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Buildings energy sustainability and health research via interdisciplinarity and harmony

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ABSTRACT

Emphasizing that sustainable development, health, social security and renewable energy sources implementation are inextricably linked, paper examines the state of the art of building's health and sustainability relevant technologies. Sustainability definitions, relevant criteria and indicators related to healthy buildings have been searched and studied. Reviewed is the wide range of physically sound interdisciplinary research, results of which are new knowledge and developed synergetic analytical/experimental methods that lead to a sustainable, healthy, comfortable/productive indoor and outdoor environment. Research and knowledge based building intelligence and e-automation are elucidated as crucial technologies and techniques for design, construction and operation of sustainable buildings. Study shows, that qualitative relations and relevant comparative evaluation methods between indoor environmental quality and work performance or health, and further relation of both to the energy and energy efficiency, are not enough neither known nor searched. Initiated research is devoted to the healthy and sustainable buildings relevant performance modeling, evaluation methods and metrics investigation, and determination of all relevant interdependent relations, as well as determination of the relevant synergetic sustainability criteria and indicators. Initial results of related research are presented. Further research needs are outlined, drawing the attention on the role of harmony and interdisciplinarity in synergetic buildings health/sustainability study.

1. Introduction

The global climatic changes and related consequences are more and more obvious, although, some scientists say it is impossible to pin the blame for individual events from hurricanes to sandstorms solely on human activities. In August 2003 the hot wave scorched EU countries claiming an estimated 35,000 lives (Eurosurveillance, Volume 12, Issue 3, March 2007, *Letter to the Editor*). In France alone, 14,802 people died from the searing temperatures (19 times the death toll from the SARS epidemic worldwide). In the worst heat spell in decades, temperatures in France soared to 40 °C and remained unusually high for 2 weeks. It would be not easy those temperatures to be explained by natural variations. Resources exhaustion and wastes generation/disposal are consequences spread nearly uniformly around the world, and CO_2 and other GHG emissions are more uniformly endangering the whole globe, showing that present rate of usage of the Earth's resources is unsustainable.

According to the need to reduce GHGs emissions, buildings should be evaluated based on their projected energy requirements and emission of refrigerants. Buildings heating, ventilating, air-conditioning and refrigerating (HVAC&R) systems contribute to GHGs releases directly through commercial, industrial and residential air ventilation and energy-related effects, and indirectly through the effect of refrigerant losses. The release-related contributions to climate change are addressed by minimizing emissions of refrigerants (that have global warming characteristics) from systems or processes into the atmosphere. The lowest release-related impacts can be achieved by taking care on rigorous refrigerant conservation measures during design, manufacture, installation, operation, service, and recovery and final disposal. Energy-related impacts – carbon dioxide and other GHGs releases can be reduced by decreasing the energy consumption of equipment, systems, and buildings – by controlling and modifying building operation and user's behavior. Both effects must be considered in a life-cycle environmental analysis.

Primary are those factors that affect the energy consumption in the operation of the building and its HVAC and other technical systems, during its useful lifetime in addition to the selection of energy-efficient equipment. Very influential factors are facades concepts and choices in building envelope alternatives, glazing and

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fenestration, types of building structure thermal mass and insulating materials, day-lighting and lighting control, natural ventilation and energy-recovery opportunities, and HVAC systems regimes and operational modes such as temperature and air volume control, motors and pump types of control, indoor and outdoor air quality and environmental protection.

All of these considerations have an impact on the HVAC requirements and resulting CO_2 emission. Additional considerations in the choices (or options) in building design, construction and operation are any excessive environmental consequences associated with the production or manufacture of building components. Decision-makers shall consider all environmental impacts prior to taking actions in response to climate change. It would be counterproductive to require that refrigerant substitutes have low global warming potentials (GWPs), which at the same time may result in higher energy requirements or compromised safety. Thus, integrated assessments and balance are needed in emphasizing environmental issues to avoid solutions that remedy one problem at the expense of another.

There are many consequences of measures taken to move toward sustainability in the creation of healthy buildings [3]. Technologies aimed at improving indoor environmental quality are to be evaluated in terms of their total environmental impacts: indoor and outdoor, local, regional, and global. Increasing ventilation and air-conditioning to improve workplace productivity may yield net economic benefits, but can increase energy use and adversely affects air pollution and increases GHG emissions. Hence, fully holistic assessment methods and metrics are needed to properly assess building technologies [3].

