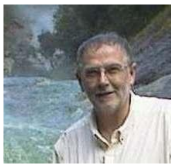
DO ENGINEERS NEED TO LEARN ABOUT SUSTAINABLE DESIGN?

HISTORICALLY, CHANGE WAS ANTICIPATED BY EXPLORING NEW TECHNIQUES WHICH THEN WENT ON TO DEFINE THEIR AGE



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Evaluating a case study of a recently completed new family home and workplace situated close to an airport, beside high-tension power lines, a motorway and a busy road:

Our design includes natural ventilation strategies and acoustic insulation using an earth roof and earth berms to minimise energy, both in used and embodied in the construction. The performance of these innovative design assumptions has now been tested [[3 & 4] above]: Monitoring included electromagnetic field (EMF) reductions from exterior to interior, noise/ vibration as attenuated internally from external environment, internal air quality in relation to hydrocarbon-rich toxic fumes externally and primary energy (embodied and in use). How much the timber building actually protects the interior; from EMF, aircraft and traffic noise/ vibration while maintaining good indoor air quality, ventilation, daylight and energy performance in use, has enabled us to better understand how to improve this, future designs including retrofit existing buildings. The skills and expertise required also involve building physics, a good working knowledge of acoustics, the calculation of embodied energy and life cycle assessment in addition to post occupancy evaluation (POE) - how buildings perform in use with respect to energy consumption targets and potential reductions through communication of the strategy to, management by, or training for, building users. Environmental impact was further reduced also by the beautiful, bio-diverse, living roof.

Engineers, working with ecological architects, are in an important position to address the social imperative to respond to a new economic framework, increasing urbanisation, population growth and demographic change: Indeed, to continue to be relevant retaining employment opportunities & reduce costs, engineers will need to hone their professional skills, expertise and methods to balance the conservation of natural resources and reduction of waste (including energy), minimising ecological impact. The engineering discipline is particularly pertinent as it simultaneously takes an overview of a system (often working on its limits and its interactions), while retaining an awareness of crucial details, and the impact of scale on practicality. The choice of terms in which a problem is stated includes its solution. Ecological engineering makes the distinction between durability and sustainability [van Bohemen 2010]. Whereas, engineers have traditionally specified robust materials for longevity and high margins of safety, these are often have a high energy profile; both embedded, in the production process and, consumed over entire lifecycle. Roman infrastructure, built on monumental scale and standing for aeons, it all but symbolises the traditional engineer's ability to harness and master the powerful forces of nature: Historically, the environmental impact was largely externalised, if costed at all; whereas life cycle assessment now allows all factors to be accounted for over time. We contrast this with the Gaia hypothesis which takes the name of the Greek goddess of mother earth to suggest a respect for the environment, in recognition of the interconnected cycles within ecosystems, being often very finely balanced. [Lovelock 2000]. Ecology shows, it is healthy for any system to foster diversity: So, we need to recognise there is an imperative to develop a resilient, cross- disciplinary approach and broad vocabulary with which to explore many different solutions: These will be necessary to address appropriately, by avoidance, mitigation or adaptation, each future challenge and opportunity.

Keywords: timber building, indoor air quality, acoustic ventilation, POE

Technological evolution and culture

Engineers need to learn techniques which balance the conservation of natural resources and reduce waste with minimal disturbance of ecosystems; the water cycle, soil systems, air quality and biodiversity. The engineering discipline is particularly pertinent as it simultaneously takes an overview of a system, often working on its limits and its interactions, with an awareness of crucial details, and the impact of scale on practicality.

The sustainable use of resources is a core concept and engineering challenge for this century, according to the Institute of Chemical Engineers' Sustainability Subject Group (2010), who detail how this may be achieved within their field, to "provide the processes and products which will give the people of the world shelter, clothing, food and drink, and which keep them in good health" (London Communiqué 1997).

