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NOISE CONTROL ON BUILDINGS

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***Abstract*- The energy consumption in the building sector can reach up to 40% of the total energy demand of an industrial country. For this reason, green building strategies can be extremely effective as far as fossil fuels savings and greenhouse gases reduction. Sustainable materials can play an important role, since less energy is generally required for their production than the one needed for conventional materials. Comfort, including personal control Research work in the 1980s into what was then called sick building syndrome (now building-related ill health) confirmed to a new generation of researchers what was already well known to an older one - that people's perception of control over their environment affects their comfort and satisfaction. Work on thermal comfort, notably that of Humphreys and McIntyre in the 1970s, had shown that the range of temperatures that building occupants reported as "comfortable" was wider in field studies than in controlled conditions in the laboratory. People seemed to be more tolerant of conditions the more control opportunities - switches, blinds and opening windows, for instance - were available to them. This is a vital finding to take from pioneering thermal comfort research and is the basis for what later came to be called 'adaptive comfort theory'. People are more forgiving of discomfort if they have some effective means of control over alleviating it. However, many modern buildings seem to have just the opposite effect. They take control away from the human occupants and try to place control in automatic systems which then govern the overall indoor environment conditions, and deny occupants means of intervention. In the last years many new materials for noise control have been studied and developed as alternatives to the traditional ones (glass or rock wool); these materials are either natural (cotton, cellulose, hemp, wool, clay, etc) or made from recycled materials (rubber, plastic, carpet, cork, etc.). Their importance is proven by the fact that in Europe many Municipalities have introduced into Building Regulations specific recommendations to improve their use in new constructions, allowing a reduction of construction taxes or other benefits. The paper presents an updated survey of the characteristics and the acoustical properties of sustainable materials for noise control and in particular sound absorption coefficient, airborne and impact sound insulation data, as well as an analysis of the procedures to asses the sustainability of these materials (LCA, Ecoinvent, Ecoprofiles).**

I. INTRODUCTION

According to the definition of sustainability of the Brundtland Report , "*Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs"*. A product can be therefore considered sustainable if its production enables the resources from which it was made to continue to be available for future generations and has the lowest possible impact on human health and on the environment. A sustainable product is generally made from natural or recycled materials and its production requires a small amount of energy, makes a limited use of non-renewable resources and has a low environmental impact. Many currently used acoustic materials can not be considered sustainable, at least as far as energy consumption and greenhouse gases emissions; moreover, some of them can be harmful for human health. Mineral wools are widely used for thermal and sound insulation, because of their good performance and low cost, but their fibres, when inhaled, can lay down in the lung alveoli, and can cause skin irritation. Hence such materials must be adequately overlaid if directly exposed to the air. Moreover they can pulverize and are not resistant to water, oil and chemical agents and this can make their application not suitable for absorbing noise barriers. In the last years a great attention has been focused on "green" materials, especially in the building sector. Many research centres have developed new sustainable materials, in many cases with interesting acoustical properties. Also the public sector started to consider these materials; in Italy, for instance, many Municipalities have introduced into Building Regulations specific recommendations to improve the use of ecological materials in new constructions, allowing a reduction of construction

taxes. These Regulations also contain a list of materials that should be avoided (e.g. mineral fibres). An increasing attention has been turned to natural fibres as alternatives to synthetic ones, in order to combine high acoustic and thermal performance with a low impact on the environment and human health. Natural fibres have very low toxicity and their production processes can contribute to protect the environment. Recycled materials, such as recycled plastic fibres and recycled rubber mats, can even be regarded as a sustainable alternative, as they contribute to lower waste production and use of raw materials.
It is however very important to assess the "sustainability" of a natural or recycled material, and to verify the total energy use in its production process.

II. SUSTAINABILITY

ASSESSMENT OF GREEN PRODUCTS

The correct approach to assess the real sustainability of a product is the so-called Life Cycle Assessment (LCA), a procedure which analyses the potential impacts deriving from the entire life history of a product (from cradle to grave). Material extraction, production, transport, construction, operating and management, de-construction and disposal, recycling and reusehave therefore to be taken into account.
For designers and decision-makers, LCA analysis results are available as "ecoprofiles"; among these the most known are Ecoinvent, BRE Eco-profiles and Eco-indicator. Ecoinvent is a Swiss LCA database which takes into account various impact assessment results: Cumulated Energy Demand, Non-Renewable Energy fraction, Global Warming Potential and Acidification Power. A comparison based on the Ecoinvent database between the environmental impacts of some traditional and natural sound insulation materials from cradle to grave.