Clean water resources are less and less available, as the amount of water impounded behind dams has quadrupled since 1960. Water withdrawals from rivers and lakes have been doubled between 1960 and 2005 [3]. In the same period, flows of reactive (biologically available) nitrogen in terrestrial ecosystems have doubled and flows of phosphorus have tripled [3].

Emphasizing that holistic approach assumes that sustainable development, health security, environment and social sustainability and renewable energy sources (RES) implementation are inextricably linked, this paper examines further more in depth the state of the art of building's health and sustainability relevant technologies, sustainability definitions generally and relevant criteria and indicators related to healthy buildings – one step forwards with the reference to the searched and studied earlier in [2].

2. Sustainability criteria and indicators

The most widely accepted definition of sustainable development is *Development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (formulated by the World Commission on Environment and Development in 1987). As engineers, environmentalists, policy makers, and others have gained experience, many have recognized a need for practical definitions that can guide decisions about materials, manufacturing processes in the product-development process, or in evaluating project proposals and granting loans for projects. This resulted in two kinds innovations of definitions: some with, and some without changing its intrinsic meaning. Variations and discrepancy in meaning related to the classical one are: tendency to define sustainability in the ways that suit particular application; its complex hierarchical character (in a certain level sustainability may be in conflict with sustainability at higher levels); politicization; presumptions that it is pure scientific concept and/or in the scientific analysis – either redundant, ambiguous or in some cases viewed as the paradox [1,2].

The role of science in this field can be crucial. Scientific knowledge shall help building the foundation and understandable formulations to support the goals of sustainable development, through scientific assessment of current conditions and future prospects for the Earth system. Related program areas, which are in harmony with such conclusions are according to [1,13]: strengthening the scientific bases for sustainable management, enhancing scientific understanding; improving long-term scientific assessment; building up scientific capacity and capability.

In 1992, the world's leaders adopted the principles of the Rio Declaration and Agenda 21 as the route to sustainable development in the 21st century. Thus, the importance of investing in improvements to people's health and their environment as a prerequisite for sustainable development was recognized at the highest decision making levels. Human health was highlighted as a central aspect of sustainable development and determined as a main indicator of the sustainable development/6/. Principle 1 of the Rio Declaration stated, "Human beings are at the centre of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature". Commitment to securing human health and a healthy environment has become widespread. The links between development, environment and health have been integrated at the global level by the World Health Organization and human health has been determined to be the main indicator of sustainability. Hence, health is to be a concern for every sector of society, not just the health sector itself. Appropriate development must occur in built environment, too, guiding for buildings healthy sustainable development [6].

2.1. Sustainability criteria

In order to quantify criterions for the sustainability assessment in any area or activity domain, of any project, system, building or anything else, indicators are to be defined to meet this requirement. Sustainability criteria, which are today dominant, in energy domain use are as defined in [1]:

Strategic design. The strategic design will require holistic planning that meets and considers all interrelated impacts e.g. logistic, space planning and resource planning. As regard the energy system, it may be interpreted as: mixed energy concept with optimization of local resources, urban and industrial planning with transport optimization, use of the renewable energy sources.

Optimized design. The design optimization of the energy system means the selection of the structure and design parameters of a system to minimize energy cost under conditions associated with available material, financial resources, protection of the environment and government regulations, together with safety, reliability, availability and maintainability of the system.

Dematerialization of design. This will imply that the energy system, plant and equipment are designed with optimal use of information technology in order to prevent duplication, prevent operational malfunction, assure rational maintenance scheduling. Dematerialization in the design may be seen as the introduction of knowledge based systems, use of virtual library, digitalized video, use of on-line diagnostic systems, development of new sensor elements and development of new combustion technologies.

Longevity of design. Complex energy system is commonly composed of different subsystems and individual equipment elements. It has been recognized that the life tie of the elements and subsystems is not equal. In this respect optimal selection of the life cycle for elements and subsystems may lead to the retrofitting procedure which will reflect need for the sustainable criterions application. Examples for this criterion can be seen as: modular design of the subsystems, standardization of the elements, lifetime monitoring and assessment, co-ordination of suppliers and buyers.

Life cycle design. This will mean that the energy system and its subsystems have to be designed to meet sustainability through every stage of the life cycle. It is known that the energy system is designed to work under different conditions in order to meet load change, environment change, social change, etc. It is obvious that there will be different cycles for each of the mentioned time scale processes. In this respect the system has to fulfill its function without failing to meet sustainability requirements.

