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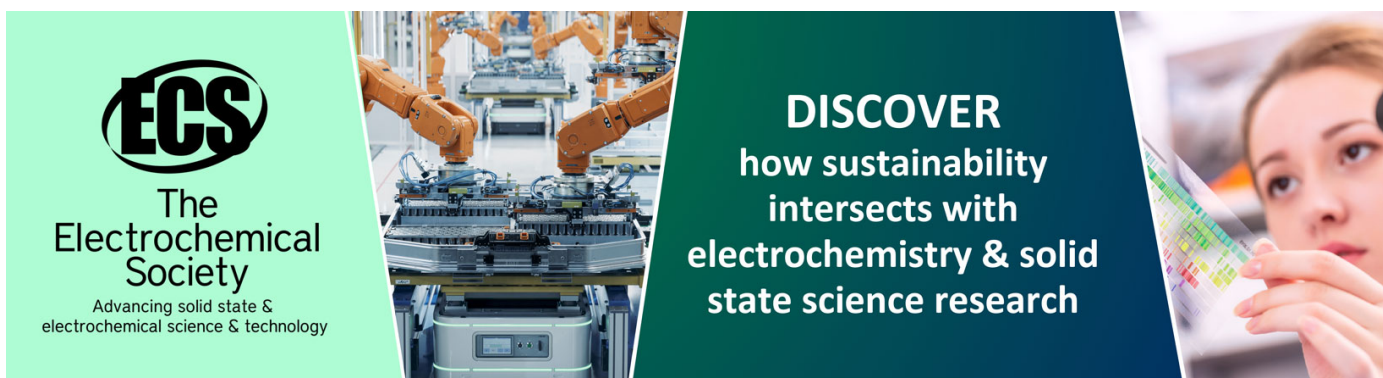
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Development of an Environmental Quality Index to Assess Physical Agents Pollution

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Abstract. Among the most common techniques and methodologies for the analysis of the exposure to polluting agents, the definition of environmental indexes represents a very useful tool to easily describe the quality of the environment. Based on experimental measurements, an approach using indicators quantitatively and qualitatively describes the 'health status' of the environments. For this reason, it is considered one of the most clear and efficient tools to support decisions and actions for the competent control authorities. In this paper the development of a general Physical Agents environmental Quality Index (PAQI) describing the potential impact related to the presence of all the different physical pollutants is discussed. The result is represented by a quantity that measures a weighted combination of sub-indices relating to each pollutant and described by means of an appropriate normalized mathematical function. The main idea is to provide an indicator able to describe, in a clear and concise way, the grade of physical pollution of the environment, suggesting in which areas it would be necessary to intervene or not, in order to improve the general environmental conditions.

1. Introduction

Quality indexes (QI) are one of the most adopted tools by government agencies and authorities to communicate to the public how polluted the air or an environment currently is or how polluted it is forecast to become. Generally, the computation of a QI, such as for the air, requires the measurement of the pollutant concentration over a specified averaging period, obtained from a continuous monitoring. Taken together, concentration and time represent the dose of the pollutant. Health effects corresponding to a given dose are established by epidemiological research, depending by the agent. Environmental pollutants differ in potency, so the function used to convert the pollutant concentration in terms of index varies by pollutant. Quality index values are typically grouped into ranges, according defined class describing the magnitude of the impact. To each range is assigned a descriptor, a colour code or a standardized public health advisory in order to easy communicate the environmental conditions, i.e. the increase or the decrease of noise emissions, air pollutant concentration etc.

The definition of a QI is not internationally common, but generally varies reflecting the governmental directions in terms of respect of national threshold values and quality standards adopted in that state. In general, the development of a unique index requires the identification and evaluation of a number of variables, a calculation method and the descriptor categories. In literature, the majority of the indices used for environmental pollutants, adopting linear or non-linear calculation methods, reports all variable individually. Only few indices are aggregated in a unique combined index [1]. In [2], some of the authors



proposed the development of a Health Quality Index, by mixing physical, chemical and biological pollutants. A GIS application of this index in two simulated case study is presented in [3].

In this paper, the development of a quality index as an indicator describing the grade of physical pollution of an environment is presented, according to the procedure proposed in [2]. This index, namely the Physical Agents Quality Index (PAQI), is conceived as a useful tool for authorities to identify areas requiring intervention to improve the general environmental conditions, to support urban planner in the identification of quite, healthy areas where to develop new residential areas etc.

2. Materials and methods

In Italy, the exposure of workers to all physical agents is regulated by Legislative Decree 81/08 [4], which defines, in section VIII, the criteria for assessing the risks arising from physical agents, including the risk related to noise, vibrations, ionizing and non-ionizing radiation, electromagnetic fields and, also, microclimatic conditions in the workplace. The PAQI index model was developed starting from this regulatory reference, but, according to its modular and flexible structure, it can be easily extended to any national regulation.