Engineering may be described as the art of solving technical problems; managing a situation or system [Oxford 2000]. Engineers are trained in the practical application of scientific principles and then to specialise in one field; civil/ structural, mechanical, electrical, chemical, mining, fire safety etc. However, there are many dimensions to sustainable development. So, the education of engineers needs to encompass the relevance of inter-relationships and reflect a wider understanding of the nature of the world. For instance, the Gaian system; as summarised by Janine Benyus (1997), "Gaia- runs on sunlight; only uses the energy she needs; fits form to function; recycles everything; rewards cooperation; banks on diversity; demands local expertise; curbs excesses from within; taps the power of limits; is inherently beautiful." Similarly, among the different strategies for development, co-operation is proven to be more stable if the consequences, or future, loom large enough (Axelrod 1984). Our immediate future includes responding to the effects of the rise in average global temperature: Evidence of this increasing rate of change, bringing the risk of more frequent extreme weather events, require the advancement of alternatives and mitigation measures. Evaluation of environmental impact promotes alternatives to avoid, reduce, mitigate or, failing that, compensate for any ecological damage [van Bohemen 2010].

Meanwhile, the threat of Peak Oil implies a need to find substitutes for the scarcer fossil fuels, to conserve remaining oil reserves, for essential uses. Reliance on petrochemicals, including in manufacturing, is likely to become expensive, prohibitively for the majority and so, shared unequally. This can be seen by the distribution of Photovoltaic electric installations concentrating in wealthy countries of Northern Europe rather than others more suited by climate or need, lacking conventional power infrastructure. Engineers learn about systems or processes through research and empirical analysis; testing traditional or innovative materials and procedures for performance and affordability. This approach should now be directed at abundant resources: In addition to petrochemicals, rare earth minerals are now also being exploited for use in new technologies in order to perpetuate high-consumption lifestyles: e.g. Neodymium for magnets in electric motors (cars, wind turbines, hard-disc drives), Terbium in low energy light bulbs, Cerium in catalytic converters for diesel engines, Lanthanum for car electric batteries. Mining rare-earth metals has environmental impacts; with radioactive by-products and acids used in processing, resulting in toxic waste [McCarthy 2010] as well as some geo-political tensions in securing their continued supply.

The anticipation of change; forecasting & future scenario planning

For engineers, learning about Sustainable Design would include minimising pollution or waste, and adapting methodologies to climate change. The probability of more frequent extreme and catastrophic events affects many engineering services; transport, water and power supplies. Exponential population growth will, in itself, require such adaptation and mitigation, regardless of Climate Change or Peak Oil.

Global Information Systems (GIS) may be used to analyse future land use; say, after sea level rise then overlaying criteria for renewable energy generation, storage and distribution, with transportation & communications infrastructure, centres of population and employment. The resultant matrix allows specific coastal protection to be designed, whereas other areas, formerly reclaimed land, be 'allowed' to return to the sea. Composite mapping allows strategic planners to visualise what measures will increase resilience for the region. Due to the unpredictability inherent in climate chaos, it only models the possible processes and, although accurate, not a precise prediction tool. [Roggema & van den Dobbelsteen 2008]

Environmentally, socially and economically, sustainable development

Prof Tim Jackson (2009), exploring a steady state economy finds, "Investment in jobs, assets and infrastructures emerges as a key component – not just of economic recovery – but of a new macroeconomics for sustainability….Targets for this include: public sector jobs in building and maintaining public assets; investments in renewable energy, public transport infrastructure, and public spaces; retrofitting the existing building stock with energy- and carbon-saving measures; investing in ecosystem maintenance and protection; and providing fiscal support and training for green businesses, clean technologies and resource efficiency."

An example of a socially, economically & environmentally sustainable community is The Village in Cloughjordan, Co Tipperary: The project's members (and owners) agreed an 'Ecological Charter' [Urbani 2003] to reduce ecological footprint of the community compared to its benchmark [Maria-Mason 2006] using regionally-appropriate, authentic, innovative solutions.

The Passivhaus brand has, perhaps, been accepted throughout Europe due to its single-number criteria and apparently simple, technical fix: However, it is far from affordable or the universal solution it has been perceived to be. Quoting Frederica Miller, our colleague in Gaia International, "The construction of passive houses everywhere is currently being promoted as a panacea to meet the climate challenge, and new regulations implicitly makes passive houses the norm for new construction in Norway. But…the average built dwelling area per person has increased in Norway from 29sq.m. in 1967 to 51sq.m. in 2000. And more holiday homes are being built. This means the energy saving is used up by the area increase, making area reduction our most important environmental parameter, also because it reduces consumption in all parts of the building life cycle. Passive house construction … is based on an airtight external envelope, high insulation values and mechanical ventilation... Also, super-tight constructions are technically demanding, have a questionable life span, being vulnerable to building faults and deterioration of the materials like taped joints and plastic sheeting…Permeable envelopes with high insulation values, low-emission materials, natural ventilation and flexible heating systems can achieve comparable results…To encourage a more holistic approach, environmental effect should be measured in CO_2 equivalents, rather than in kWh/sq.m. – a measure that would ensure that really passive houses could reduce the total climate effect of the building industry."

