used in buildings is used for heating, cooling and ventilation. However these figure mask the most dangerous aspect of this energy use, that on very hot days and in particular afternoons, the electricity use in air condition not only dominates demand requiring over 90% of all electricity generate, but it creates demand peaks that are difficult, and at times impossible, to service with existing generation capacities threatening the energy security of regions at the most lethal weather times of the year.

[1] Electricity consumption by sector: Building Operations, 76%, (Residential 39%, commercial operations 36%) Industry 23%, Transport >1%

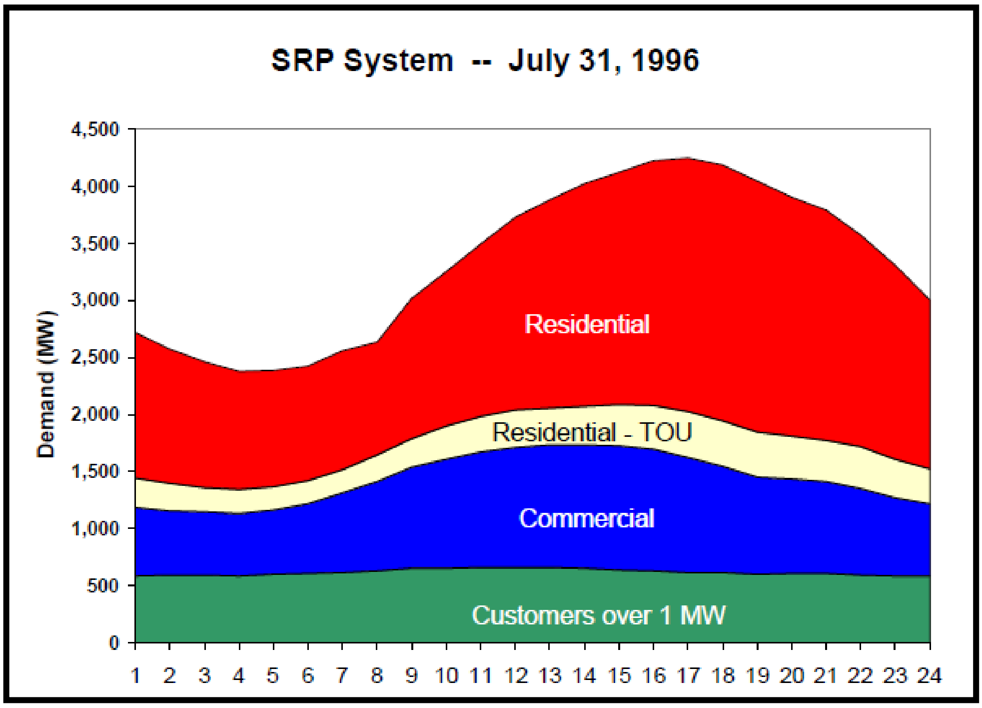

Figure 1. Daily electricity demand in Arizona from the Salt River Project Utility in July 1996 showing the well behaved loads of the large commercial customers and the uncontrolled demand of the residential sector not subject to Time of Use Charging (Source: Harvey Bryan)

Key to the design and construction of comfortable, low carbon and low energy buildings at interaction are three core behavioural characteristics of the way Key to mastering the skill of producing comfortable, low carbon buildings is to look at the 'whole system' when designing. The adaptive comfort approach alone is able to deal with the many attributes of these complex systems.

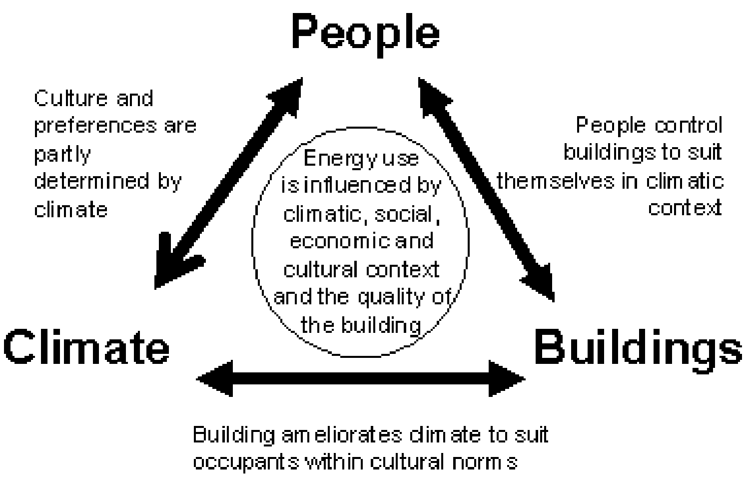

Figure 2. To successfully design for comfort in a free-running, low energy building requires an understanding of the three-way interaction between climate, people and buildings (Source: Nicol et al, 2012).