2.2. Sustainability indicators

According to the sustainability approach, established and systematically developed by Naim Afgan [1,8,13], sustainability indicators represent the measuring parameters for the comparison between the different states or structures of the system. The energy efficiency of the system is the indicator for the quality of energy use in observed system depending in short term on the efficiency of resources use and technology development status, and on the long term on technology R&D results and science advances, as well as social, cultural and mental changes. Distinct indicators characterizing changes, as defined in [1] are as follows:

Possible change indicator. Possible change indicator is characterizing changes, which are determined by the maximum change technically possible. If applied to the energy resource, it is a difference between known resources exploitable with known technology and current resource to be obtained with present technological capacity. Possible change indicator is a function of the technology development in the resource discovery. This imply that there are two means for the increase of the resources, namely the additional investment for the new discovery and the new technology for the resource exploration.

Current change indicator. Current change indicator is defined as the resource consumption change of the respective resource. It is known that the current consumption of the energy resources strongly depend on the efficiency of energy use. Possible change in the efficiency of energy use includes the efficiency of the primary energy source conversion and second, the efficiency of the finale energy use.

Resource indicator index. By definition, the Resource Index (RI) is the ration between the Current Change Indicator and the Possible Change Indicator. In essence it will represent the qualitative measure of the resource depletion. Also, it may be interpreted as the resource scarcity change due to the resource depletion.

Financial effect of resource use indicator. Financial effect of resource use indicator reflects material balance of the respective primary energy resource. In order to use it for the quality assessment of the primary energy use, it has to be connected with the financial effect resulting form its use.

The energy system is generally characterized by organizational, operational, financial, resourceful, social and capacity building properties and its assessment and evaluation requires all properties of the system to be taken into consideration. The contribution of each property to the General Sustainability Index is defined with appropriately selected weighting coefficients. Graphical presentation of the algorithm for sustainability evaluation and determination of the SI (Sustainability Index) of a complex system encompassing listed sustainability criteria and indicators is presented in [3]. If it is assumed that the Energy System Hierarchy (ESH) of indicators will meet condition:

$$m(0) > m(1) >> \cdots m(t) > \cdots > m(k) = 1, \quad \text{and} \quad m(0) = N_0, \quad \text{and} \quad m(1) = N_1 \quad \text{and} \quad m(2) = N_2 \tag{1}$$

the pyramidal hierarchy of energy system will be reduced to a multi-criteria value of the fixed quality of complex energy systems [3]. Related scheme given in/8/ shows graphical presentation of the algorithm to be used in the evaluation of energy systems.

Data base, on the scheme, is collection of data comprising physical and chemical properties of the material and fuel, geometrical characteristics of element, intensity of the processes, temperature and pressure field within the element of the system, and other characteristics of complex energy system which are of importance for the determination of indices of "zero level". The date base is used for the calculation of the indicators of "zero level", based on the respective models which are obtained by the description of the integral characteristics of the complex system. Next step is the agglomeration of "zero level" indicators into indicators "level-1": resource indicator, economic indicator, environment indicator, technology indicator, and social indicator which are formed as an m (1)-dimensional vector. The mathematical operation used for the formation of the indicators of 1-level and 2-level is called aggregation and is defined by the linear additive function of the components of the vector of 0-level and 1-level, respectively.

Review of the given listing and the algorithm scheme shows that concerning buildings sustainability is missing indicator relevant to the buildings indoor comfort and people health (indoor environment acceptance indicator, health indicators, cultural, and other). Integration of IAQ concerns in so-called sustainable designs has suffered from a lack of comprehensive, science-based assessment methodology for building environmental performance [3]. Further, criteria and indicators related to healthy buildings have been searched and studied. By the series of the LAEL & CSHeB's wide range physically sound interdisciplinary research [15–22] has been significantly advanced knowledge and developed synergetic analytical/experimental models and methods that can powerfully lead to a sustainable, healthy, comfortable, productive indoor and outdoor environment.

Taking in account the LAEL's voluminous research data, a graphical presentation of the algorithm for the building's sustainability evaluation and determination of its holistic SI (Sustainability Index) as of a whole complex system is presented in Fig. 1. It is improved scheme given in [8] showing the evaluation algorithm of complex building energy systems with the reference to the built – indoor environment quality and people health in addition to the environmental outdoor ambient criteria as shown in [8]. This is crucial difference, because the scheme and related table in [8] treat health as an element of social indicator, and as thus comfort and health are not directly taking part in building's construction, and HVAC and other building's technical systems, energy efficiency optimization.