Main scope is to define, through a single quantity, the relation between different behaviours in different regimes. The idea is to represent, in a unique practical quality index, the action of the various physical agents through a general tool able to easily adapt to the different investigated environment. It should be stressed that, at this level, the formulation of an environmental quality index represents only a proposal project, without the intent to provide a rigorous analysis of the problem. The main purpose is, in fact, to suggest, rather, a simple methodology, in order to verify the 'health status' of any environment in relation to the presence of polluting physical agents.

The first step is to identify the descriptive relevant physical variables. It is, of course, more convenient and useful, from a practical point of view, to refer to well established parameters defined by regulation and the international or national specific standards. Once identified, in the second phase, it is necessary to distinguish each quantity with a specific parameter and then transform each of them into a well-defined relative sub-index. This approach implies forcing these different quantities within a common scale, so as to make the sub-indices considered comparable. This resizing is necessary because if the different variables are not defined by the same physical units it would be impossible, at first, to build a coherent relation between them. The third phase is the definition of a 'weight', for each sub-index in order to establish its relative importance with respect to the overall size, e.g. the quality of the environment.

From a practical point of view, the easiest way to overcome the problem of commensurability in the combination phase is to take into consideration the ratios among the environmental descriptors Q_i , and their reference value Q_{ref} . In this way, the physical indicator ('descriptor'), q_i , can be transformed into a dimensionless sub-index which provides a measure of the phenomenon with respect to a reference value set by the user:

$$q_i = \frac{Q_i}{Q_{ref}} \quad (1)$$

An important remark concerns the choice of the reference value Q_{ref} . In fact, depending on its value, the sub-indices could have a positive or negative sign, and be greater or less than 1. The solution to this problem, which requires an accurate analysis, can be found considering a coherent definition of sub-quantities, screening all the positive or negative sub-indices and all the upper or lower limits of the reference value parameters in the sub-index definition. In this way, a well-defined overall quantity easily and clearly interpreted can be obtained. This important step moves from the certainty that a unique general index would be easily understood by the public, spatially meaningful, would include major pollutant (and able to include future ones), be calculated in a simple manner using reasonable assumption, rests on a reasonable scientific basis, relates to ambient air quality standards and goals, exhibit variation and can be forecast in advance.

2.1. Sub-indexes definition

As previously discussed, the identification of the descriptors, representative of the quality level of a certain environment, is the first fundamental step. A wide range of environmental stressors have an impact on the health and the understanding which pollutants have the greatest magnitude of effect on health. In this paper, the authors will focus on the following environmental physical agents, considered as representative of the major hazard for human health and well-being: acoustic noise, electromagnetic noise (both electric and magnetic at low and high frequency), ionizing radiation and microclimate. The other physical agents (i.e. vibrations...) are not taken in to account here but it could be easily implemented, in the future, in the general formula.

2.1.1 Acoustic noise

In the last decades a large number of studies on the relation between environmental noise and health have been carried out. Recent researches have strengthened the evidence that, beyond effects on annoyance and sleep, noise affects human health in terms of hypertension, risk of ischaemic heart disease and mortality [5, 6]. Acoustic pressure levels represent one of the central problems that must be taken into consideration in the definition of a global quality index. The selected descriptor is the equivalent A-weighted noise level L_{eq} , measured in dBA, which describe average sound levels over the time period of interest (day or night for example). This parameter is usually used in regulations and in simple or advanced predictive models (see for instance [7, 8]). Thus, the corresponding sub-index, obtained according to equation 1, will refer to a reference value $L_{eq,ref}$ depending on the particular investigated area and on the time base of interest.

2.1.2 Electromagnetic fields

Electromagnetic field is one of the physical phenomena around which there is a complex issue related to its so disputed biological effects. Out of this argument, an important observation concerns, of course, the different action of electric and magnetic fields, or low frequency, and high frequencies. Therefore, the effects of the so-called non-ionizing radiation must be carefully studied in relation to its frequency. For this reason, four sub-indices have been developed in [2] for the electric field (E) and the magnetic one, represented, in Table 1 by the letter “ B ” for low frequency and the letter “ H ” for the high one.

2.1.3 Natural radiation

Human exposure to natural background radiation is an inevitable event since the main sources of natural radiation are the cosmic rays and primordial radionuclides contained in the earth's crust. The main contribute of exposure arises from the natural radiation either than from cosmic rays and nuclear processes. Referring, only to the larger contribute, i.e. ionizing radiation of natural origin, more than three quarters of the entire total comes from radionuclides present in the earth's crust, such as, for example, uranium and thorium whose decay product is radon. Radon is a radioactive gas, which, under certain specific conditions, can accumulate in closed rooms and constitute a serious hazard to human health because of its carcinogenicity[9]. For this reason, the control of radon concentrations is fundamental in the evaluation of the environmental quality in terms of its ‘healthy’[10]. The radiological risk related to the inhalation of radon and its progeny is based on the integrated measurement of radon activity concentration over a year (C_{Rn}) and expressed in terms of effective annual dose, D (mSv y^{-1}) according the following expression [11]:

$$D = C_{Rn} \times F \times O \times DCF \quad (2)$$

F is the equilibrium factor for Radon, O is the global average factor of indoor occupation, DCF is the dose conversion factor for Radon and its progeny, C_{Rn} is the annual averaged Radon activity concentration. The radon sub-index will consider the dose D , with respect to the reference value (D_{ref}) calculated by replacing C_{Rn} with the threshold value established by the national legislation ($C_{Rn,ref}$).