The outside climate, the building's context, its form, services and occupants as well as the seasons and times of day are all part of the attributes that determine our comfort in a system that is:

1.1 *Dynamic and Interactive*: The process of adapting to different thermal environments is essentially dynamic. Understanding that the buildings we design are part of this dynamic system necessitates a different approach to achieving comfort than one that assumes that the buildings we occupy are inert boxes that are supplied with 'comfort' at a single steady temperature through a duct in the wall, floor or ceiling. Not that one approach to comfort is wrong and the other right, but rather that the different comfort approaches require different palettes of strategies, both for building design and for building services, to achieve comfort.

1.2 *Changing:* Change and movement, typically within the context of well understood patterns of behaviour, are intrinsic to the adaptive approach. Change can include changes of location for different actives, as well as changes in the building itself over time. It includes movement between buildings, between rooms, around rooms, out of the sun, into the breeze, closer to the fire, with the blinds shut, with the curtains open and so on.

1.3 *Customary:* People who regularly occupy a particular space will have a customary temperature which they associate with that place for a particular time of day or year. It will be part of a thermal pathway they follow each day, a pathway that at times may be too hot or too cold, but on average constitutes a well understood pattern for a generally comfortable life.

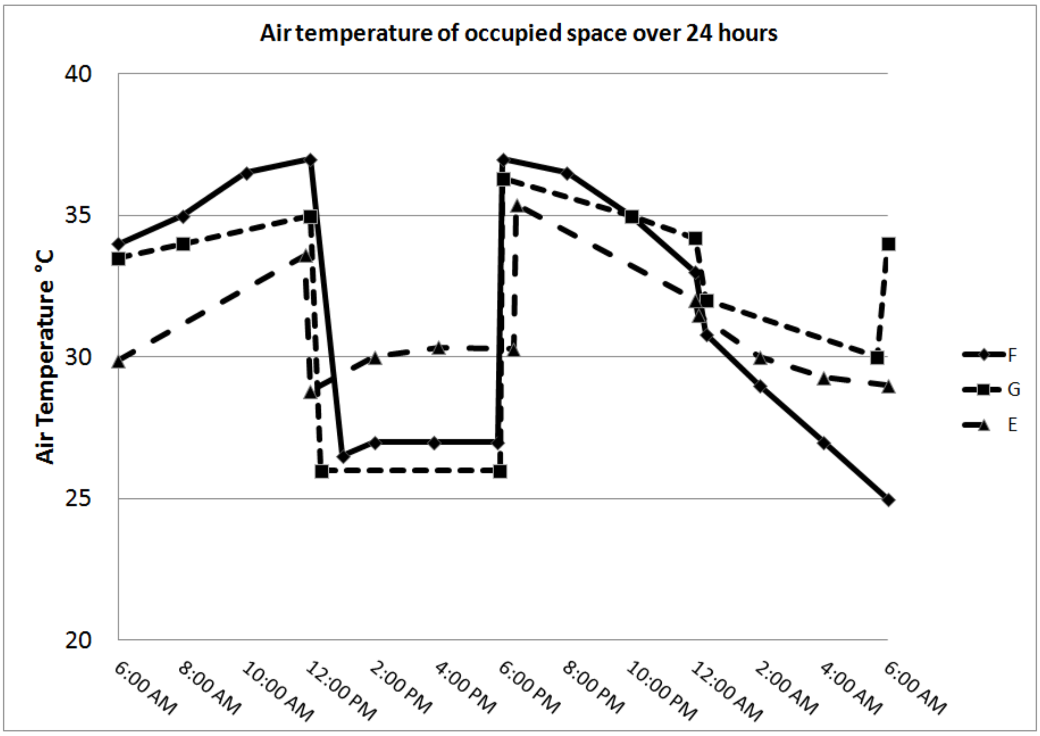

Figure 3. This graphs shows the thermal history of occupants in three different courtyard house in Yazd, Iran as they move from the warming courtyard in the morning, to the deep basement for lunch and a siesta in the afternoon, back into the cooling courtyard around sunset and then onto the roof to sleep beneath the stars at night (Source: Susan Roaf).