BRE Eco-Profiles (UK) assign a score (in "eco-points") to a product or a process by weighting normalized impacts on climate change, acid deposition, eutrophication, eco-toxicity, ozone depletion, mineral extraction, fossil fuel extraction, human toxicity, waste disposal, transport pollution. The results for some insulation products, from cradle to their on site installation, are: EPS (15 kg/m3) 0.028 pt., rock-wool (45 kg/m3) 0.020 pt., rock-wool (33 kg/m3) 0.016 pt., recycled newspaper cellulose 0.002 points.
Eco-indicator '99 (NL) supplies a final score by weighting various potential damages: to human health, expressed as number of life years lost and lived with disability; to ecosystem quality, expressed as the loss of species over a certain area in a certain time; to resources, expressed as the surplus energy needed for future extractions of minerals and fossil fuels.
Two well-known labels concerning green products are Natureplus and Ecolabel. Natureplus is a label for high-quality building products, construction materials, and home furnishings. Products that carry this label have been produced in an environmentally friendly way, do not represent a health risk, and will perform their allotted functions trouble-free. The Natureplus seal of quality is only awarded to products that comprise a proportion of at least 85 % renewable and/or mineral raw materials, according to the principle of sustainability; the product must also carry a full declaration of all its input materials.
Finally, ECOLABEL, whose symbol is a "Flower", has become a European-wide symbol for products, providing simple and accurate guidance to consumers. All products bearing the "Flower" have been checked by independent bodies for complying with strict ecological and performance criteria; there are currently twenty-three different product groups, and already more than 250 licences have been awarded for several hundred products, though currently no sound or thermal insulating material has been awarded with ECOLABEL.

Many studies have been carried out to estimate the use of primary energy for the extraction, transport, production and packing of different insulating materials. Not always a "green" material requires less energy in its life cycle than a traditional one: flax, for example, requires approximately 38 MJ/kg while rock wool 35 MJ/kg. However, synthetic plastic fibres (ExpandedPolystyrene, Polyuretan) always show the greatest impacts, especially as far as fossil fuel consumption, with more than 100 MJ/kg.

III. GREEN AND SUSTAINABLE MATERIALS FOR NOISE CONTROL

As previously said, many new materials for noise control as alternatives to the traditional ones have been proposed in recent years. These materials can be divided into two main categories:

- natural materials;
- recycled materials.

Recent Literature reports a wide variety of materials, from the most common to the less conventional solutions; some LCA studies are also available, showing that natural fibres are cheaper, lighter and environmentally superior to glass fibres composites.

Sustainable materials are in many cases comparable to traditional ones as far as thermal and acoustic performance. Though for many products physical properties have not been deeply analyzed and are not yet certified, they have already reached a certain technical and commercial maturity; in Italy, for example, many sustainable materials are listed in official prices lists for public tenders.

There is a great variety of natural fibres proposed for thermal and acoustical applications; most of them are commercially available such as coconut, kenaf, hemp, mineralized wood. As for natural materials, the less treated they are, the higher they perform in energy saving; native materials have to be preferred to reduce transport energy. It is well known that natural fibres have negative impact as far as climate change due to CO_2 absorption during the growth of the plant. Nevertheless other performance have to be considered: vegetal fibres are more subject to fungal and parasites attack and are less resistant to fire than mineral fibres. The non-toxicity of the chemical products used for cultivation must be taken into account too. Many recycled materials, such as waste rubber, metal shavings, plastic, textile agglomerates can be used to prepare acoustic materials. It can be useful to mix various recycled materials of different granulometries to obtain the desired performance; in these cases a binder or glue have to be added in a proper proportion.

IV. SOUND ABSORPTION

Natural fibres are generally good absorbers. The extremely wide variety of natural fibres allows to find a suitable material for almost every absorbing need. Many natural materials as kenaf, flax, sisal, hemp, cork, sheep wool, bamboo or coconut fibres show good absorbing performance and can therefore be used as sound absorbers in room acoustics and noise barriers. Table 2 reports the coefficients of absorption as well as the values of Noise Reduction Coefficient (NRC), for some conventional and sustainable materials. The NRC rating is an average of how absorptive is a material at four frequencies (250, 500, 1000 and 2000 Hz) and is here used for a comparison of the various materials.

In particular, bamboo and sisal fibres show an absorption coefficient at 1000 Hz and more very close to the one of glass fibres (more than 0,90). Kenaf panels show an absorption coefficient higher than 0.80 above 500 Hz . Coconut fibres panels have an absorption peak of about 0,80 at 1000 Hz [16], for flax panels the peak reaches 0,90 at 800 Hz while for sheep wool panels the peak is 0,90 at 3000 Hz. Vegetable wastes such as grass, pine or gorse leaves, corn cobs, used in sandwich panels, have an absorption coefficient similar to polyurethane foam or mineral wool. Reed matting has been recently proposed for absorption applications, with excellent performance at medium-high frequencies [18]. Not all natural materials, of course, have satisfying absorption performance: wood and cork, for example, due to their structure, show poor absorption properties.

Among alternative materials from a mineral origin, expanded clay, expanded perlite, expanded vermiculite, pumice can be quoted. Expanded clay shows good sound absorption performance in a wide frequency range (higher than 0,80 in the range 500-5000 Hz), though it requires quite a high amount of energy for its production.

The recycled material mostly used to correct the sound environment in enclosed spaces is cellulose obtained from used newspapers, added with flame retardants and biocides. Wet cellulose fibres are generally sprayed directly on walls or ceilings and their sound absorption properties are even better than those of mineral wool: absorption coefficient is over 0,70 in a significant frequency range (500-1000 Hz). Other promising materials are metal shavings and textile agglomerates. Rubber crumbs are good acoustic materials with a broadband absorption spectrum and are particularly suitable for traffic noise barriers, also due to their durability.

