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Model for Health Risk Assessment in Portuguese Housing Spaces

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Abstract: Currently, people spend most of their time inside their homes. However, poor conditions in terms of comfort and quality of the indoor environment can pose high risks to the inhabitants' health. Therefore, a good quality environment is essential, since, in addition to the hazards present in indoor air (e.g., particles, (S)VOCs, CO, radon and tobacco smoke), extreme temperatures, relative humidity levels, pests (e.g., mold, dust mites and bioaerosols), noise, airborne infectious agents (e.g., SARS-CoV-2) and contamination through water and soil can cause physical injuries, respiratory diseases, damage to multiple organ systems as well as harmful effects on the mental health of the occupants. Faced with this requirement, housing evaluation models were studied together with the main types of risk that could affect the health of the inhabitants, with the objective of proposing a new evaluation model for housing health and safety risks, fitted to the occupants, and especially suitable for Portuguese dwellings, although applicable in other geographical contexts. As a result of this analysis, this article proposes a new model for evaluating health and safety risks in housing, applicable in Portugal, supported by an inspection form and, as the main difference from the existing models, parameter measurements, providing complementary data for the evaluation. This model was created based on a set of functional and regulatory requirements that were identified for the healthy use of living spaces. Twenty-eight hazards were identified, and the respective risk factors were assessed using different processes and target demographics, including visual inspection, parameter measurements, occupants' age and location and age of housing. In order to validate the model and determine its usefulness, it was applied to a set of houses with different construction dates, locations and occupants. This exercise enabled the identification of hazard classes and the calibration and fine tuning of the model application. Finally, proposals for future work are presented in order to create a base of evolution for the model.

Keywords: hazard; risk; safety; health; housing; assessment; MASHH

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1. Introduction

There is a body of evidence on how multiple factors of inadequate housing can negatively affect the health of occupants. A dwelling usually comprises four interrelated dimensions—its physical structure, the home (psychosocial, economic and cultural construction created by the family), the neighborhood infrastructure (physical conditions of the housing's immediate environment) and the community (neighborhood's social environment, population, and services). Each of these four dimensions has the potential to have a direct influence on physical, social and mental health, and two or more of them combined can have an even greater impact [1].

It is a fact that, nowadays, people, especially the elderly and more vulnerable, spend much of their time indoors (mostly inside their own homes), increasing the exposure to health and well-being hazards, which they are generally unaware of. These hazards consist, for example, of indoor air pollution (e.g., CO, (S)VOCs and indoor chemistry products), extreme indoor temperatures, pests (e.g., dust mites), noise, infectious agents and airborne particles, contaminants in water, fungi and other microorganisms and bioaerosols, which can lead to injuries of traumatic, infectious or inflammatory etiology and poisoning, and may also cause effects on the mental health of the occupants. Risks related to housing conditions can be defined as psychological and physiological risks and risks of infections and injuries [2].

Among the occupants of a dwelling, children and the elderly deserve special attention, particularly in the view of their dependence, motor weaknesses, and the fact that they are living in periods of particular sensitivity to chemical and non-chemical stressors (called "windows of susceptibility").

There is now a consensus that protecting children's health from environmental hazards is a solid foundation for their health throughout their lives. There is compelling evidence to suggest that children's experiences during the first five years of life (including the intra-uterine life) lay the foundation for physical and mental health, affecting their ability to adapt, learn and thrive later in life. Adverse environmental exposures in embryonic, fetal, post-natal and childhood stages of development can increase the risk of disease throughout life, such as cardiovascular diseases, obesity, diabetes and cancer. Measures to curb environmental degradation must take into account children's vulnerabilities during development in order to effectively protect them from harmful exposures with irreversible consequences [3,4].

There is very large variation in personal exposure among children, caused by differences in building design, indoor and outdoor sources, and activity patterns [5]. During childhood, one of the most significant chronic conditions in developed countries is asthma. A considerable proportion of childhood asthma cases are attributable to exposure to indoor humidity and mold [1].

The risk factors most frequently identified in children include the presence of formaldehyde or chipboard panels, plastic materials, and recent application of paint in spaces intended for children's activities. Elevated risks were also reported for housing rehabilitation and cleaning activities, new furniture, textile rugs or wallpaper [6,7].

In most developed countries, the demographic pyramid clearly shows the aging of the population. In Portugal, between 2011 and 2021, there was a decrease in the population in all age groups, with the exception of the elderly population group (aged 65 and over), which had a growth of 20.6%. In 2021, the percentage of elderly population in Portugal represents 23.4% of the total [8].