3. Sustainability index (SI) definition and determination

SI definition. Sustainability index definition and processing method will be here presented as given in [6]. According to [8] when an alternative of the energy system technology is assigned as the object, then all alternatives that are taken into consideration are making the finite set of objects [5].

$$X = X(x(j)), \quad j = 1, \ldots, k \tag{2}$$

where X represents the finite set of all objects; k represents the total number of objects.

(a) Vectors $X = (x_1, x_2, x_m)$ of the total initial quality is needed for the full assessment of the investigated object's quality.

It is assumed that energy technology objects are identified with vectors:

$$X(j) = (x_i(j), \ldots, x_m(j)) \tag{3}$$

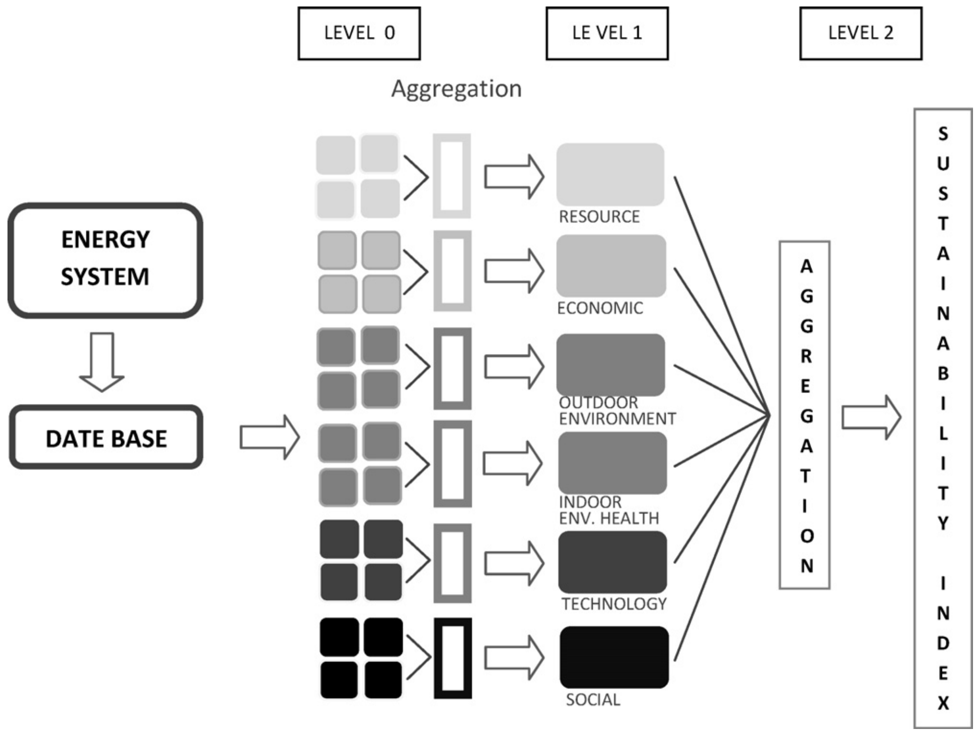

Fig. 1. Sustainability Index evaluation algorithm of the building's complex system.

where $i = 1, \ldots, m$; $j = (1, \ldots, k)$, k represents the number of objects under investigation and $x_i(j)$ is a value of the T-th initial parameter; x_i for 'j'-th energy technology object.Component $x_i(j)$ of vector $X(j)$ refers to the value of the initial quality (indicator) x_i of object $x(j)$. The finite set of objects shows the base for the fuzzy sets. The initial quality of the energy technology object can be defined by the vector:

$$X(j) = (x_i(j), \ldots x_m(j)) \tag{4}$$

It is supposed that each value of the vector x_i is necessary and that the total value of the quality vector is sufficient for the fixed quality of the energy object, respectively for the sustainability assessment of configured energy object.

(b) Forming vectors of specific energy object quality $q = (q_1, \ldots q_m)$
Quality of the energy technology objects $x(j)$, $j = 1, \ldots, k$, is defined by a number of specific quality $q_1, \ldots q_m$, where each is a function of a corresponding attribute (or initial parameters of vector):

$$q_i = q_i(x(i)), \; i = 1, \ldots, m \tag{5}$$

where m is the number of the specific energy technology object quality.
The function $q_i = q_i(xi)$ may be treated as a particular membership function of a fuzzy set of objects which are preferable from the point of the 'i'-th criterion's view. The quality level (degree of preferability) of the 'j'-th object is estimated by the value $q_i(j) = q_i(x_i(j))$ of function $q_i(x_i)$ from the point of the 'I'-th criterion's view. The quality vector is an indicator defined with a number of attributes reflecting its properties.

