Performance criteria for healthy buildings: target values for some indoor air quality parameters

M. Maroni[a,*], P. Carrer[a], D. Cavallo[b], M. della Torre[a], N. Boschi[c]

[a]*Department of Occupational Health, University of Milan, 'L. Sacco' Hospital, Milan, Italy;* [b]*Department of Environmental Sciences, University of Insubria, Como, Italy;* [c]*Department of Building Construction, Virginia Polytechnic Institute and State University, USA*

ABSTRACT
The scope of this paper is the definition of some indoor air quality health-based criteria for healthy buildings. One possible approach to establish indoor air quality health-based criteria could be to define target values of a set of measurable parameters (chemical, physical and biological) related to health. Target values to assess the parameters are set according to full exposure (e.g. WHO guidelines, 24 h all people) or partial exposure (e.g., EPA guidelines, 8 h average adult). As for health protection, a Basic Target is a No Effect Level, while a Best Target is a further reduced value to account for uncertainty and human inter-individual variation. As for comfort, a Basic Target is considered the minimum acceptable condition (i.e. 80% of the population satisfied), while Best Target represents a condition of excellent quality, in the context of current building design, operation and management (i.e. >80% of the population satisfied). This paper also provides a list of factors/conditions that can be checked in a building for a preliminary, qualitative assessment.

INDEX TERMS
IAQ assessment; Health criteria; Healthy buildings

INTRODUCTION
During the last decades, the concepts of 'sick' and 'healthy' buildings have been introduced and debated at regional, national and international conferences. In 2000, WHO defined a 'healthy building' as a construction free of hazardous material (e.g. lead and asbestos) and capable of fostering health and comfort of the occupants during its entire life cycle, supporting social needs and enhancing productivity. It derives from this that a building ought to recognize that human health needs are a priority, but at the same time, a healthy building should not negatively impact the larger environment or other life systems (WHO, 2000).

The scope of this paper is to define a set of indoor air quality health-based performance criteria for 'healthy buildings' based on current literature review of standards, guidelines and research papers. Evaluation criteria consist of a *set* of measurable and controllable parameters, the values of which define healthy or unhealthy situations. As a further contribution to air quality practitioners, this paper also provides a list of factors/conditions that can be checked in a building for a preliminary, qualitative assessment of each parameter before undertaking their instrumental measurement or when such a measurement cannot be made. The listed factors/conditions do not obviously provide accurate assessment of the parameters but rather indicate with some approximation the likelihood that the considered parameter be of particular interest in the context of the overall health risk assessment of a building.

MEASURABLE HEALTH PARAMETERS AND RELATED TARGET VALUES
The set of criteria for health risk assessment of a building consists of measurable parameters related to health. Target values to assess the parameters are set according to full exposure (e.g. WHO guidelines, 24 h all people) or partial exposure (e.g. EPA guidelines, 8 h average adult).

[*] Corresponding author.

Surely values for full exposure are more stringent. As for health protection, a Basic Target is a No Effect Level, while a Best Target is a further reduced value to account for uncertainty and human inter-individual variation. As for comfort, a Basic Target is considered the minimum acceptable condition (i.e. 80% of the population satisfied), while Best Target represents a condition of excellent quality, in the context of current building design, operation and management (i.e. >80% of the population satisfied). Here a summary of the measurable health parameters and related values, and associated factors/building objects to be assessed are reported.

Physical Agent and Target Values

Radon (Table 1). Among physical agents, the most important health risk factor is represented by radon, a radioactive noble gas, which exists in several isotopic forms. Radon exposure in houses and other buildings is estimated to be responsible for a remarkable proportion of lung cancers occurring in the population (5–15% depending on the local radon level in soil). In most situations it appears that elevated indoor radon levels originate from radon in the underlying rocks and soils that may enter living spaces by diffusion. Since radon is a genotoxic carcinogen for man (i.e. is a cancer initiator), there is not a radon level to be considered 'safe' in absolute and the desirable level should follow the 'ALARA' principle (As Low As Reasonably Achievable). The 'Unit Risk' as defined by WHO (the probability of excess cancer for lifetime exposure to the unit value—in this case 1 Bq/m^3) is estimated to be $3–6 \times 10^{-5}$; this means that a person living in a house with 50 Bq/m^3 has a lifetime lung cancer excess risk of $1.5–3 \times 10^{-3}$. The level for remedial action in buildings recommended by WHO is 100 Bq/m^3, although various different levels (generally higher) have been set in national and international legislation (WHO, 2000) (Table 1).

Table 1 Radon: target values and factors/conditions to be checked for a preliminary building assessment

Parameter	Target values	Factors to be checked
Radon (Bq/m^3)	Basic: 100 (annual average) (WHO, 2000: Recommended level for remedial action in buildings) Best: 50 (annual average)	Underground and ground floor Building materials (by product gypsum, alum shale, granites and volcanic tuffs) Area with high levels of radon in ground and /or water

Chemical Agents and Target Values

This part summarizes the guideline values recommended for a number of chemical air pollutants, namely CO_2, CO, NO_2, PM_{10} and $PM_{2.5}$, ETS, VOCs and formaldehyde.