Housing has the potential to influence the lives of the elderly socially, physically and psychologically. Older people may be particularly at risk from the effects of air pollutants, even at low concentrations, due to their reduced immune competence and multiple underlying chronic diseases [9]. Older people tend to have different thermal sensations and preferences compared to younger people. This, in turn, affects how older people respond to changes in the thermal conditions around them [10].

Ensuring that older people live in appropriately sized, easily managed and air-conditioned housing is linked to improving their health and can promote better social relationships, both inside and outside the home. Elderly people require housing that allows them to stay safe and comfortable, regardless of their age, economic or physical capabilities. For some people, this reality can translate into a desire to grow old in the same home—that is, to remain in the same home and community as they age. Thus, many older people live in housing that has been built long ago and has features that can be hazardous—the presence of carpets, narrow doors and difficult-to-access toilets—and act as barriers to independence as people age and lose physical abilities. When people experience a significant loss of physical ability, previously minor household barriers can become major obstacles to daily needs. Falls are a major health problem for the elderly. It is estimated that 30% of people over age 65 and 50% of people over age 85 will fall at least once a year. Some risk factors for falls are slippery floors, poor lighting and poorly designed stairs [11].

Energy poverty affects millions of homes in Europe, leading to poor hygrothermal conditions and the risk of mold and dust mite contamination, which in turn increases the risk of asthma exacerbations. The risk of mold development may be dependent on the age of the occupants, the type of occupation, the socio-economic status, the presence of pets, the drying of clothes indoors, the geographical location, the architectural design/age of the property, the levels of thermal insulation and the type of heating. On the other hand, populations affected by energy poverty may not benefit from energy efficiency interventions, due to ineffective occupier-initiated heating and ventilation practices [12].

In Portugal, energy poverty is particularly important. Indoor temperatures of 141 dwellings in northern Portugal were measured during the winter of 2013–2014. The average daily internal temperature during the period of occupancy was 14.9 °C for the sleeping rooms and 16.6 °C for the living rooms. The results show that indoor temperatures are significantly below the generally accepted comfort levels and reinforce the idea that "cold houses" during winter are a reality even in southern European countries [13].

Extreme temperatures (excessive heat and excessive cold) are also associated with a high risk of mortality, particularly in Mediterranean countries [14,15]. If the current climate change trends continue to intensify, health and well-being could also be affected by extreme variations in temperature inside homes, leading this thermal stress to increase morbidity and mortality [2].

In view of the problems presented above (the need to protect children's health from environmental risks, population aging and the respective necessity to adjust housing, energy poverty and climate change), there is a need to adapt/create assessment models for housing health and safety. This article aims to propose a new assessment model for the health and safety of housing, adapted to the occupants and especially suitable for Portuguese dwellings, while guaranteeing the application in other geographical contexts.

2. Assessment Models of Housing Conservation Status and Associated Risks

In Europe and particularly in Portugal, large-scale projects to assess the security and indoor environment quality (IEQ) in housing have been scarce.

The LARES project dataset revealed that inadequate housing conditions have a significant impact on health, such as accidents (falls), respiratory diseases, development of depression and perceived safety. The project consisted of interviews and inspections, covering 8519 people and 3373 families/dwellings from 8 European cities. In Portugal, 357 families/dwellings were involved (one survey per dwelling; the vast majority being single-family dwellings) and 1055 people. The main conclusions were as follows [16,17]:

- A total of 47% of households reported very cold temperatures in winter and/or transitional seasons (spring and autumn). In Portugal, 60 and 70% of respondents reported temperature problems, in summer and winter, respectively;
- In 76% of homes, there are doors that can be hazardous for children, the elderly and residents with physical or visual limitations. In addition, 70% have steps or gaps at the main entrance;
- Almost 25% of residents had a domestic accident during the year prior to the survey. The most frequent types of accidents were cuts, falls and burns;
- The causes for accidents are related to age (younger and older residents suffer relatively more accidents), housing design and layout (overcrowded dwellings and lack of work space in the kitchen lead to an increase in the number of accidents) and lighting (poor lighting is associated with more accidents);
- More than 25% of households reported that there were places or objects in the house that were especially dangerous for children, while researchers found places that were generally unsafe (loose rugs, open electrical installations, etc.) in many of the houses'

rooms. Another identified problem was the safety of stairs and steps inside dwellings, where 30% of all stairs are insufficiently equipped with guardrails and balustrades.

The findings of the LARES project clearly indicated that housing problems have direct or indirect health relevance. They are mainly linked to insufficient construction and maintenance, but also to the residential lifestyle.