(c) The process of normalization of a specific quality
Normalization of specific criteria is done on the basis of initial values of indices. Sustainability indices are not suitable for use because they have different dimensions and interval of range ($/kWh, kg/kWh, kWh/$,...), and can thus not be compared. With the normalization of sustainability indices, comparison among indices is achieved.

(d) Introducing the weight coefficient and choosing the vectors of weight coefficientsThe weight-coefficient w_i ($i = 1, \ldots, m$) shows which importance is given to particular criterion qi when the General Index Q(q;w) is formed. The weight-coefficient $0 < w_i < 1$, for each $I = 1, \ldots, m$ is called the relative "weight" of the specific criterion q_i. Specific quality q_i has more influence on the value of General Index Q(q) with increasing values of w_i. Varying coefficient w_i, ($w_i = 1$; $w_i = 0$), the influence of $q_i = q_i(x_i)$ on the General Index Q(q;w) is changed, and respective importance is given to the specific quality qi at General Index forming. The General Index method comprises formation of an aggregative function with the weighted arithmetic mean as the synthesizing function defined as:

$$Q = \Sigma w_i q_i \quad \text{for} \quad i = 1, \ldots, k \tag{6}$$

where w_i is the weight-coefficient elements of vector w; q_i are indicators of specific criteria.

Based on the presented procedure, the Sustainability Index is defined as the General Index in form of an aggregative function with weighted arithmetic means as the synthesizing function. It is assumed that the Sustainability index is a linear agglomeration function of the products between indicators and corresponding weighting coefficients, which is presented in the form of additive convolution. If it will be adapted that each of the criteria is weighted by the respective factor, the sum of criteria multiplied by the corresponding factor will lead to the Sustainability Index.

Hierarchical character of indicators. Concerning the Hierarchical character of indicators, in order to develop appropriate tool for the quantitative presentation of one complex system properties it is of interest to introduce notion of the indicators which are measuring parameters of the respective quality [8,13]. To introduce individual indicators, it is necessary to describe the agglomeration procedure.

As different complexity elements are expressing the integral property of energy system, for the determination of these elements respective model are used based on the mathematical description

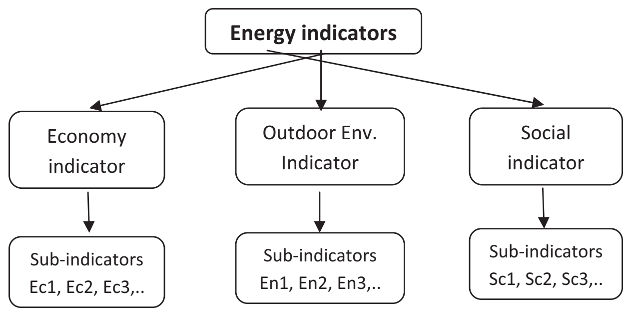

Fig. 2. Scheme of relevant indicators for sustainability assessment of a residential building.

of the processes within the system. When the integral parameters are formed and appropriate scale is defined, the proceeding step in deriving quantitative values complexity elements is the agglomeration of the indicators. There may be number of the indicators levels, and each level will represent platform for the agglomeration in order for the integral property of the energy system. In order to measure these integral properties it is necessary to govern the respective scale of each component of the complex indicator.Presented method includes mutual relationship of all weighting factors to be taken in account. Priority is to be given to the criteria by weighting factor and should depend on an expert opinion. The goal of future work, is to choose more sub-indicators and more objects and perform sensitivity analysis in order to obtain more accurate values of the total index of sustainability