Carbon dioxide (Table 2). Carbon dioxide represents the main combustion product deriving from domestic energy use for cooking and heating, and being the leading human exhalation product, is also a good indicator of indoor pollution caused by human beings. About 1% is the lowest level at which adverse health effects have been observed, including increase in respiration, changes in blood PH and pCO_2, and decreased ability to perform strenuous exercise. Concentrations above 3% cause headaches, dizziness and nausea. The limit value for an adequately ventilated room is 0.1% (1800 mg/m^3) (ASHRAE, 1989).

Carbon monoxide (Table 2). Carbon monoxide is generated indoors by unvented combustion appliances and may accumulate particularly in poorly ventilated rooms. Tobacco smoking is also an important source of indoor CO pollution. The health effects of CO on human health consist of headaches, decreased attention and reaction time, nausea, increased ventilation, changes in serum electrolytes and cardiovascular diseases such as increased blood pressure, angina, cardiac arrythmia. The acceptable exposure levels set by WHO for CO are 10 mg/m^3 (8 h), 30 (1 h) and 60 (30 min) (WHO, 2000).

Table 2 Chemical parameters (I): target values and factors/conditions to be checked for a preliminary building assessment

Parameter	Target values	Factors/conditions to be checked for a preliminary building assessment
Carbon dioxide (mg/m^3)	Basic: 1800 (ASHRAE, 1989) Best: 900	Cooking in inadequate conditions (presence of local exhaust equipment), Combustion appliances (gas, kerosene, wood fuelled appliances), Tobacco smoking, Density of occupants Exhaust from vehicles on nearby roads or in parking lots, or garages
Carbon monoxide (mg/m^3)	Basic: 10 (8 h); 30 (1 h); 60 (30 min); 100 (15 min) (WHO, 2000) Best: 5 (8 h); 15 (1 h); 30 (30 min); 50 (15 min)	Cooking in inadequate conditions (presence of local exhaust equipment), Combustion appliances (fireplace, gas cooking stoves), Tobacco smoking, Exhaust from vehicles on nearby roads or in parking lots, or garages, Presence of industrial furnaces nearby
Nitrogen dioxide (µg/m^3)	Basic: 200 (1 h) (WHO, 2000) Best: 100 (1 h)	Cooking in inadequate conditions (presence of local exhaust equipment), Combustion appliances, Exhaust from vehicles on nearby roads or in parking lots, or garages
Ozone (µg/m^3)	Basic: 120 (8 h) (WHO, 2000) Best: 60 (8 h)	Laser printers, Photocopiers, Any equipment which uses high voltage or ultraviolet light, Electronic air filters, Equipment which uses ozone to purify air or water, Exhaust from vehicles on nearby roads
Particulate matter, PM_{10} (µg/m^3)	Basic: 50 (24 h) (UE, 1999) Best: 25[a]	Cooking in inadequate conditions (presence of local exhaust equipment),Combustion appliances, Tobacco smoking, Dust from indoor demolition, Airborne dust or dirt (e.g., circulated by sweeping and vacuuming), Paper in open shelves, Exhaust from vehicles on nearby roads Dust from outdoor demolition, Outdoor industrial emissions

[a]No guideline value without health effects recommended by WHO (WHO, 2000).

Nitrogen dioxide (Table 2). The primary indoor sources for these gases are represented by unvented fuel burning appliances and tobacco smoking. Use of open gas flame in the kitchens may be a relevant source of peak concentrations. Health effects caused by NO_x are irritation of the skin, eyes and respiratory tract, increased bronchial reactivity at more than 1000 µg/m^3. Some studies have shown changes in pulmonary function in asthmatics at levels as low as 376–560 µg/m^3. Long term exposure can increase the risk of respiratory illness, particularly in children. The acceptable short term exposure level (1 h) set by WHO for NO_2 is 200 µg/m^3 (WHO, 2000).

Particulate matter (Table 2). Combustion sources such as combustion appliances and tobacco smoking are probably the chief indoor generators of fine-mode particles which contain a host of organic and inorganic materials. WHO has concluded that even very low levels of particulate in the air (f.i. 10–20 µg/m^3 PM_{10}) are associated with an increased health risk in the population especially for premature mortality and perhaps also for chronic respiratory diseases (asthma, bronchitis and emphysema) and lung cancer. Therefore, in defining ‘health-based guideline values’, no figures have been given. Instead, in agreement with the WHO assessment, the desirable level should follow the ‘ALARA’ principle. The table shows the regulatory values adopted for outdoor air by European Commission: 40 μg/m^3 (1 year) and 50 μg/m^3 (24 h) (UE, 1997). They represent figures that ought not to be exceeded in any indoor condition.