Multidisciplinary integrated design teamwork including Post Occupancy Evaluation

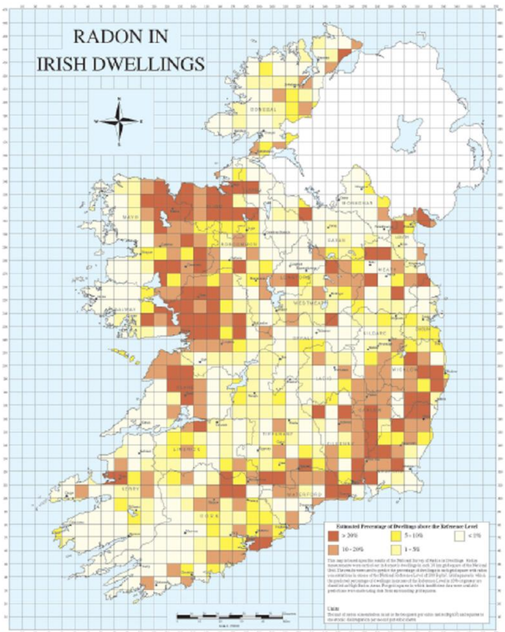
Ecological engineering works with natural systems to improve both resilience and biodiversity. One principle is to balance the traditional analytical approach with an holistic overview, using natural systems or working with them [van Bohemen 2010]. Engineers' understanding of the dynamics of a system, should include its interaction with the ecological context by collaborating with other professions and specialists; multi-disciplinary teams are essential for integrated design. For instance, Navan Credit Union's Architects worked closely with Civil, Structural and M&E Engineers to achieve the LAMA most eco-friendly building award 2010. Through monitoring in use, the clients are able to achieve their energy efficiency targets [Baird 2010]. Minimisation of the built environment's impact has wider engineering aspects, including transport, provision of drinking water & wastewater treatment (both very high energy consumption). The US City of Portland's Landscape Architect has designated water quality as the design driver for road and drainage engineering, including to, "Remove unnecessary pavement and excavate areas to allow stormwater runoff to enter and plant vegetation: 'Rain Gardens'" (Liptan n.d). Wildlife corridors of this kind reconnect fragmented habitats at different scales for specific species based on local and regional characteristics, including microclimate and materials. For instance, Living roofs offer another means to address the effects of hotter/ drier summers, wetter/ warmer winters, and (at any time) extreme weather like flooding caused by Summertime cloudbusts already being experienced in central London [Gedge 2010].

Communication, education and training; Continuing Professional Development

Experience of practice in Ireland, would seem to show that there is a need for specific education/ training for Government Agency/ Local Authority planning officers and engineers, so that the principles of sustainability are understood, agreements can be reached and then enforced if necessary. There is currently an absence of quality control through inspection of energy-efficiency initiatives at the installation stage, monitoring or enforcement on completion: While financial incentives are funded by public money, it seems bad practice not to resource inspection either, through these public departments or, independent professional consultants. This is particularly relevant to energy retrofit as now being promoted but without coordination, hence the danger of building defects affecting the occupants' health.

Quality of indoor environmental and life

Ireland has the second highest death rate from respiratory diseases of 38 European countries, exceeding those from coronary artery disease, at one in five deaths, twice the EU average. Asthma is the most common chronic childhood disease, more and more so irrespective of social class, and among the highest prevalence in the world. Lung Cancer is the third most common type of cancer in Ireland, varying by region within Ireland. Survival rates are considerably lower than the other common major cancers [Brennan McCormack O'Connor 2008]. Approx 1/8th of all lung cancer deaths are of non-smokers and attributed by the Radiological Protection Institute of Ireland (RPII) to Radon gas: For people who smoke, or have smoked, the risk of lung cancer due to Radon is 25 times greater. Ireland ranks sixth in the world for the highest average levels of Radon gas. The RPII estimates that 91,000 homes in Ireland have levels over the 'safe' reference level. A high Radon area is where 10% of homes are predicted to be over this level. [RPII 2008] It is associated with granite geology; as evident in Counties Wicklow, Louth, Waterford, Galway and Mayo, for instance, and is mapped by the RPII.