SI determination. A practical procedure of screening selection of an energy indicator and sub-indicators determination for a residential buildings [14] is presented in Fig. 2. The economy indicator is based on the elements including: energy unit cost sub-indicator (Ec1), heating load sub-indicator (Ec2) and efficiency sub-indicator (Ec3).Energy unit cost sub-indicator (Ec1) is the cost of energy per unit of produced energy. For all chosen objects for this analysis, Efficiency sub-indicator (Ec3) is defined as thermodynamic efficiency of the energy producing system. It is efficiency of conversion from the energy resources to the final energy.The ambient – outdoor environment indicator consists of three sub-indicators En1, En2 and En3 showing, respectively emitted amounts of CO_2, NO_x and SO_2 to the environment during production of the energy unit.The social indicator is based on three sub-indicators Sc1, Sc2 and Sc3 giving a social picture of introduced household. In/8/Sc1 shows percentage of household income spent on a living space heating. Sc2 is income per person in a household, and Sc3 is sub-indicator representing commodity of dwellers depended on "how much space per person is available in the object".To obtain the unique assessment quantity of various examined alternatives (there were four objects: A–D) by multicriterial analysis methodology, ASPID method was used (Hovanov, N. 1996). The procedure is based on a list of initial values of 9 chosen sub-indicators from three different groups of indicators and a list of 4 different options under investigation. Those sub-indicators and options construct a matrix (x_i^j), $i=1,\ldots,m=9$, $j=1,\ldots,k=4$ where x_i^j is the value of ith indicator for jth option. The first level of calculation is to normalize all sub-indicators. Normalization consists of determination of membership functions.$q_i^j(x_i^j)$, $i=1,\ldots,m=9$, $j=1,\ldots,k=4$. For every indicator x_i is necessary to fix Min (x_i^j for i=const. and $j=1,\ldots,k$) and Max (x_i^j for i=const. and $j=1,\ldots,k$) from all 4 initial values. In the study/14/linear normalization was adopted and membership functions are given in a form:

$$q_i^j = \begin{cases} 0, & x_i^j = \mathrm{Min}(x_i^j) \\ \dfrac{(x_i^j - \mathrm{Min}(x_i^j))}{\mathrm{Max}(x_i^j) - \mathrm{Min}(x_i^j)}, & \mathrm{Min}(x_i^j)\langle x_i^j \langle \mathrm{Max}(x_i^j) \\ 1, & x_i^j = \mathrm{Max}(x_i^j) \end{cases} \quad (7)$$

for every $i=a$, $1<a<m$ and $j=1,\ldots,k$.The second level of sustainability determination is to agglomerate specific criteria (normalized sub-indicator values) in one value for each indicator group: economical, environmental and social for each object. Agglomerated values are obtained by using linear agglomeration function:

$$Q(q, w) = \sum_i q_i w_i \quad (8)$$

In the presented case priority was given (by weighting factor w) to the first of three sub-indicators from each indicator group and for each object under consideration. The weighting factors are normalized in a way that their sum is always equal to 1.At the third level of calculation, General Index of Sustainability has been determined as an additive function based on agglomerated values of economic, environmental and social indicators for each object and weighting coefficients in the condition on predefined constraints.For each group of energy indicators in [14], a set of three sub-indicators were defined: energy unit cost, heating load and efficiency sub-indicators as the consisting elements of economic indicator. Also, attention is focused on the environment aspect of the building including CO_2, SO_2 and NO_x environmental sub-indicators as the consisting elements of environmental indicator. Special attention was devoted to the social indicator consisting of: heating share sub-indicator, family income per member of household and commodity sub-indicator.Presented method includes mutual relationship of all weighting factors taken in account. Priority is given to the criteria by weighting factor and should depend on an expert opinion in final results discussion and decision determination, dominant were economic parameters in [14]. Thus, presented practical implementation of the SI determination method shows that the selection of relevant indicators and sub-indicators themselves, as well as relevant constrains, is pretty free, but has nearly decisive impact on the final results.Consequently, attention is to be, in further study, focused on the physically – scientifically more sound multicriterial analysis, which will take in account, in addition to economic, environmental and social sub-indicators, in calculating the total index of sustainability, particularly indoor environment as indicator and people comfort and health as sub-indicators.

4. Alternatives to approach sustainability relevant criteria and indicators

In addition to the presented multi-criteria sustainability "metrics" including sustainability criteria, indicators and sustainability index definition and processing, two other methods deserve attention: the concept of the 2nd Law of thermodynamics or exergy method [7,9] and the "emergy" approach or method [19]. In [7] Birol Kilkis presents *Exergy Aware Optimization and Control Algorithm for Sustainable Buildings*, and in [23] Robert A. Herendeen presents *Energy analysis and EMERGY analysis – a comparison*.

The energy and entropy balance equations sets are ground for the "exergy" balance, which includes the term of "consumption" explicitly, by combining the two equations and by introducing the concept of "environmental temperature". Exergy consumption occurs as energy or mass disperses for their transfer into the system. Exergy-balance and entropy-balance models of a system reveal that it works as exergy is supplied, its portion consumed and thereby the corresponding entropy is generated, and the generated entropy is discarded into its environmental space. Emergy is a measure of energy used in the past and thus is different from a measure of energy now. The unit of emergy (past available energy use) is called the "emjoule" distinguishing it from joules used for available energy remaining now. Scientifically emergy is equalized with the "energy memory".

