Ecospace®: healthy, comfortable, safe, smart and sustainable spaces for the people of Europe

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ABSTRACT

The human well-being is largely affected by health, comfort and safety during living, working and transportation in enclosed environments ('spaces') in which a person performs these activities, such as a building, car, train, aeroplane or even a satellite. To address the societal needs of improving health, comfort and safety of the European population, simultaneously reducing energy demands, as laid down basically in the WHO targets and the Kyoto protocol, respectively, the integration of different sectors, disciplines, stakeholders and organizations for realization on a European scale is a must.

Ecospace® is a first step towards the realization of healthy, comfortable, safe, smart and sustainable spaces for the people of Europe. Ecospace® is an *innovation platform* for a group of entities from different markets and sectors (construction, aeroplane, space, train and auto industry). And Ecospace® is a *concept* for an enclosed space, which is experienced by the occupants or visitors as being healthy, comfortable and safe, and that is constructed smart and sustainable. Ecospace® will be submitted as an integrated project under the European sixth Framework Programme.

INDEX TERMS

Healthy and comfortable spaces; Sustainable and smart spaces

INTRODUCTION

The well-being of the people of Europe is largely affected by health, comfort and safety during the main activities living, working and transportation in an enclosed space, where they spend more than 90% of their time (Jenkins, 1990). In more than 40% of these spaces, people suffer of health-, comfort- and safety-related complaints and illnesses (Dorgan Associates, 1993).

Percentage of time spend in a certain space (Jenkins, 1990)

Space	% of time spent
Living	62
Working	25
Transport	7
Outdoors	6

A more comfortable and healthier indoor environment will result in fewer people with complaints (Bluyssen *et al.*, 1995). Indoor environmental (IEQ) complaints are related to the sickness absence rates of office workers due to the Sick Building Syndrome (SBS) and the building-related illnesses (BRI) (Preller *et al.*, 1990). The percentage of people having asthma and allergies in domestic buildings is increasing (Sundell, 2000) leading to increased healthcare costs. Losses in work productivity and performance have a direct, financial impact to businesses.

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Improving health, comfort and safety of the European population in those spaces has consequently a huge potential for economic and societal benefits obtained by increased productivity, reduced sick leave and medical costs and reduction of number of casualties in accidents, but also by the prevention of liabilities.

Only 20% of the building stock can be qualified as healthy implying that in 80% a potential benefit of 1–6% improved productivity is present (Dorgan Associates, 1993). For the US (270 million inhabitants), Fisk (2000) estimated annual savings and productivity gains from reduced allergies and asthma, reduced SBS symptoms and direct improvements in worker performance that are related to comfort. These figures are transferred to Europe-15 (375 million inhabitants) in the table below. The potential savings are enormous.

Estimated savings for Europe-15 in billion Euro/year

Buildings	Savings
Reduced allergies and asthma (based on a reduction of 8–25% of medical costs)[a]	3–6
Reduced sick building syndrome symptoms (based on 20–50% reduction and 2% productivity improvement)	15–45
Increased productivity by comfort related improvements(based on 0.5–5% increase in worker performance)	30–240

Healthy/unhealthy buildings (Dorgan Associates, 1993)

Category	% of total number of buildings[a]	Potential productivity improvement (%)
Healthy	20	0
Generally healthy	40	1.5
Unhealthy, source unknown	20	3.5
Unhealthy, source known	10	3.5
SBS/BRI	10	6

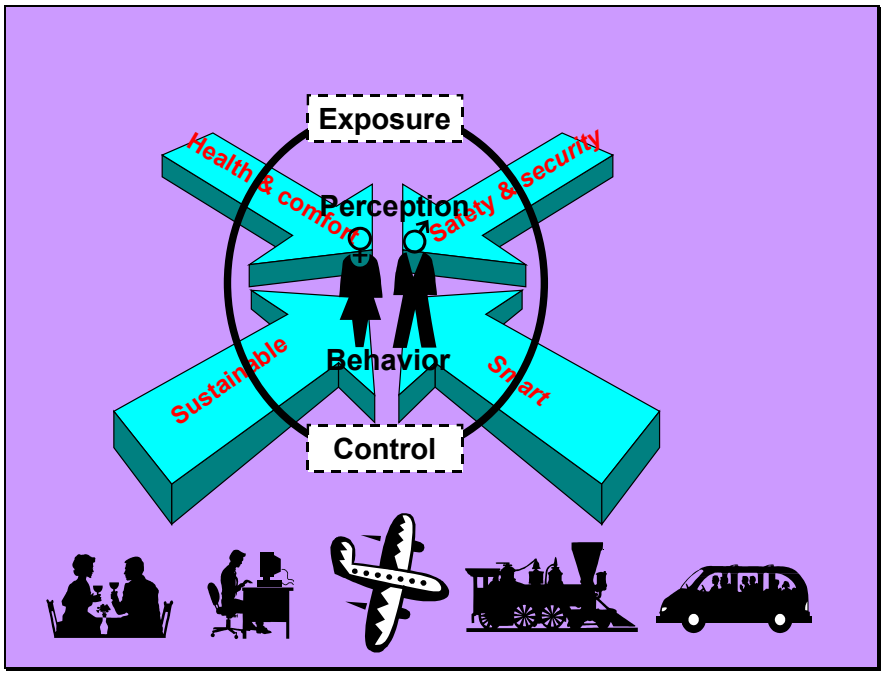
[a]Including office, educational, mercantile and service, lodging and food service buildings.

