The Handbook of Sustainable Refurbishment

Non-Domestic Buildings



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Preface

In most European cities there is a vast stock of existing buildings, many of which are getting to the end of their useful life. To replace the stock would take several decades and incur an unrealistic financial burden. It would also create a large contribution to CO_2 emissions, as a result of the energy associated with the production of materials and the construction of replacement buildings.

It is therefore essential that we develop strategies and techniques to improve the energy performance of our existing stock. It is commonly understood that the heating, cooling, lighting and ventilation of buildings accounts for nearly half of global energy consumption, with the consequent CO_2 emissions having an effect on global warming. The reduction of day-to-day consumption of fossil fuels for heating, cooling, lighting and ventilation must be the main objective in any attempt to refurbish a building sustainably.

This guide is a product of the European Union (EU) funded REVIVAL project, which set out to demonstrate some of these principles by incorporating them in five refurbishment projects of large non-domestic buildings. Wherever possible it draws from the experience of the REVIVAL project, but includes other examples and illustrations when necessary.

This guide is aimed at the architect, engineer, surveyor and project manager. It sets out the case for sustainable refurbishment and the principle measures that can be adopted. It presents principles in a concise technical language, but follows with an explanation of practical implications. It does not attempt to be a source book of manufacturer's information and technical data, or to deal with construction detail.

REVIVAL Team
July 2009

List of Acronyms and Abbreviations

AC	air-conditioned
ANV	advanced natural ventilation
BEMS	building energymanagement systems
BREEAM	Building Research Establishment Environmental Assessment Method
CHP	combined heat and power
CRC	Carbon Reduction Commitment
COP	Coefficient of Performance
CSR	Corporate Social Responsibility
DEC	Display Energy Certificate
DEFRA	Department for Environment, Food and Rural Affairs
DF	daylight factor
DX	direct expansion
EEAS	Energy Efficiency Accreditation Scheme
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
IR	infrared
IRC	internally reflected component
LED	light emitting diode
l/w	luminaires per watt
MM	mixed mode
NV	natural ventilation
PAC	partially air-conditioned
PCM	phase change material
PIR	passive infrared
PSALi	permanent supplementary artificial lighting
PV	photovoltaic
SBS	sick building syndrome
SHF	Solar Heat Gain Factor
UV	ultraviolet

Part One **Principles**

1 Strategy for Low Emission Refurbishment

1.1 The case for low emission refurbishment: Energy use in buildings

In the non-domestic sector in Europe, building refurbishments offer far more opportunities for reducing emissions than new building; the latter represents annually less than 1.5 per cent of the building stock. The usual motivation for refurbishment includes:

- replacement of degraded finishes and components;
- tailoring space organization to new uses;
- improving environmental quality.

These reasons may be sufficient in themselves to justify the cost. If at the same time the building can be made more energy efficient, there will be a reduction in running cost and a reduction in CO_2 emissions. This will often be at a modest extra cost that can be justified by reduced running costs, or in some cases even, no extra cost.

1.2 Refurbishment versus rebuild: Economics and environmental impact

There are many instances when demolition and rebuild will be considered as an alternative to refurbishment. This could be justified purely on economic grounds, or the advantages offered by a new building could be considered to justify the extra cost. However, two non-economic factors should be considered:

1 The environmental impact of refurbishment versus newbuild.

2 The socio-economic impact.

Initially, the environmental impact of refurbishment will almost always be less than demolition and newbuild. This is because all the materials carry embodied energy – to replace them causes new carbon emissions (Figure 1.1). Furthermore, the demolition process and waste disposal creates carbon emission as well as other waste disposal impacts.