5. Buildings and HVAC system health and sustainability

The most important options to delay fossil energy resources total exhaustion, to reduce pollution and to control climate change are renewable energy sources (RES) and low-carbon energy technologies combined with major improvements in end-use efficiencies. New breakthroughs in efficiency of energy conversion and transfer can be expected through miniaturization. Process intensification is a measure of the amount of productivity that can be accomplished per unit volume. It occurs because miniaturization significantly reduces the resistances to heat and mass transfer. Manufacturing processes developed in the frame of microelectronic component production have been recognized as an innovative conceptual model to construct miniature mechanical systems able to operate effective and efficient while making enormous reduction in material and work use. New miniature energy systems, miniature heat engines and heat pumps are in R&D, which is promising to bring new systems architectures for high energy density flux transfer and control in building structures. Thus, miniaturization opens revolutionary changes in energy conversion and transfer. Regarding prospect for new technologies (including renewable energy sources and miniaturization) further development and implementation, it is necessary to be aware that there is an important geological dimension of any major decision to plan broader installation of new systems – it is the geological availability of relevant materials resources.

General environmental concern is driving expansion of all the RES, but the pattern of uptake reflects the variations of political and geographic – meteorological climate, from country to country. Potential investors need reliable information about efficient and cost-effective systems, design criteria and predictions of system's long term useful energy gains and relevant energy economy. In many cases, energy policy planners and decision makers hesitate to introduce renewable energy sources RES in energy structure analysis because of hampered and limited access to reliable data on developed technologies and engineering systems operation and performance monitoring data. Using new information technologies gained and exchanged knowledge and experience shall become instrumental to the success of approaching sustainable buildings and sustainability generally.

LAEL and CSHeB at the Kyung Hee University is covering a wide range of interdisciplinary research topics connected to healthy building physics aimed to acquire new knowledge and integrate and develop analytical versus experimental models and methods (including design) that lead to a sustainable, healthy, comfortable/productive indoor and outdoor environment, and natural renewable energy sources implementation. Attention is on physical aspects and processes: indoor environment quality, lighting, heating, ventilation and subjective evaluation, air-conditioning, physiological and visual experimenting, considering holistic approach to the building construction and quality of building services as the essential. For example, light is essential for human life. Influencing the well-being of people in a physiological, psychological and biological way, it is one of the key elements in designing buildings. Lighting study focuses on identifying/analyzing the parameters that lead to the creation of a lit optimal environment, requiring knowledge of all human related aspects of lighting and physics of both daylight and artificial lighting. The optimal integral design of a building requires bridging gaps and exploring synergies between light and the other physical aspects involved in buildings, as well as those between light and the non-physical aspects of buildings as people health and comfort.

Hence, there is a need for building synergetic environmental performance – two-fold metrics with the reference to outdoor and indoor built environment concerning people health and comfort. Consequently, it is necessary to develop methods and tools to assess buildings environmental performance. Indoor environment performance characterize thermal comfort, indoor air quality, acoustics, daylighting–lighting, and electromagnetic radiation. For the outdoor environmental performance energy is the main factor in most of the studies, but there are some models which include energy consumption associated with different indoor environmental control approaches and levels. However, fully integrated models, that describe dynamic interdependence and interaction of the outdoor energy related, and indoor health related environmental synergy do not exist.

BPS simulations and buildings thermal behavior predictions are reliable foundation for building's energy efficiency intelligence and e-automation, and are to be elucidated further as crucial technologies/techniques for design, construction and operation of sustainable buildings, or so called Green buildings integrally with its distributed energy supply system, HVAC, lighting and other technical systems. Specific attention has to be drawn to the energy supply system, particularly integrated clean energy – renewable energy sources including storage, distribution and use.

Smart buildings take advantage of information exchange to provide energy efficient, flexible, productive, and cost-effective environment for building occupants. Its Energy management systems – EMS and Building automation systems – BAS, that include a "smart metering" component for electricity and other utilities increase the energy efficiency performance capabilities, giving facilities managers the information necessary to make better decisions that can reduce overall energy use and costs. EMS controlling energy-consumption of building equipment can make it operate efficiently and effectively.