Cold extrusion processes have been recently proposed to obtain porous materials from recycled carpet waste; the results show absorption coefficients very close to the ones of a standard commercial glass wool . Also Polyester fibrous materials, made from recycled plastic bottles (PET), have been recently investigated.

Environmental control operates at the interface between a building's physical and technical systems and its human occupants, or, less visibly, automatically and often under the supervision of computer-controlled building management systems. Perhaps seduced by the promise of technology rather than its delivered performance, designers assign more functions to automatic control than are usually warranted and, knowingly or not, make the interfaces obscure. They then often do not seem to make clear to the client the management implications of the technology, and whether these are acceptable to them. Simpler and more robust systems are required, with greater opportunities for users to intervene - especially for opportunities to override existing settings, better feedback on what is supposed to be happening and whether or not the system is actually working. This point is picked up in more detail later under design intent. Building design is split into architectural and building services tasks, often with surprisingly little integration between them. Poor attention to detail in building controls is a common symptom of an incomplete design and specification process with gaps between areas of professional responsibility. As well as lack of recognition of the problems here, there is also an absence of tools for specification and briefing, and absence of suitable standard componentry and systems. Manufacturers find it difficult to invest in suitable new or modified products to meet such requirements, owing to a diffuse market with no well-articulated demand. Those who have tried have found success elusive. For example, the promising environmentally advanced Colt window system was taken off the market as a complete package.

V. AIRBORNE SOUND INSULATION

Several natural materials are commonly used as thermal and acoustical insulation in multilayered walls: among these flax, coconut, cotton, sheep wool and kenaf mats are the most present on the market. Their sound and thermal insulation performance are in many cases as good as those of traditional materials (Tables 3 and 4): many studies have demonstrated that the sound insulation of double-leaf walls with low density animal wool (sheep wool) or heavy vegetal wool (latex-coco) is equal or better than the one of walls with mineral wool or polystyrene of the same thickness (about 69 dB in heavy double walls). Loose-fill cellulose fibres and batts made of cellulose or flax fibres in timber frame walls showed the same airborne insulation of glass wool. Also mineralized wood panels with magnesite or Portland concrete are used for sound insulation applications, as well as cork panels, with satisfying properties. Dry loose cellulose fibres are already commonly used for thermal and acoustical insulation by filling the cavities in walls and roofs, especially in the United States. When it is obtained fromrecycled newspapers, it appears to match energy and raw materials savings and health issues. As for the acoustical properties, they are as good as traditional material ones .

VI. IMPACT SOUND INSULATION

This is probably the most common use for many natural materials (cork, coconut fibres, wood, wool) and also for many recycled materials. Resilient layers made of natural materials can be very good for floating floors to increase impact sound insulation: when the panels are accurately designed and installed, their performances are as good as other traditional materials.

Recycled rubber layers made of waste tyres granules are an interesting alternative to traditional materials, especially now that tyres are banned from landfills. Because of the large amount of used tyres available worldwide, new applications have to be found and their use as impact sound insulating layers is very promising . Also recycled carpet wastes are interesting materials as far as impact sound insulation, especially if made of a mixture of fibrous and granular waste. The acoustic properties of these

underlay materials compare favourably with those of commercially available ones.
Rw (dB) of heavy double walls (each 7 cm of concrete) with different materials used as insulation in the gap

Another proposed material is EVA (Ethylene-vinyl Acetate Copolymers) residues employed in the manufacturing of shoes soles; thanks to its elastic properties, the performance is comparable to traditional materials, with a reduced cost [29]. Finally, wood tailings and cork shavings have been recently investigated, as well as natural wool; the main peculiarity of these materials is the aptitude to keep acoustical performance nearly constant in time [30].

VII. CONCLUSIONS

The interest in the acoustic performance of green and sustainable materials seems to beincreasing in technical and scientific Literature. Many related researches have been recently published in International Journals and in the Proceedings of International Conferences; a Structured Session on "Sustainable Materials for Noise Control, has been organized at Euronoise 2006 in Tampere, Finland.
As a matter of fact, these materials show many advantages. They generally have a lower environmental impact then conventional ones, though a proper analysis of their sustainability, through Life Cycle Assessment procedures, has to be carried out. Also the total energy demand is generally lower, but it has to be accurately evaluated, since not always an "ecological" material requires less energy in its life cycle than a traditional one. Furthermore, many of these materials are currently available on the market at competitive prices.
Acoustical sustainable materials, either natural or made from recycled materials, are quite often a valid alternative to traditional synthetic materials. Airborne sound insulation of natural materials such as flax or recycled cellulose fibres is similar to the one of rock or glass wool. Many natural materials (bamboo, kenaf, sisal, coco fibres) show good sound absorbing performance; cork or recycled rubber or polymers layers can be very effective for impact sound insulation. These materials also show good thermal insulation properties, are often light and they are not harmful for human health. There is however a need to complete their characterization, both from an experimental and a theoretical point of view, and especially to propose a standard and unique procedure to evaluate their actual sustainability.

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