A European-wide project (HOPE), carried out in 9 countries, involving 164 buildings, 66 apartments and 98 offices (75% of which are energy efficient), aimed to assess the integrated performance of buildings, both in terms of energy and in terms of occupant health and comfort. The performance was evaluated using, sequentially, the inspection of the building (collection of data from the building and surroundings), questionnaires applied to the workers/residents and measurements of specific parameters/chemicals (e.g., CO and VOCs). Twenty-four apartment buildings were classified as "green" (good performance), in contrast to only eight office buildings, and "red" (poor performance) for thirty-four apartment buildings and fifteen office buildings. Table 1 presents selected results obtained for the apartment buildings (adapted from [18,19]).

Table 1. Selected results of the HOPE program collected from surveyed apartments (adapted from [18,19]).

Item		Average	Item	Probably Present [2]	Present [2]
Prevalence of symptoms SBS	Blocked nose	33%	Low concentration of CO	76%	9%
	Lethargy, fatigue	39%	Infection from the building	82%	0%
Disease declared prevalence and allergies	Allergic rhinitis	56%	Infection from the occupants	94%	0%
	Migraine	53%	Ozone	3%	0%
	Skin problems other than eczema	51%	Non-carcinogenic VOCs	21%	79%
	Bronchitis	51%	Carcinogenic VOCs	59%	6%
Air quality—Average summer/winter (scale: 1–7) [1]		2.95	Fungi	50%	50%
Thermal comfort—Average summer/winter (scale: 1–7) [1]		2.87	Particles	56%	41%

Remarks: [1]—scale: 1—satisfied; 7—dissatisfied; [2]—the values presented refer only to the group of buildings classified as "red".

The same project also involved Portugal, where 10 apartment buildings were analyzed, with 639 occupied apartments. Three-hundred and fifty-two surveys were collected from adult occupants of the apartments, with the following most significant average results (scale from 1, satisfied, to 7, dissatisfied):

- Air quality—winter: 3.08;
- Air quality—summer: 2.84;
- Air quality—average winter/summer: 2.96;
- Thermal comfort—winter: 3.17;
- Thermal comfort—summer: 2.64;
- Thermal comfort—average winter/summer: 2.91.

By analyzing the results of the HOPE project, it can be concluded that, in relation to the parameters of air quality and thermal comfort, Portuguese dwellings have similar levels to European ones. Research on IEQ conducted in Portugal regarding housing has focused, in particular, on families' way of life [20], comfort conditions, measurements of temperature and relative humidity, and pollutants' concentration (e.g., VOCs, $PM_{2.5}$, PM_{10}, CO and CO_2) and the presence of bacteria and fungi [21–23].

Indoor environments have a huge impact on health and well-being, and for that reason, it is important to understand the basic requisites to ensure they are healthy. There is substantial knowledge about individual factors and their effects, although it is understood that there is a lack of knowledge about how the factors interact and what is the role of occupants in these interactions. Some areas/phenomena have shown preponderance in the health of the occupants, including the biopsychosocial aspects of health; the interaction between occupants, buildings and the interior environment; climate change and its impact on IEQ and health; the energy efficiency measures and their impact in the indoor environment. As such, the indoor environment must be considered as a dynamic and complex system subject to multiple interactions and this requires a transdisciplinary and holistic approach [24].

As a result of the aforementioned findings, together with the importance of housing for the comfort, health and safety of occupants of housing spaces, it is very important to have instruments that allow for credible assessments that are likely to assess the true adaptability of housing spaces to their potential occupants.

There are several proposed evaluation models [25,26]. However, most are for the purpose of assessing the state of conservation of the properties and the prospects for rehabilitation [27–30].

It is also important to present notions and definitions of hazards, and, ultimately, the risks to which the occupants of housing spaces are exposed.

2.1. Model for Assessing the State of Conservation of Properties (MAEC)

The MAEC model was developed by the National Laboratory of Civil Engineering (LNEC), Portugal and makes it possible to determine the state of conservation of residential and non-residential properties and the existence of basic infrastructure. The evaluation criteria allow the determination of the level of anomalies that affect each functional element. The following four criteria are used [31]:

- Consequence of the anomaly in meeting functional requirements;
- Type and extent of work required to correct the anomaly;
- Relevance of the locations affected by the anomaly;
- Existence of an alternative for the affected space or equipment.

The first two criteria refer to the severity of the anomaly and are applied according to the rules summarized in Table 2.

Table 2. Rules for assessing the severity of defects.

<table>
<tr><th>Slight Defects</th><th>Medium Defects</th><th>Severe Defects</th><th>Critical Defects</th></tr>
<tr><td rowspan="2">Defects prejudicial to aesthetics, requiring simple repairs</td><td>Defects prejudicial to aesthetics, requiring complex repairs</td><td>Defects prejudicial to use or comfort, requiring complex repairs.</td><td>Defects that endanger health or safety and may cause minor accidents, requiring complex repairs.</td></tr>
<tr><td>Defects prejudicial to use or comfort, requiring simple repairs</td><td>Defects that endanger health or safety and may cause minor accidents, requiring simple repairs</td><td>Defects that endanger health or safety and may cause major accidents</td></tr>
</table>

The final result obtained is converted into a five-level scale called the Anomaly Index, with a scale of very bad, bad, average, good and excellent.