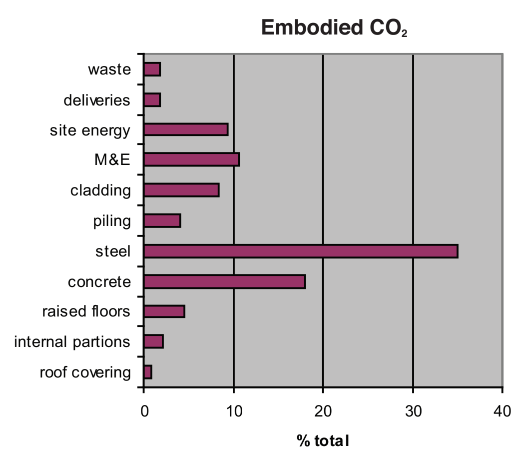

Figure 1.1 Embodied CO_2 associated with newbuild and refurbishment. Note large CO_2 content for bulk materials such as concrete and steel. Components made of these materials are the ones that are not normally replaced in refurbishment

Source: Thomas Lane quoting the Simons Construction Group in 'Our dark materials', *Building*, 9 November 2007

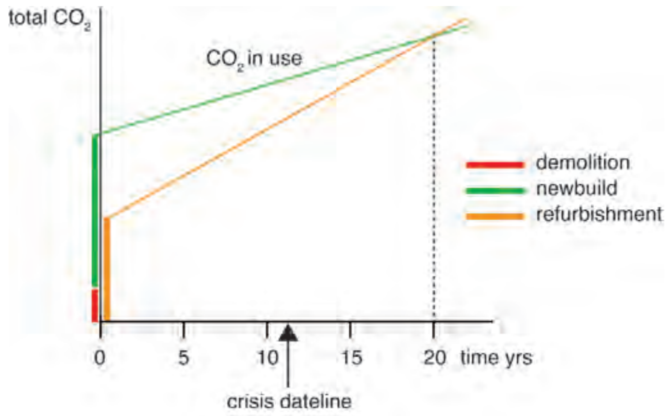

Figure 1.2 CO_2 emissions for newbuild and refurbishment as a function of time. The break-even point is very dependent upon the difference in performance (indicated by the slope of the graph) of the refurbished and newbuild.

It is often argued that a new building will operate at higher energy performance than a refurbished one, and that during its lifetime, may have less environmental impact. This dynamic relationship is shown in Figure 1.2. It demonstrates two important effects – that newbuild is only the lowest emitter after the break-even time period, and that this period can be extended by improved performance of the refurbished option. It also demonstrates that if the break-even time is beyond the time of the environmental crisis (or emission reduction target), the life-cycle emission is irrelevant and the refurbished building is the best choice. It is also evident that the break-even point is sensitive to the *actual* performance of the buildings; new buildings have not in general performed as well as predicted and this will postpone the break-even point.

The second consideration is about social benefit and employment. Generally, refurbishment carries a higher proportion of labour cost than newbuild. For example, the repair of a concrete structure and the cleaning of concrete finishes will direct money to tradesmen that in the case of new build would go to investors in concrete and steel manufacture.

1.3 The building, plant, and occupants as a system

Building simulations and analyses of monitored data have shown that the building fabric alone does not narrowly determine the energy performance. Figure 1.3 shows the performance being determined by three sub-systems, each having a variance in performance of about two-fold. When a poor building combines with badly designed systems and poor management, the resulting energy performance can be dramatically worse than the best. This wide variation of performance has been observed as shown in Figure 1.4. It is interesting to note that building no. 92 (extreme right) was built in 1987 and refurbished in 1992.

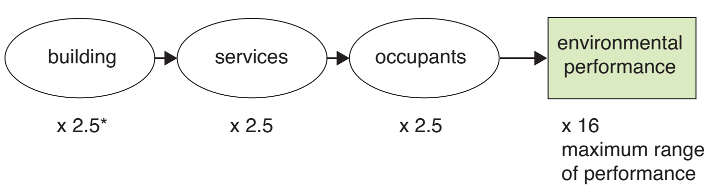

Figure 1.3 The building, the mechanical services and the occupants, as a system. Each controls a range of performance. A poor building may require much input from services which if badly managed leads to high energy consumption. The reverse may also be true. This accounts for a wide variance in energy consumption of similar buildings

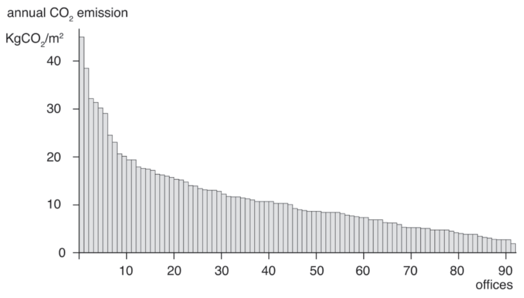

Figure 1.4 The annual CO_2 emissions per m^2 for 92 office buildings in the UK. The 20-fold variance illustrates the interactive effect between building, services and occupants

Source: Data from *Energy Consumption Guide 19 – Energy Efficiency in Offices* (1998) BRECSU, Watford

This evidence weakens the case for newbuild, since it shows that the inherent properties of the building are only one of the determining factors. This is particularly true in non-domestic buildings where overall energy consumption is dominated by processes and activities in the building. Both systems and management can be of as high performance in a refurbished building as in a newbuild.