Although the constant or gently changing indoor temperature promised by air conditioned buildings is one way to provide occupant comfort, Figure 3 demonstrated that it is by no means the only way in the hot desert of the Middle East. In colder climates many traditional buildings relied on point sources of heat from fires, stoves and on hot water bottles to provide localised warmth while the background temperatures in the room were well below usual 'comfort temperatures' (Humphreys et al, 2011). Sharp temperature differences were accepted and even enjoyed, when set against a well understood behavioural pathway.

4) *Seasonally adjusted:* The customary temperature in naturally ventilated buildings changes with outdoor temperature in a more or less linear relationship when the buildings are in free-running mode, the rooms much warmer in summer than in winter. CEN Standard 15251 (2007) gives a range of comfortable indoor temperature related to the running mean of the outdoor temperature. Very passive, heavy-weight buildings can include areas that maintain almost constant indoor temperatures, rather like air conditioned buildings, and remain perfectly comfortable, being de-coupled from the rising and falling outdoor temperatures.

5) *A goal not a product.* Comfort has been seen as a 'product' provided by the building for its occupants, as defined by Ole Fanger in 1970. This is a premise favoured by those who sell 'comfort' as a product in the form of mechanical systems that are installed, the control systems that run them and the services associated with both of these. It is also the result of a litigious construction industry where designers strive to avoid risk of building performance failure.

Architects are more than happy to assign the risk of performance failures of their buildings to the mechanical system installers and designers. This is not least because many schools of architecture no longer teach climatic design in their curricula in any depth, resulting in a de-skilled generation of poor building performance designers.

Traditionally trained building service engineer are often not taught how to design low energy buildings using non-mechanical natural ventilation systems, or about the use of renewable energy technologies to lower carbon emissions from buildings.

Designers are increasingly dependent on a generation of design simulation tools that do not have the capacity to model effectively complex natural cooling and heating systems and even traditional approaches to the provision of comfort in buildings, let alone the complex behaviours of people within them in neither our current nor less predictable future climates. This is why we are building the REALL project at Heriot Watt University to explore the ways to dynamically provide comfort with low carbon buildings, technologies and behaviours.

2. The REALL project

We are building the Riccarton Eco-village And Living Laboratory to address the following issues:

- How to design optimised, affordable resource efficient / low energy / low carbon housing.

- The need to produce scientifically rigorous evidence that is transparent, comparable and independent in this demonstration project that will help to de-risk the passive design process.
- The challenge of creating complex science and robust, marketable, design solutions from multiply complex variables including people, buildings, technologies and renewable energy systems that will provide comfort in a changing climate.
- Producing evidence for vital validation of simulation models and field trials

Figure 4: Image of the REALL Eco-village

From these overall research aims the primary research questions posed by this project within the first 3 years of operation are centred on the comparative performance of:

- Dwellings built to 2013 and 2016 Scottish Building Standards Dwelling Emission Ratings
- Lightweight timber frame homes versus heavyweight blockwork cavity homes.
- Comparative performance of Naturally Ventilated homes versus Mechanically Ventilated with Heat recovery homes in relation to comfort and energy use.

After the baseline performance data has been established in the first 2-3 years, the 10 home Living Laboratory will be used as a research incubator investigating the integrations of innovative low carbon technologies. The most promising technologies will then be rolled out on larger scale on the 80 housing hub homes for longer term study.

3. REALL Project Description

The Village is sited at the south west corner of Heriot-Watt University's Riccarton Campus, and will contain a number of zones which will be used to run four principal parallel experiments. It is also proposed that a visitor centre will be built to provide a focus for the dissemination of research of the Eco-village and a social facility for the staff and students in this part of the campus.