RPII map of Radon risk for The Republic of Ireland

60 per cent of those surveyed by the ESRI in 2001 had never smoked, 70 per cent being non-smokers.

However, young Irish adults smoke more than the European average, particularly among the skilled working class. [Brennan McCormack O'Connor 2008]

Since 2004, when smoking has been banned in public and workplaces in Ireland, this activity will have become concentrated within private homes.

271 respiratory deaths per year in Ireland have been attributed to poor housing conditions alone [Clinch Healy 1999].

Airtightness or permeability standards are required for new buildings to eliminate incidental air infiltration and improve energy efficiency: So, enhanced background ventilation adequate for the building's occupants now needs to be designed. This may be achieved by mechanical ventilation with Heat Recovery (MVHR), MV with Demand Control, passive stack or other (possibly hybrid) natural ventilation strategy: Natural ventilation emits 40% less Carbon Dioxide than MV, in electrical consumption over a 20 year life cycle. [Danish Teknoligisk Institut 2007]. Poor indoor air quality (IAQ) and high ambient noise levels are both factors implicated in Sick Building Syndrome [Clancy 2011]. Symptoms such as fatigue, headache, irritation/ dryness of eyes or ears, reduced concentration and productivity have been shown to arise more in mechanically ventilated (MV) than in naturally ventilated spaces [Meyer et al 2005]. In 2008, the same researchers showed high levels of mould in dust a greater problem in MV rather than naturally ventilated rooms in following ratios of %: Dizziness 21:12; Concentration problems 32:13; Fatigue 32:22; Headache 26:12; Throat irritation 21:3: Nasal congestion 37:25; Nasal irritation 12:5; Eye irritation 14:8. Using window systems, finely controlled, gives the building user optimum control of temperature and CO_2, noise, draughts and security.

Evaluation of a case study of a recently completed family home and workplace situated close to an airport, beside high tension power lines, a motorway and a busy road:



This farm has become absorbed into the urban fringe; between the approach to Dublin Airport, a new motorway to the East, an overpass of that to the North and further heavy traffic to the West of the original house. Our brief was for a new eco-friendly dwelling for a member of the family to establish permaculture on their remaining land. This earth-covered, atrium dwelling with controlled ventilation addresses the problematic visual prospect/ aspect, noise, vibration, dust, air-borne pollution and other particulate toxins ie diesel emissions. High tension electrical supply lines required a min separation of 50 metres(m) from the new dwelling. The design is passive solar, managing ventilation to conserve energy. The core of the plan is a daylit atrium, with glazed rooflight ventilator overhead; circulation without corridors, separated from the bedroom area. The roof planting will improve biodiversity, oxygenation, reduce air pollution, fix carbon dioxide (CO_2), particulates, reduce surfaces water run-off and, by its weight, provides some acoustic insulation within the proposed house. A deep eaves overhang of the roof and landscaped earth berms are useful in deflecting noise. The Atrium glass was specified to reduce resonance. However, changes by the builder during construction (for practicality and cost reasons), which had reduced the acoustic insulation include substituting an Intensive roof finish for a lighter Extensive type and fitting rooflights without the trickle-ventilators specified.

Noise reduction inside a timber building

Typically massive materials, often concrete, are used to reduce sound transmission through walls and floors. Such heavyweight construction types require stronger foundations (so more concrete, water, steel reinforcement, all to be transported to site). The manufacture of Portland cement for concrete is a highly carbon intensive process. This may be moderated somewhat by replacing it by ground granulated blast furnace slag (GGBS) cement, as in the ground-bearing floor slab and foundations of the case study above (thus saving over 56kg of CO_2/m^2, plus other noxious polluting gases). Concrete construction also takes longer than timber. Other means to reduce sound transfer are the avoidance of solid construction elements, using cavities with sound insulating materials. The case study used a layered wall/ roof build up to reduce sound transfer.

POST OCCUPANCY EVALUATION

A. INDOOR AIR QUALITY TESTING

"Thermal, physical, gaseous and chemical parameter measurements were taken with windows closed, trickle venting and, then, opened: Temperature, Relative Humidity, Carbon Monoxide, Sulphur Dioxide, Ozone were all within best practice limits. Total volatile organic compound levels (VOCs) were above best practice limits in the Kitchen when the windows were shut but were within best practice limits when the trickle vents were open. While levels for CO_2 and total VOC levels were above best practice limits in some instances with the trickle vents opened, it must be noted that the levels were lower than the scenario of when the trickle vents were closed. Significantly, the measurements with the trickle vents open were taken 20 minutes after the trickle vent closed scenario and so it must be assumed that the levels would continue to drop the longer the trickle vents remained open. Possible general sources of VOC emissions can include building materials, paints, furnishing and electronic equipment and cleaning products."