Figure 1.5 Deep-plan buildings such as these, built in the era of cheap energy and relying on air-conditioning and artificial lighting, may present insurmountable problems for sustainable refurbishment

However, there may be individual cases where the inherent qualities of a building present insurmountable problems. For example, buildings with very deep plans, relying entirely on air-conditioning and artificial lighting, built in an era of cheap energy (Figure 1.5), will always be problematic both for their energy consumption, and internal environmental quality. Thus it is important to properly assess the potential for refurbishment, before conclusions are drawn.

1.4 Implications for change of use

Refurbishment is often accompanied by change of use. This may be across recognized use types – for example a nursing area of a hospital becoming an administrative centre (Figure 1.6), or a change from residential to office use (Figure 1.7). Or it may be that within a use type the functional demands on spaces are changing due to reorganization and the impact of changes in practice and technology. For example, developments in IT have a continuing influence on office practice and the spaces that support it.

Figure 1.6 REVIVAL building Meyer Hospital, Florence: Refurbishment accompanies change of use from nursing area to hospital administrative and reception area, involving different environmental conditions

Figure 1.7 REVIVAL building The Albatros, Den Helder, The Netherlands: Refurbished in conjunction with change of use from residential to offices

It is difficult to generalize here, but it could be said that opportunities are sometimes missed because designers impose stereotypical solutions, often ignoring the serendipity of fitting a new function into a building generated by a different set of aims.

For example, in a conversion of an old factory workshop to modern office use, high ceilings with exposed structural slabs are often replaced with suspended ceilings for acoustic reasons, and under the misguided impression that the original spaces would be impossible to heat efficiently. This action not only destroys much of the architectural quality of the space, but will also have a negative influence on daylight distribution, natural ventilation and, possibly, thermal response.

Change of use may bring about changes in purely technical parameters. These include:

- occupancy pattern and density;
- internal gains;
- lighting levels;
- ventilation rates;
- thermal set-points and response;
- acoustic properties (reverberation time, noise exclusion).

These changes may bring about benefits and disbenefits. For example, an historic warehouse converted into a library will create a difficult challenge to the designer if the intention is to provide daylight, due to the shallow floor-to-ceiling height. On the other hand, a heavyweight building that required wasteful intermittent heating in its original function as a primary school, would not be so inefficient if used for a much longer occupied period as, for example, a health clinic. Furthermore, the intermittent heating would be less wasteful anyway if the envelope insulation was improved as part of the refurbishment package.

Thus, the inherent properties of the building, the operational requirements of the new use, and the technical options in the refurbishment all have to be considered interactively.

Impact on energy consumption

In spite of improvements to the performance of the fabric and systems, change of use may bring about an increase in the energy consumption. This does not necessarily mean that the low-energy refurbishment has failed, since the measures adopted have undoubtedly led to lower energy consumption than if absent.

In measuring the success of the refurbishment then, it would be fair to make a comparison of the building's actual energy performance (shown at A in Figure 1.8) with, firstly, the existing building under the new use and complying with accepted comfort conditions, but without adopting low-energy measures (B). Secondly, a comparison should be made with a new building of similar use type (C). We might expect a performance somewhere between these two or with really successful refurbishments, even surpassing typical newbuild performance. Finally, a comparison should be made with the average emissions for the building stock of the same use type (D).

The example here shows that the refurbished building emits 35 per cent of that predicted for the original building with a change of use, and

58 per cent of that of the measured average for the existing building stock, although it emits 10 per cent more than a new building. The fact that the refurbished building with its new use emits nearly twice that of the original building with its original use, is not of much relevance.