The house type chosen for the study is a 2 storey semi-detached dwelling. The reason for this are threefold because semi-detached dwellings 1) account for the second largest type of housing within Scotland and the UK of approximately 26%, 2) allow for long term comparative studies of technology between neighbouring dwellings and 3) allow for study of party wall performance plus external perimeter walls simultaneously.

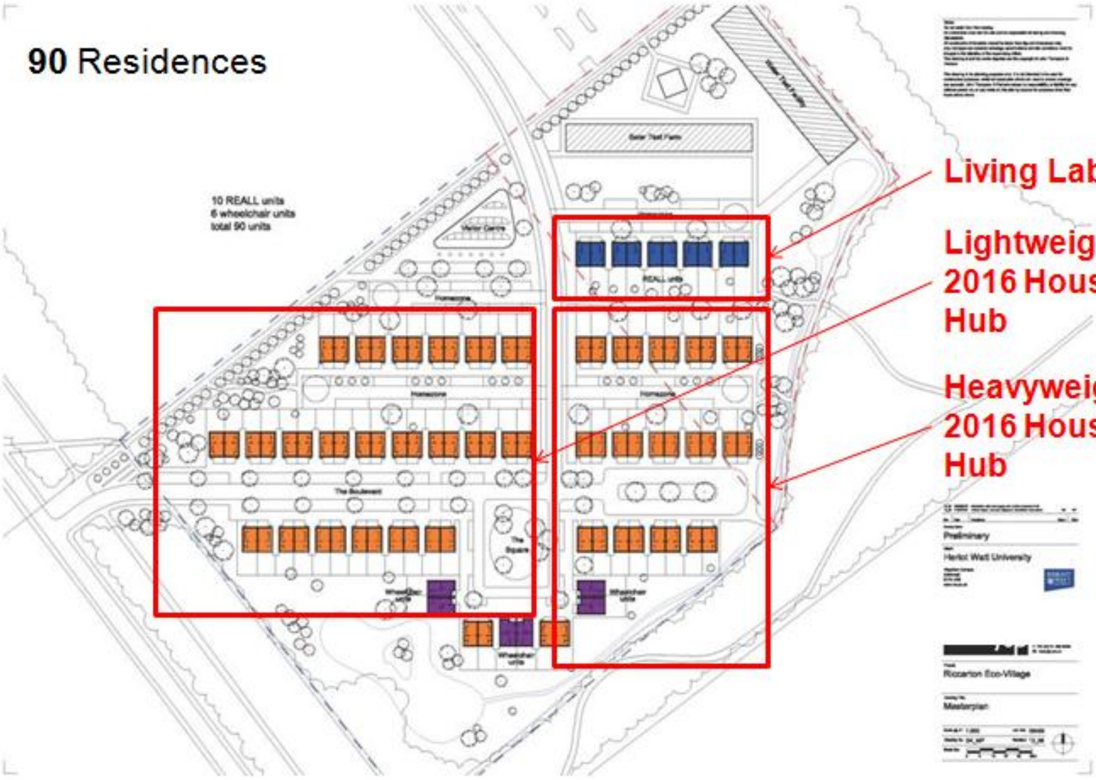

Figure 5: Site Plan of Eco-village

3.1 Materials and Appearance

There are three types of semi-detached dwelling houses within the eco-village. The 2bed living lab house and a 3bed hub house will have the same gross internal floor area of 94m2, while the accessible house is slightly larger to accommodate wheelchair access requirements.

The external materials of the houses has been varied to ensure a diversity of appearance and to express the various types of construction build-ups that have been used on the project. Figure 4 and Figure 5 highlight the various types of external finishes related to construction build ups.

3.2 Living Laboratory

The Living Laboratory will consist of five pairs of semi detached houses to 2013 standards. Each construction pair will test construction systems including fabric weight, insulation, appliance energy rating, resource use and occupancy according to existing and predicted building standards. Figure 4 highlights the various wall constructions to be tested.

3.3 Low Carbon Housing Hubs

The aim of the 'Lightweight Housing Hub' is to build timber frame houses to future 2016 Scottish Building regulations. All the houses will be the same specification except that 20 of the houses will be naturally ventilated and 20 will have mechanical ventilation with heat recovery.