Conclusions of initial indoor air quality monitoring:

1. "Adequate ventilation is necessary in order to remove contaminants from indoor air. So, the trickle vents should be kept open while the house is occupied. Ensuring effective general ventilation should reduce total VOC, CO_2 and total suspended particulate levels.

2. To keep indoor sources of VOC to a minimum, possible general sources of VOC emissions should also be investigated: Commonly-found household products can contribute to high TVOC levels. Selecting cleaning products labelled 'non-toxic' or use baking soda, washing soda crystals, white vinegar and pure lemon juice, all of which are VOC free and can work well for the majority of cleaning tasks. Also when selecting paints consider low-VOC or zero-VOC paint; durable, cost-effective and less harmful to human and environmental health.

3. As the levels of nitrogen dioxide are slightly above international best practice limits, the gas boiler and wood stove within the house to be properly used and maintained, ongoing.

4. Effective general cleaning of the house should be maintained with frequent surface cleaning of all surfaces and thorough vacuuming, paying particular attention to carpeted areas."

B. ACOUSTIC TESTING

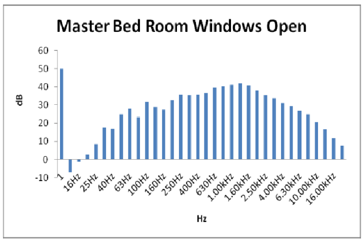
The specification included sound reduction targets to address the external environment characterised by high noise levels:

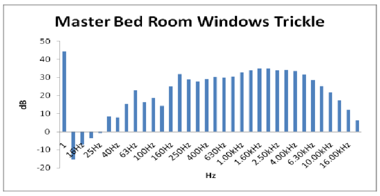
- Aircraft, overhead close to take -off and landing, peaking 70-74 decibels(dB(A))
- vehicular traffic on adjacent roads, maximising between 58 dB(A) and 62 dB(A)

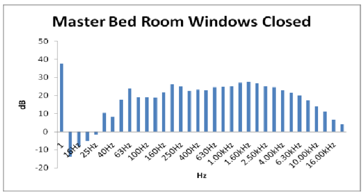
The measurements were carried out in fully enclosed habitable rooms (such as Atrium, Living Room and Bedrooms), with windows closed, trickle venting and fully open. The time-averaged level or the equivalent continuous sound level (commonly referred to as LEQ), rather than sound exposure level in decibels, was used for noise measurement. The attenuation achieved by the building fabric, when windows closed was of the order of 22dB(A) and for trickle venting 20dB(A) based on the range of reported measurements.

While it appears that for aircraft noise these two attenuation figures become 32dB(A) and 18dB(A), the aircraft noise did vary widely in both noise levels and type. Measurements inside and outside would need to be simultaneous and synchronised for full analysis. The earth berms (embankment) surrounding the house seemed to contribute to abating noise levels at the house itself by approximately 2dB. Comparing graphed results, to visually assess the performance of the building fabric either against a single dB(A) performance specification target or intuitively: - Decibels use a logarithmic scale: In the case of road traffic noise, and all other things being equal, a doubling of the vehicle flow volume would be expected to give a 3dB increase in noise level (LEQ). This might not be very noticeable to the human ear. Acoustic features such a tonality and impulsivity are important in noise perception. Noise nuisance/ annoyance is based on increase in noise level but, equally important, is the type of noise itself. In summary, effective noise assessments have to be based on pragmatic considerations of multiple factors.

Example of 1/3 Octative Band Analysis inside the house







Transition; from theory into practice

The case study shows it is possible to balance several variables in designing human habitat even in a challenging external environment: Daylighting, acoustics, thermal-comfort are among the many which interplay to optimize the quality of life for occupants or building users, who remain the ultimate arbiters of success.

To quote Paul Hawken, “The Stone Age did not end because we humans ran out of stones. It also follows that the Oil Age will not end because we ran out of oil”. New ideas need to be resourced to allow principles and skills to evolve into practical applications.

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