With an aim to establish a holistic, fully relevant aggregated evaluation – system for buildings health and sustainability, results of related research are in preparation for presentation within the new framework interfaced with the BPS – building thermal performance modeling, integrating further fully with: total indoor and outdoor environment quality; total energy HVAC and water flow domains within the architectural modeling. Attention has been drawn on the key role of interdisciplinarity in sustainability study and on the crucial need to evaluate definitions of relevant indicators and criteria as well as related methodological content itself with an aim to develop integrated sustainable planning methodology, integrated sustainable systems designing, engineering and management.

The study demonstrates that effective demand side integrated resource planning, encompassing integrated sustainable healthy building planning, combining new urban segments, implementing renewable energy and materials sources, creative energy conscious urban alterations, reconstruction and energy revitalisation, offer excellent opportunities for application of the principles of sustainable development in the urban areas. Its general objectives are: promotion of the integrated sustainable, healthy building engineering approach, efficient energy use and resources conservation, renewable energies and materials utilisation, as well as outdoor and indoor environment and people health protection.

6. To reach sustainability via harmony and interdisciplinarity

It has been shown that conventional business and policies approaches to major global problems are making the world unsustainable and urgent need has to be outlined for searching economic possibilities, appropriate policies and market incentives, for sustainable management of natural resources. Development of renewable-energy technologies shall contribute saving natural resources. Opening huge opportunities of economic and social relevance, RES will also make the world less unsustainable. The balance has to be obtained between the developing countries reduction of their population growth rates and developed countries drastically reduced consumption and waste of natural resources.

Nonpathological development is development which respects all Man's and Women's needs as personalities – material and spiritual, emotional; a freedom of their own will, their right to live, to work, to dress, to have home; their needs for goodness, love, cordiality, their sense and striving for beauty, mercy, aspiration to creativity. There is no hierarchy of priorities among these series of needs. Cruciallity of these needs is equal, and without either one of numbered above we cannot find the harmony [2]. Inter- and -multidisciplinarity in sustainability phenomena mutual study is necessary to increase understanding of biophysical and physical priorities. Determination of hierarchy of subsystem's sustainability and relevant criteria definition taking in account direct interaction, indirect and cross interaction as well as possible impact of harmony on the sustainability barriers, their identification and solutions.

Having in mind the evidence on certain pathological aspects of the "wrong" of the extreme technological development, it is necessary to stress, that there is *one way to reach sustainable development – it is a way* via *harmony*. The contrary idea – *to war for energy sources, water and raw materials* is leading to more extreme oppositions and heavier conflicts, to *entropically unavoidable explosion* of the orderly growing reach/poor extremes and ever-growing disharmony.

Since the times of the Greek antiquity, the discussion of harmony was based on a fruitful understanding and profound inter-connection of flows, relations, forms, quality and other fundamental categories of human experience. It was always a sign of the human spirit's singular maturity and readiness to confront the most difficult problems. Approaching harmony new culture of ethics of sustainability can be created. *Studying harmony*. Dialogue and cooperation between communities and countries and between different economic sectors, as well as greater efforts in research technology and development, are the tools to overcome the major challenges to humanity and to ensure sustainability for current and future generations. Sustainability is, above all, a mental question and reflects our understanding of hierarchy of needs and of who is responsible for whom and for what in making sure that the world functions in a productive, effective and sustainable way. Sustainable development can be reliable only if it is based on a system of real human and ethical values. Such values system has to contain common elements which apply to every social, cultural and economic situation.

As final concluding remarks may be summarized needs for future multidisciplinary, inter- and cross-disciplinary study on healthy sustainable buildings, interwoven with harmony and holistic people health and well-being research [15–22] with following goals:

To develop sustainable healthy buildings intrinsic synergetic energy/people comfort and health relevant parameter determination and optimization based on the multivariate analysis, encompassing building's HVAC and other technical systems [11,12].

To choose more physically sound relevant sub-indicators and objects in order to obtain more accurate integral values of the Total Index of Sustainability, and to go beyond – trying to approach universal definitions of relevant quantities for the SI determination in its whole holistic complexity, based on the comprehensive review of numerous research studies – theoretical and experimental ([4,10,15,22], and other).

To conduct comparative analysis of the presented multi-criterial method of the Sustainability Index determination [1,2,8,13], and the alternative approaches via 2nd Law of thermodynamics–exergy method [7,9] and emergy method [19], determine correlations of relevant quantities and eventually try to go beyond and approach a generalization.

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