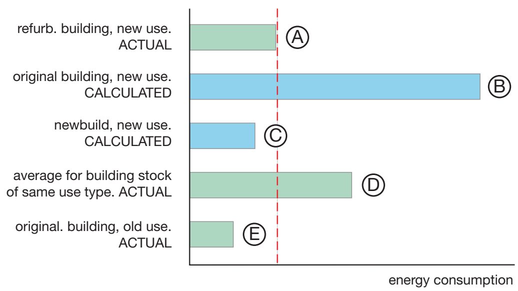

Figure 1.8 Comparing like with like: Assessing the improved performance of a refurbished building

Figure 1.9 An over-glazed lightweight building of the 1970s suffering from overheating in summer and under-heating in winter. The client's perception is often that the only solution to comfort problems is air-conditioning

1.5 Environmental comfort standards

Improved comfort standards are often the initial motivation for refurbishment. The building shown in Figure 1.9, an office block built in the 1970s, is poorly insulated with large areas of single tinted glazing, no shading and a poorly controlled heating system. Since its original occupation, density has increased, and there has been a proliferation of computers and other business machines. The frequent complaint is overheating in summer, both under-heating and overheating in winter, and poor air quality.

The client's presumption may well be that full air-conditioning would be the answer. If conventional comfort standards were sought, this could indeed true, although this would be neither an economical nor environmentally friendly solution.

If refurbishment measures included shading, improving the envelope insulation, and reinstating openable windows, comfort conditions would be greatly improved, although the strict standards achievable by air-conditioning may still not be met for all of the year. However, it is now widely accepted that for buildings running under predominantly passive systems, occupant satisfaction can be high, even when the conventional standards are not met.

A key factor is the presence of *adaptive opportunity*. This is the ability of the occupant to make changes to the environment, and/or make changes to their personal condition, in order to improve their comfort. Typical opportunities that might be present are listed below.

Positive adaptive attributes

- relaxed dress code;
- occupant mobility;
- access to hot/cold drinks;
- openable windows;
- adjustable blinds;
- desk fan or locally controlled ceiling fan;
- local heating/cooling controls;
- workstation/furniture flexibility;
- shallow plan (minimizing distance from windows);
- cellular rooms (reduces mutual disturbance);
- surface finishes appropriate to visual task;

- daylight and task lighting backup;
- good views (external and internal);
- transitional spaces (verandahs, atria, etc.);
- good access to outside areas.

Negative adaptive attributes

- uniformity of physical environment (temperature, lighting, colour);
- deep plan, reduced access to perimeter;
- dense occupation with restricted workstation options;
- sealed windows;
- views obstructed by fixed shading devices;
- central mechanical services control.

Studies have shown (Baker and Standeven, 1994) that the presence of several of the positive attributes will result in occupants tolerating temperature excursions typically up to 5°C above conventional upper temperature limits, and around 3°C below conventional lower limits. This may allow the designer to opt for the passive solution rather than the air-conditioned solution.

This will have implications for initial cost, maintenance cost and carbon emissions. It will also have implications for the choice and prioritizing of refurbishment measures. For example, if it were decided to air-condition the building, the replacement of standard double glazing with high performance low-e units would have a greater impact on carbon emissions than if the building were to be freely ventilated by openable windows. This is because the temperature differential in the latter case would be small or even non-existent. However in *both* cases, shading would be highly beneficial.

In some cases, exceptional overheating conditions may be unacceptable, although conditions prevailing for most of the year may be satisfactory without air-conditioning. In this case, intermittent comfort cooling may be applied. The technological aspects of this are discussed in section 7.11. Here we make the point that a modest dependence on comfort cooling may result in a building being able to take the predominantly passive option. Furthermore, because of the intermittent nature of the comfort cooling, and its controllability, it will not be necessary to apply such strict comfort limits as in a conventional air-conditioned building. This strategy, often referred to as 'hybrid' or 'mixed mode', results in comfort cooling often being a viable and energy efficient option.