However, the ambition of healthy, comfortable and safe indoor spaces on the one hand and the target of smart and sustainable spaces on the other appear to be conflicting and contra productive, which may have serious implications for innovations in the industry. To address the societal needs of improving health, comfort and safety of the European population, simultaneously reducing energy demands, as laid down basically in the WHO targets and the Kyoto protocol, respectively, the integration of different sectors, disciplines, stakeholders and organizations for realization on a European scale is a must.

The health targets specified by the WHO Europe (WHO, 2000):

- "*By the year 2015, people in the Region should live in a safer physical environment, with exposure to contaminants hazardous to health at levels not exceeding internationally agreed standard." (European Health21 target 10) and*
- *"By the year 2015, people in the Region should have greater opportunities to live in healthy physical and social environments at home, at school, at the workplace and in the local community." (European Health31 target 13)*

Kyoto protocol target: "*to reduce the demand for energy by 18% by the year 2010, to contribute to meeting the EU's commitments to combat climate change and to improve the security of energy supply*"



The definition of 'Spaces' is conceptual and refers to enclosed environments such as: Living space (apartment buildings, private homes), Working space (office buildings, industrial working places), Recreation space (gyms, swimming pools,), Public space (hotels, stations, schools, theatres), Transport (land: cars, busses, trucks, trains, trams; and air: aeroplanes, satellites).

MAJOR TRENDS

Besides these two major targets, the following trends regarding the issues 'smart and sustainable', 'health, comfort and safety', and 'industrial competitiveness' should be considered in such an integrated/interdisciplinary approach.

Smart and Sustainable

Reduction of energy use: Products and services that reduce energy use in buildings and transport (respectively circa 40 and 32% of the total primary energy used in Europe (EU, 2000)).

Policies towards enhanced sustainability: Extending the service life of materials and constructions is one of the most effective ways to enhance sustainability of the overall economy. Sustainability, including sustainable construction and sustainability of the built environment is in the very centre of the social, economic, environmental and political attention of all member states.

Towards eco-friendlier products: Products and services with a low emission of harmful substances and a long life cycle. This addresses the growing ecological demands and environmental legislation (e.g. tightening up of the Biocides Directive (EU, 1998)).

The industrial shift from a product towards performance-based approach: Integrating a low energy use and a high sustainability, leading to high CO_2 reductions.

The major shift towards re-evaluating and upgrading the existing building stock: Has great potential to save energy as well as to improve the indoor environmental quality of existing building stock. This applies especially to candidate countries, where energy consumption is projected to increase even faster than for the member states and their ;related indoor environmental complaints are foreseen to have large consequences for the near future.

Energy use and CO_2 emissions in Europe

Year→	2000		Projected 2010[b]
	Energy use (Mtoe)[a]	CO_2 emission (10^{10} kg)[a]	Energy use (Mtoe)
Europe-30	1250	250	1750
Buildings	500	100	700
Extra caused by inadequate design[c]	up to 20%	20	140
Transport	400	80	560
Europe-15[b]	1000	200	1340

[a]Millions of oil equivalent (1 Mtoe equals 4×10^7 GJ); assuming 1 GJ generates 50 kg CO_2.
[b]Current EU accounts for almost 80% of the energy consumption in Europe-30. The candidate countries are projected to become more similar to the energy structure of the EU over the next decades; If no action is taken the energy demand for the current EU member states may grow with 2–4% per year and for the applicant countries 3–6% up to 2010 (EU, 2000).
[c]Besides development of new and renewable energies, appropriate design of buildings is a potential solution to cut energy demand (Adan, 2000).