The Heavyweight Housing Hub will be similar to the Lightweight Hub, except the houses will be constructed with insulated blockwork cavity walls. The performance of these 40 homes will be compared with the lightweight houses.

4. Research Method

One aim in the project experimental development has been to minimise the number of physical variables that will be tested during the base 3 year study. A 'paired design' experimental methodology has also been proposed in consultation with Environmental Psychologists and Statisticians at Heriot Watt and Sheffield Universities, the University of West of Scotland and UCL London. The key steps within this methodology are:

1. Each hub house has 3 occupants (triplets)
2. Within lightweight and heavyweight housing hubs there are 20 triplets in natural ventilation houses and 20 in mechanical ventilation houses for one year
3. After one year, you move the 20 from the natural houses to mechanical ventilation houses and vice versa for another year
4. At the end of two years you have a sample of 40 triplets each of which has two energy use measures, one for natural and one for mechanical ventilation
5. A test for differences may be done using a paired t-test and analysis of Co-variance.

4.1 Post Occupancy Evaluation Technique

The core method for Post Occupancy Evaluation during the first 3 years of occupation will be DOMEARN (TM22) energy in use measurement developed by CISBE, and the Domestic Building Use Satisfaction (BUS) survey method developed by Adrian Leaman (. Both these core POE methods will be set within the UBT/BSRIA Soft Landings Framework (2009).

4.2 Sensors and Controls Methodology

The ten living laboratory homes and four of the housing hub homes, one of each house type, will be monitored more closely with hard-wired sensors measuring temperature, humidity and CO_2in every room along with VOC's, CO, formaldehydes, vapour pressure and NO_2 to more precisely monitor indoor air quality. Sensors will be placed on all windows, external and internal doors to correlate indoor air quality with the occupants' use of natural ventilation. Lighting levels will also be measured in each room. U-values of each living laboratory home type will be measured on walls facing in all directions initially and over time to establish any changes in U-value as building materials age and degrade. The living laboratory homes' energy usage will be measured using smart meters plus additional sensors to record directly gas and hot water usage.

On-site weather stations will record temperature, rain fall, wind speed and direction and solar radiation and indoor climates studies during normal and extreme weather events and occupants will undertake full surveys of pre, during and post occupancy comfort responses and attitudes.

Discussion

It is virtually impossible to explore the issues around the provision of, and design for, comfortable housing / buildings with the now technology-heavy mix of complex building types, technologies and behaviours using the current range of fairly blunt simulation tools available. This is not least because models largely cannot, and do not, include issues of individual behaviours and expectations within them. At Heriot Watt University we will be building a world leading Living Laboratory to explore and test approaches to the provision of comfort in what we believe will provide a vital facility for the validation of approaches to comfort in buildings in current and future climates and the modelling of them.

The REALL project is currently within a detailed business case review phase, however initial estimates indicate the project is financially viable by using the income generated by student rent to fund and operate the facility. It is anticipated that the project will be tendered in April or May of 2012 to appoint a research and development partner to in turn build and operate the facility. The anticipated completion date is summer 2013 with the first data being released in early 2014.

References and further reading

BSRIA (2009). Soft Landings Framework, BSRIA BG 4.
CEN (2007) Standard EN15251 Indoor environmental parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics Brussels: Comité Européen de Normalisation CEN), Brussels
CIBSE. Domestic TM22 method- DOMEARM
CIBSE Ventilation and Indoor Air Quality Task Group (2012). Mechanical ventilation with heat recovery in new homes, interim report, January.
DECC (2010). Great Britain's housing energy fact file.
DOE (2011) Building energy databook http://buildingdatabook.even.doe.gov (September 2011).
Humphreys, M., Nicol, F. and S. Roaf (2011). Keeping Warm in a Cool House, Historic Scotland Technical Paper 14, Edinburgh, http://www.historic-scotland.gov.uk/technicalpaper14.pdf
Nicol, F., M.A.Humphreys and S. Roaf (2012). Adaptive Thermal Comfort: Principles and Practice, Earthscan.
Leaman, A. Domestic Building Use Satisfaction Survey Method (BUS www.usablebuildingstrust.org).