1.6 Passive environmental strategies

Statistically, air-conditioned buildings consume significantly more energy than naturally ventilated buildings. In temperate climates, field studies have shown that in spite of the extra capital and running costs, occupant satisfaction was no greater than in naturally ventilated buildings (Figure 1.10). Even in hotter climates, as a study of office buildings in Lisbon showed, satisfaction in some air-conditioned buildings may be significantly less than in some naturally ventilated buildings. Thus the strategy for avoiding air-conditioning is a good one, although hybrid systems and comfort cooling (described later in section 7.11) may represent a viable alternative.

The situation often faced in refurbishment is of a building with very poor comfort conditions, where air-conditioning is seen as the only solution. However, it could be that after making fabric and system improvements, comfort conditions become acceptable. This should be tested by analysis or simulation before the air-conditioning option is adopted.

This may even apply to a building that has air-conditioning already. Many over-glazed buildings of the 1960s and 1970s were subsequently air-conditioned to make conditions bearable. However, measures such as shading, fabric insulation, reduction of glazing area, adoption of adaptive controls, may well render full air-conditioning unnecessary. Even if air-conditioning is adopted, these measures will reduce the air-conditioning loads significantly.

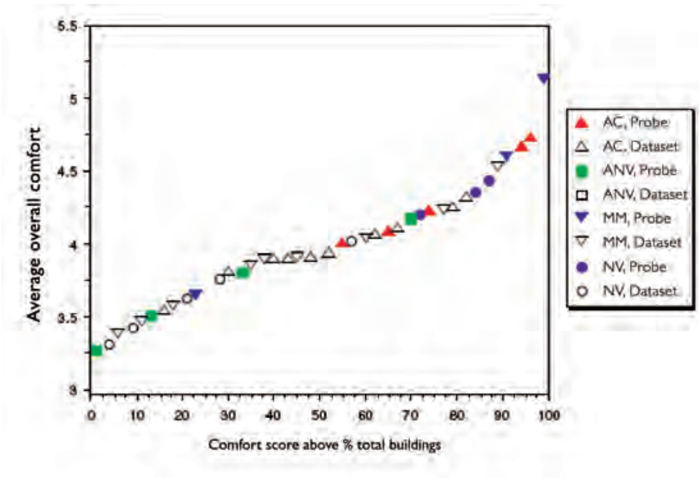

Figure 1.10 Overall occupant comfort by ventilation types; natural ventilation (NV), advanced natural ventilation (ANV), mixed mode (MM) and air-conditioned (AC). The coloured plots are for the PROBE (UK) survey and the open plots from the Building Use Studies data. Summer survey results from 26 office buildings in Lisbon show that occupant satisfaction in naturally ventilated buildings (NV) and partially air-conditioned buildings (PAC) was higher than in air-conditioned buildings (AC)

Source: The Probe Study (2001) *Building Research and Information*, vol 29, 2 March

Natural ventilation

Many candidate buildings for refurbishment will have high rates of infiltration. This is particularly true of buildings constructed using pre-cast concrete components, and panel and curtain wall systems, with dry linings – typical construction techniques of the 1960s to 1980s era (Figure 1.11). In buildings with original glazing systems, these too were very leaky. In cooler climates, the result of the high infiltration rate is a waste of energy due to heat loss. However, one benefit of the high air-change rate was good air quality.

Figure 1.11 REVIVAL building Lycée Chevrollier, Angers, France: Built in 1958 of pre-cast concrete construction with dry lining and poorly fitting metal windows, it had very high infiltration rates before refurbishment

Refurbishment measures to reduce uncontrolled infiltration must then recognize the need to provide ventilation to ensure that a minimum air quality is maintained. This does not mean that the benefits of the more airtight envelope will all be lost, provided some means to prevent over-ventilation is present. Broadly, the principle is 'build tight, ventilate right'.

In predominantly warm climates (i.e. with little winter heating) reduction of infiltration only brings energy benefits if the building is air-conditioned to a temperature significantly below the prevailing outdoor temperature. If it is not to be air-conditioned the main concern switches to getting enough ventilation to remove heat gains and to generate air movement. This will demand large openable areas.

Night ventilation

A further important function may be the provision of night ventilation to cool the structural mass. The principle is illustrated in Figure 1.12. This function will also require large openable areas in the envelope, and unobstructed flow paths within the building. Furthermore, it is essential that the ventilating air can be thermally coupled with the thermal mass of the building. These requirements may present design challenges, particularly in relation to security and noise control.