Health, Comfort and Safety

Health, comfort and safety of occupants is far from ideal: There is a need for products and services that contribute to the general well-being of people, to increase of productivity, reduction of absence due to illness and reduction of the percentage of people having asthma and allergies, and to decrease of the number of casualties in the transport sector. The increasing ageing population causes a corresponding increase in high-risk groups from the point of view of respiratory health complaints. It is estimated that the percentage of the Europe-15 population by age of 65 and more will grow from 15.5 in 2000 to 19.6% in 2020 (Doll and Haffner, 2001).

Consequences of microbial growth: Moisture problems are widespread, ranging from electronic components, wiring circuits, space stations and satellites, air conditioning systems to visual effects in the living environment. Though 'moisture problems' are not perceived as being a societal problem, they in fact are (Samson *et al.*, 1994). It is estimated that approximately 20% of the human population in Europe is allergic to mites and fungi (not related to the outdoor environment (Institute of Medicine, 2000; Jantunen *et al.*, 1999).

Feeling of safety: Besides physical safety and security, people's feeling of safety is an emerging topic for discussion. After 11 September 2001, safety at home, on the way and at work have become major issues.

Industrial Competitiveness

Transition from a product-based (supply) to a service-customer oriented (demand) approach: There is a need for consumer-tailored products and services, including flexibility of buildings, and different and more space requirements inspired by increasing individualization. This need driven by the fact that the average household size in Europe-15 has been decreasing from 2.9 in 1980 to 2.5 in 2000 (Doll and Haffner, 2001).

Transition towards knowledge-based society: A growing need for added value products and services will increase the attractiveness of industries in terms of better employment conditions.

Towards an increased complexity of the building process: There is a need for products and services supporting an integrated approach of the building and manufacturing process, e.g. through the integration of design, construction and management processes and the integration of the different professions. The different incentives of the stakeholders and the communication between them are crucial in this.

Commonly agreed and uniform European regulation: There is a need for consensus regulation. Currently, different national approaches make it practically impossible to comply with different regulations in the various member states.

INTEGRATED/INTERDISCIPLINARY APPROACH

To create healthy, comfortable, safe, smart and sustainable spaces, so-called Ecospaces®, several steps need to be taken:

1. *Performance and human perception:* The human requirements with respect to health, comfort and safety need to be clearly identified. A comprehensive and coherent knowledge basis for human health, comfort and safety in enclosed spaces under living, working and transportation conditions is therefore required.
2. *Interaction enclosure–space* (passive): The system and material requirements (enclosure of space) can then be identified and innovative techniques and systems can be applied to reach these requirements. An enhanced high performance enclosure that guarantees a high basic level of health, comfort and safety in enclosed spaces can then be created.
3. *Interaction human–space* (active)*:* The demand from the occupants' point of view should be regulated with the supply side (possible enclosure-environmental configuration) with the use of sensors, interfaces and actuators. An adaptive space, allowing individual control of the environmental conditions in the personal space, should thus be created.
4. *A holistic approach of Ecospaces®:* And last but not least, all of the above should be integrated in a holistic design (concept) of the 'space' considered. Healthy, comfortable and safe, smart and sustainable spaces can then be realized.

The first and the last step require both an integrated approach mainly focussed on and with people and communication processes, while the second and the third step are mostly individual innovative breakthroughs with respect to products, materials or production processes, depending on techniques and materials available.

PERFORMANCE AND HUMAN PERCEPTION

From the occupants' point-of-view, the ideal situation is an indoor environment that satisfies all occupants (i.e. they have no complaints) and does not unnecessarily increase the risk or severity of illness or injury. Both the satisfaction of people (comfort) and health status are influenced by numerous factors: general well-being, mental drive, job satisfaction, technical competence, career achievements, home/work interface, relationship with others, personal circumstances, organizational matters, etc. and last but not least, environmental factors**,** such as:

- Indoor air quality: comprising odour, indoor air pollution, fresh air supply, etc.;
- Thermal comfort: moisture, air velocity, temperature, etc.;
- Acoustical quality: noise from outside, indoors, vibrations, etc.;
- Visual or lighting quality: view, illuminance, luminance ratios, reflection, etc.;
- Aesthetic quality.