2.1.4 Microclimate

Microclimate fundamental descriptors are temperature and humidity, although, in principle, wind speed could also be taken into consideration. The development of a sub-index describing the effects of

temperature is not simple, since the harmful effects for human health occur both to low and high temperature. Moreover, a unique reference value is not defined but rather a range (for example from 10°C to 25 °C) which guarantees conditions of comfort. Thus, it is necessary to introduce a penalty factor, once an average value is set, for the positive or negative deviations from the preferred value. To overcome this problem, in [2] the authors adopted the difference between the measured temperature and a comfort reference one, under square root. As regard humidity the definition of the sub-index is similar to the other previous sub-indices.

Table 1. PAQI sub-indices

	Acoustic noise	Electromagnetic fields		Radon	Temperature	Humidity
		$\frac{B}{B_{ref}}$	$\frac{H}{H_{ref}}$			
Pollutant sub-index	$\frac{L_{eq}}{L_{eq}^{ref}}$	E_{ref}^{Low}	E_{ref}^{High}	$\frac{D}{D_{ref}}$	$\sqrt{\frac{ T-T_{ref} }{T_{ref}}}$	$\frac{RH}{RH_{ref}}$
q_i		$\frac{E_{ref}^{low}}{E_{ref}^{high}}$	$\frac{E_{ref}^{high}}{E_{ref}^{low}}$			

3. PAQI index

The most immediate assumption for the definition of the global index is a linear combination of all the sub-indices (q_i), reported synthetically in Table 1, by means of weight coefficients (p_i) appropriately assessed. The compact form of the descriptive equation of PAQI index can be expressed as follow:

$$PAQI = \sum_i p_i q_i \quad (3)$$

For this kind of approach, the evaluation of the weights constitutes a very critical point since the chosen value discriminate the major influence or not of the parameter with respect to the other ones. In this context the evaluation could be based on the 'size' of the impacts on human health for each pollutant (for example the low frequency electromagnetic field affects the biological systems in a different way compared to a high frequency one). In other words, descriptors of phenomena with worse impact on human health will be weighted with a higher factor, and vice versa. The attribution of values to these coefficients could be based for instance on epidemiological data, expert judgment, etc. After that, to complete the approach it is fundamental to define a criteria for the assessment of the total risk. One of the more practical and used methods in risk assessment is to define a critical scale classifying the level of risk, based on the attribution of a health risk proportional to the level of pollution determined by the overall value of the index. Of course, such approach cannot attribute a clear scientific meaning to a given level, but must be considered only on a phenomenological basis.

In order to provide an example of risk classification, in relation to our definition of the PAQI global index, 6 classes of safety or bio-sustainability level of the environment can be defined. From a practical point of view, each class can be formulated as follows:

$$k_A \sum_i p_i \leq PAQI < k_B \sum_i p_i \quad (4)$$

where k_A and k_B are the constant values bounding levels for each class. By assigning values to them, for example, six risk level classes can be defined as reported in Table 2, in which P_{tot} is the sum of the weights p_i .

This definition of the level of risk for human health, in the presence of physical polluting agents, obtained by means of the PAQI, allows to easily describe the phenomenon. It is clear that the level of risk depends on the proximity of the measured physical quantity to the established reference values. In reality, describing with "alert level" the PAQI values obtained in correspondence with the sub-indices ranging from 0.75 to 1 seems quite plausible since the value 1 will represent the achievement of the reference values.

Table 2. Example of risk classification according to PAQI values

Class	Level	Range
VI	Very high risk	$PAQI \geq 1.5 P_{tot}$
V	High risk	$1.25 P_{tot} \leq PAQI < 1.5 P_{tot}$
IV	Risk	$P_{tot} \leq PAQI < 1.25 P_{tot}$
III	Alert	$0.75 P_{tot} \leq PAQI < P_{tot}$
II	Moderate safe	$0.5 P_{tot} \leq PAQI < 0.75 P_{tot}$
I	Safe	$PAQI < 0.5 P_{tot}$

4. Conclusions

Having a collective index available that can describe the overall effect of different polluting agents can be very useful in order to assess the quality level of a given environment in terms of human health and safety. Such a quality index could be able to prevent long-term exposure to potentially dangerous living conditions both in work areas and in residential settlements. Furthermore, it could be used as a tool to measure the effect on the environment or the verification of the correct design of a certain infrastructure. Further developments will concern the improvement of the PAQI model, the possible application with GIS and the extension of the approach to chemical and biological polluting agents.

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