Table 3 Chemical parameters (II): target values and factors/conditions to be checked for a preliminary building assessment

Parameter	Target values	Factors/conditions to be checked for a preliminary building assessment
VOCs (μg/m^3)		Building materials (pressed wood products, construction adhesive, insulating materials, plastic wall coverings)
		Carpets and all purpose adhesive
Toluene	260 (1 week)	Recent interior treatments
Benzene	UR: 6 × 10^{-6} (WHO, 2000)	Use of materials with organic volatile compounds (paint, adhesives)
		Laser printers
TVOCs	Basic: 300	Photocopiers machines
Alifatic hydrocarbons	100	Use of room deodorants
Aromatic Hydrocarb.	50	Odours of detergents, cosmetics and personal deodorants
Halogenated Hydroc.	30	Household disinfectants
Terpenes	30	Mould inhibitors
Esters	20	Dry-cleaned clothes
Aldehydes and ketones		Tobacco smoking
(no formaldehyde)	20 (Seifert, 1990)	Combustion appliances (unvented heaters, kerosene, gas cooking stoves and fireplace)
	TVOCs best: 200	Exhaust from vehicles on nearby roads or in parking lots, or garages
Formaldehyde (μg/m^3)	Basic: 100 (30 min) (WHO, 2000)	Building materials made with adhesives containing formaldehyde such as plastic surfaces, Urea–formaldehyde resin based lacquers and varnishes for furniture and parquet,
	Best: 50 (30 min)	Particle boards (mainly furniture)
		Urea–formaldehyde foam insulation (UFFI), Cigarette smoke and others combustion sources, Gas cookers, Open fireplace

VOCs (Table 3). VOCs include many substances with different chemical structures and toxicities. The number of VOCs detected in indoor air is usually higher than in outdoor air and now over 1000 VOCs had been identified at detectable levels in indoor air. They are released into indoor air by almost all materials and the source list includes consumer products, furnishings, pesticides, fuels, cosmetics and personal care products, combustion appliances and tobacco smoke. The acute effects on human health include irritation of eyes and respiratory tract, sensitization reactions involving eyes, skin and respiratory tract. Some of them are known as mutagens or carcinogens, but the long-term toxicity of many of them has not yet been assessed. There is also some evidence that VOCs can provoke some of the symptoms typically seen in the Sick Building Syndrome and they are invoked as a primary cause of the Multiple Chemical Sensitivity Syndrome. Guideline values have been adopted only for some of them at national or international level. In an attempt at defining comfort target values for Total VOCs and some groups of VOCs, tentative values were proposed by Seifert (1990). As also specified by the author, these values have to be taken as indicative, order-of-magnitude values and not as absolute figures. Moreover, depending on the specific single compounds present in the mixture in the air, adverse comfort effects may occur even respecting these group values. Benzene, being a human carcinogen, does not have a health-based recommended limit but WHO has estimated a Unit Risk of 6 × 10^{-6} (WHO, 2000). A numerical value of benzene concentration in outdoor air is taken as a target value in some countries: in Italy 10 μg/m^3 (Ministry of Environment of Italy, 1994).

Formaldehyde (Table 3). Formaldehyde is the simplest and most common aldehyde found in indoor environment. The main sources are: combustion sources, cigarette smoke, gas cookers, open fireplaces, and urea-formaldehyde resins in furniture, parquet and insulants. The effects on human health comprise irritation of eyes, nose, skin, throat and upper respiratory tract, sensitization, decrease in lung function, and discomfort of the occupants due to its odorous and irritating properties. IARC has classified formaldheyde as carcinogen for animal and possible carcinogen for human (class 2B) so the indoor levels should be kept as low as possible. The acceptable short term exposure level (30 min) set by WHO is 100 $\mu g/m^3$ (WHO, 2000).

ETS. Exposure to ETS is associated with an increased risk of lung cancer and several other health effects, such as irritation of eyes, nose and throat, increase of respiratory infections in children, decrease of lung function and increased risk of cardiovascular diseases. There is no evidence for a safe exposure level. Acute and chronic respiratory effects on children have been demonstrated even in houses with occasional smoking (0.1–1 mg/m^3 nicotine in the air) in particular as for concerns acute upper and middle respiratory tract illnesses, such asthma, bronchitis and bronchiolitis; in addition ETS can increase the occurrence of acute middle ear infections in children. The unit risk for lifetime ETS exposure in a house where one person smokes is approximately 1×10^{-3} (WHO, 2000).

Biological Agents

This is a very complex and heterogeneous area of pollutants including dust mites, dander from pets, fungi including moulds and yeasts, bacteria and viruses. The effects on health are allergic manifestations such as rhinitis, asthma, extrinsic allergic alveolitis, atopic allergic dermatitis; and infective disease such as humidifier fever, pneumonic (Legionnaires disease) and non-pneumonic disease (Pontiac Fever). No specific guidelines or regulatory values are available at national or international level. The European Collaborative Action 'Indoor Air Quality and its Impact on Man' in reviewing existing studies in homes and offices in 1993 classified the concentration of bacteria, fungi and allergens in air of the indoor environments (CEC, 1993).

CONCLUSIONS AND IMPLICATIONS

Criteria for healthy building definition can be represented by target values of some indoor air quality parameters. A multicentric study on performance criteria for healthy and energy efficient building (HOPE) involving seven European country including Italy (University of Milan) was started in 2002. This study will test the validity of the performance criteria for healthy buildings in different European climatic conditions.

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