These environmental factors highly depend on the performance of the enclosure, as well as on the interaction between the human being and the enclosure. People are being exposed during more than 90% of their life to these factors in enclosed spaces. As the focus is on value-added technical solutions, the work only addresses these environmental factors as related to the hardware, with aesthetics serving as a second order issue. Human assessment of

the environment is basically expressed in human perception of the environmental factors, and the subsequent assessment of this.

Human Perception

The objective performance of the environment can be measured in terms of physical quantities (temperature, decibel, Lux, etc.). The human perception and assessment can be expressed by a person with so called subjective environmental performance indicators**,** such as control of environment or specific items (ventilation, noise, light, etc.), acceptability of environment or specific item (air quality, thermal comfort, colour, etc.) and complaints or symptoms related to the environment (irritating eyes, skin, headaches, etc.).

The relationship between objective measurement and human assessment is not known for all physical parameters. Mature models for separate subjective issues exist (e.g. thermal comfort (Fanger, 1972) and noise) but are not available for all. For example, no consensus model for air quality exists. The reasons have various grounds:

- *Sensory assessment:* The principles behind the sensory evaluation of smell are still under investigation.
- *Measurement of pollutants:* The indoor environment comprises of thousands of chemical compounds in low concentrations, of which current available equipment cannot measure all, simultaneously. The nose can detect very low concentrations (ptt range) and interpret all at the same time (perceived air quality).
- *Measurement unit:* As long as no unambiguous unit as an indicator for perceived air quality exists, dose–response relations are difficult. TVOC (total volatile organic compounds) has been used for some time, but the drawback is twofold as it does not represent all pollutants in the air and ignores the effect of single compounds (Seifert, 2000).

For light, recent findings showing that the amount of light falling into the eye is important to non-visual aspects (such as alertness and performance), redirected lighting modelling. Lighting models are basically grounded on the illuminance of the environment (Light & Health Research Foundation, 2002). The new information indicates that brightness of the surroundings is the key element.

Performance Assessment

The most currently used performance indicators that quantify the comfort, health and safety of people, the quantifiable performance indicators are:

- *Productivity:* quantitative and/or qualitative work output of people (product or service they deliver) (Clements-Croome, 2002).
- *Sick leave:* number of days sick, away from work place, per year.
- *Estimates of life expectation* (Carrothers *et al.*, 1999):
  - Value of statistical life (VSL): approach to value reductions in premature deaths attributed to short-term pollution episodes. VSL measures how much wealth people are willing to forego for small reductions in mortality risk.
  - QALY (Quality-Adjusted-Life-Year): the QALY approach deals with changes in expected survival, i.e. years of lost life, and its weighs the years lived by a measure of their health-based quality. It estimates the longevity and quality-of-life changes attributable to each health effects, converted into economic figures.
- *Number of deaths*.

Productivity, the highest potential gain of a healthy, comfortable, safe and secure space, has received a lot of attention in the past 5 years. Productivity can be measured:

- *Objectively:* for example, by measuring the speed of working and the accuracy of outputs in highly controlled experiments with well-focussed tests (e.g. productivity effects as related to thermal comfort (Wyon, 1993), air quality (Wargocki *et al.*, 2000)).
- *Subjectively:* by using self-estimated scales and questionnaires to assess the individual opinions of people concerning their work and environment (Raw, 1990)
- *Combined measures:* using, for example, some physiological measures such as brain rhythms to see whether variations in the patterns of the brain responses correlate with the responses assessed by questionnaires (e.g. alertness and light, Light & Health Research Foundation, 2002).

A HOLISTIC APPROACH OF ECOSPACE®

Ecospace®

Various space-concepts with respect to targeted minimized environmental impact have been subjected to research and development in various user sectors, such as zero-emission buildings and zero-energy buildings and transport vehicles. As yet, no enclosed space has been prototyped consciously optimizing health, comfort, safety, smart and sustainable in a coherent way (Ecospace®), although in several sectors research has been clearly directed towards part of those issues, e.g. the healthy buildings concept, safe and comfortable aeroplanes (EU projects HOPE (Bluyssen, 2002) and Cabinair (2000), respectively) and the ultimate eco-building concept (including self-containing climate control for optimum health and comfort) developed for and by the space industry, addressing a multitude of new materials, technologies and production processes (the Space-House).

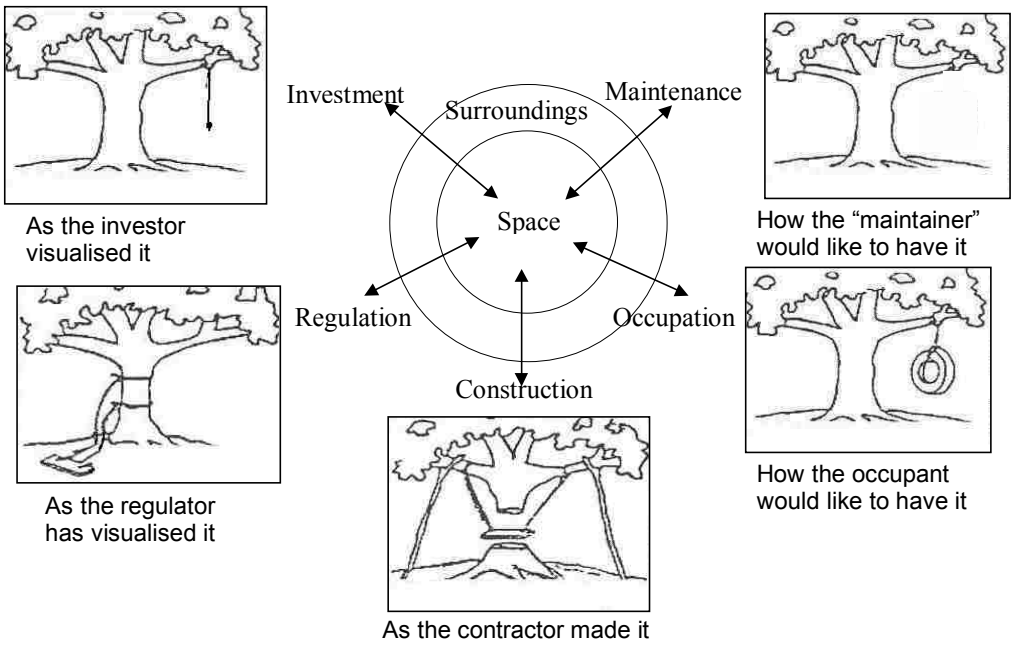
Communication

The road towards implementation and realization of a healthy, comfortable, safe, smart and sustainable space inherently requires tools to optimize:

- Communication i.e. interaction between supply and demand, and knowledge and/or technology transfer between sectors and stakeholders;
- Tuning of separate products and services, leading to new production technology, all in an integrated and holistic approach.

It is obvious that all stakeholders have their own demands or views. They all play different roles in the various stages of establishing a space. This complex process inherently includes many conflicts of interest. Eventually, the most dominant stakeholders determine the result, which may result in dissatisfied end-users. In negotiation between different stakeholders, user-oriented and long-term aspects are often underestimated. Individual needs become more and more important.

No operational communication tools for this complex process exist yet. The Internet offers potential capabilities for providing new communication services in this context. From recent experience in trial projects it is evident that using the Internet structure will improve communication to its maximum potential only in case adequate attention is given to control the complexity of the design process. Such a control of complexity may provide an underlying structure to the communication process making it more effective and efficient whilst reducing the risks that overall project goals are not achieved. Several useful concepts herein exist, such as the value-domain model (Rutten and Trum, 1998).



It is clear that there is a whole gamut of values and needs that will determine the desired functions of an Ecospace® and that there is not a direct corresponding one to one relationship between a specific function and the accomplishing of a particular value or vice versa. In the building industry, this approach can also be referred to as the performance-based building concept: 'thinking and working in terms of ends rather than means' (CIB, 1982; Foliente *et al.*, 1998). Currently running projects with respect to this approach are a Thematic Network Performance-based Building (PeBBu) (Loomans and Bluyssen, 2002), initiated by CIB, and a European project HOPE (Bluyssen, 2002). A different approach with regard to performance-based building has been developed by the Finnish Society of Indoor Air Quality and Climate (FiSIAQ). They have combined specific performance criteria in order to come up with a classification of the indoor climate (FiSIAQ, 2001).

Successfully creating and realizing a space that is healthy, comfortable and safe at the same time highly depends on integrating existing and new (added value) products and services. Optimizing their functionalities for various application in different user sectors, as well as integrating their functionalities in such a way that the result is more than the sum of the separate functionalities, basically being the holistic approach, should automatically induce tuning of products and services in design to production stages and will possibly lead to tuned production processes or new production technology. Basically, this refers to early communication between involved producing industries.

INTEGRATED PROJECT ECOSPACE®

To pave the way for solving/taking a step towards solution of the problems sketched before, an integrated project named 'Ecospace®' is submitted to the European Union. The duration of this project is estimated to be 5 years with a global budget of 50 million euro. The participants of 'Ecospace®' consist of partners from various (industrial) sectors (building, automotive, aerospace, suppliers and investors) and covering a variety of disciplines (engineers, designers, psychologists and medical doctors).

Objectives

The overall objectives of the integrated project 'Ecospace®' are:

- Within a multidisciplinary and design-production-use-services-end-of-life approach:
  - Industrial: To realize new industrial concepts of products and services for future healthy, comfortable, safe, smart and sustainable spaces (automotive, aerospace, offices, housing, etc.) and inter-sector system integration of so far stand-alone technologies.
  - Scientific: To realize the scientific and technological bases to create smart & sustainable future spaces, in which the people of Europe live, work or move in, under healthy, comfortable and safe and secure conditions.
- To make the transition from a product-based (supply) to a service-customer oriented (demand) approach.

The deliverables will consist of knowledge, products and services that contribute to the realization of 'Future spaces' which are healthy and comfortable, safe and secure, sustainable and smart.

Projects

The actual work programme comprises two types of projects: cluster and activity projects.

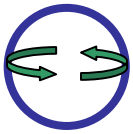
Activity projects: Basically each project will comprise of multiple activities or stages: research (development of knowledge to create products and services), dissemination (to ensure that new knowledge reaches the targeted recipient) and exploitation of products and services. Therefore, as a 'horizontal' integration activity, cross-linking the separate

breakthroughs as three activity projects has been foreseen. Each activity includes two stages, with separate leaders in the project.

- *Activity Project Research:* including activities 'Gaps & RTD' and 'Innovation', with the objective 'to define gaps in present-day knowledge, prioritize research in view of the "Ecospace®" objectives and initiate innovation in (new) projects to increase competitiveness'.
- *Activity Project Dissemination:* including activities 'Standardization' and 'Education and Training', with the objective 'to ensure knowledge dissemination to potential target groups outside the consortium through EU standardization activities (CEN initiation), through new curricula, courses in education, instruction and training etc.'.
- *Activity Project Exploitation:* including activities 'Prototyping' and 'Production process', with the objective 'to cross-link prototyping activities and define opportunities for (joint, added-value) exploitation, new business or new markets; initiate special exploitation vehicles when the occasion arises'.

In view of the overall 'Ecospace®' objectives, tasks of all activity projects include adequate internal knowledge dissemination, explicitly bringing together different industrial sectors and a wide range of disciplines throughout clusters and projects. Further tasks include progressive road mapping to tune the projects, activities and envisaged deliverables.

Cluster projects: Each cluster consists of key components or issues that will be addressed in projects.

 *Human being*	 *Enclosure*	 *Personal control*	 *Ecospace®*
Human perception Performance assessment	Non-transparent parts - thermal insulation - interior finishes Transparent parts	Sensors and signals From sensors to actuators Actuators and local control	Communication between stakeholders, sectors, technologies, etc. Knowledge management Realization of Ecospaces®

In the cluster projects, basically the following key questions form the challenge the find answers on:

- *Cluster 1:* How to create a conceptual and comprehensive model for human health, comfort and safety in an enclosed space?
- *Cluster 2:* How to create 'value-added' materials and products, with improved or new (multi)functionality and/or automatic change or adaptation upon an environmental stimulus ('smart 'materials), contributing to a high basic level of health, comfort and safety in enclosed spaces?
- *Cluster 3:* How to create optimal opportunities for human beings to control environmental performance of their (local) space individually?
- *Cluster 4:* How to realize healthy, comfortable and safe spaces interactively with new products and services for materials, systems and control (the other clusters)?

CONCLUSIONS

To address the societal needs of improving health, comfort and safety of the European population, simultaneously reducing energy demands, as laid down basically in the WHO targets and the Kyoto protocol, respectively, the integration of different sectors, disciplines, stakeholders and organizations for realization on a European scale is a must. The integrated project or concept Ecospace® is a first step.

The definition of Ecospace® is thus applied in two ways:

- As an *innovation platform* for a group of entities from different markets and sectors (construction, aeroplane, space, train and auto industry, investors and owners, universities and research institutes).
- As a *concept* for an enclosed space, which is experienced by the occupants or visitors as being healthy ,comfortable and safe, and that is constructed smart and sustainable. An enclosed space is defined as a space in which a person stays for a short or longer period of time and which has a physical enclosure. For example, a room in a dwelling, an apartment, an office building, a car, an aeroplane or a train.

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