The assessment of the state of conservation is carried out based on a visual inspection of the dwelling. There is no need to resort to consulting projects, analyzing the history of repairs or carrying out tests or probing. It is considered that with the inspection alone, it is possible to carry out a screening of the main anomalies and obtain results with an adequate degree of accuracy. The breakdown of the property and the dwelling into 37 functional elements (e.g., exterior walls and frames) requires that the inspection is carried out in some detail.

This model has some limitations, namely the assessment does not guarantee all the minimum conditions of safety, comfort, use or appearance, since the assessment focuses on the functional elements that make up the building.

2.2. Housing Health and Safety Rating System

The model defined in the Housing Health and Safety Rating System (HHSRS) was created in 2000 in the United Kingdom. This classification model intends to carry out the assessment of the potential risks to safety or health in housing and is built on the principle that "any residential location should allow a healthy and safe environment for any potential occupant or visitor". At the base of the model is the philosophy that any dwelling should be built and maintained with materials that make it possible to avoid the occurrence of anomalies that, in some way, contribute to hazards that enhance the risk of accidents in the use of spaces [32].

The methodology for evaluating the dwellings is based on a visual inspection of the state of conservation of the construction elements, leading to the detection of present anomalies. Whenever an anomaly is observed, the hazards that may arise from that occurrence are verified and, consequently, the probabilities of these constituting a risk to the health and safety of the occupants of the spaces are expressed as the hazard score or hazard rating. It is considered that there is a hazard when the dwelling does not ensure compliance with the applicable functional requirements, and that this non-compliance arises from the existence of anomalies in the various constructive elements. Twenty-nine hazard categories have been defined, divided into the following four main groups depending on the kind of threat to health:

A Physiological requirements, including hygrothermal and pollutants (non-microbial);
B Psychological requirements, including space, security, light and noise;
C Protection against infection, including hygiene, sanitation and water supply;
D Protection against accidents, including falls, electric shocks, fires, burns and scalds, and collisions, cuts and strains.

Anomalies are rated on a four-level scale according to how they influence the identified hazard, which includes seriously defective, defective, not satisfactory and satisfactory.

The final result obtained is converted into a hazard class, with ten classes corresponding to the result obtained, A to J, where A is the class that corresponds to a greater hazard of use and J the class that represents a property with a lower probability of occurrence of damages due to that specific hazard.

The model introduces the concepts of hazard and risk in the assessment. The HHSRS directly relates the detected anomalies with the possible risks to the health and safety of the users of the spaces, obtaining as a result the coefficients for each of the analyzed hazards and not a value that allows the reference of the evaluated fire as a whole or, in the case of multi-family buildings, for the building in its entirety.

Classification is performed solely on the basis of anomalies that are visible at the time of inspection and that may contribute to health and safety hazards. Any anomalies that may be of aesthetic, quality or comfort origin are not taken into account.

3. Housing Safety and Health Assessment Model (MASHH)

In view of the inadequacy of most models to the Portuguese reality, a model developed within the scope of a doctoral thesis is presented below [33].

In a first phase of the development of the proposed methodology, the types of danger were identified and then grouped by typologies, taking into account their nature. The assessment of each of the hazards was carried out in a different way, some of them using weekly monitoring (parameter measurements) and others visual inspection (surveying the technical and constructive characteristics of each of the dwellings).

For the definition of the model for the evaluation of the safety and health of the dwellings and their classification, it was decided, based on the risks that the hazards can cause to the health of its occupants, to carry out an individual evaluation of each parameter.

The application of this approach, produced, in the end, by using an original and pondered mathematical expression, an individualized housing risk class (*HRC*).

The hazards considered most prominent were adopted and for each of them, a risk factor and the respective weights were defined, taking into account the age of the occupants, and the location and age of the dwellings. In order to proceed with the evaluation and presentation of results, as well as their degree of risk in relation to the score obtained, a risk classification was prepared with scores divided into four intervals. The scores assigned to each degree of risk were based on the negative influence that the assessment parameters can have on the health and well-being of the occupants of the dwellings.

3.1. Types of Hazards Adopted

The hazards adopted for the development of the evaluation model proposed in this article are based on the HHSRS model, with some changes and improvements, so that the proposed model is directed to the Portuguese housing stock, although it is adaptable to other geographical contexts. Changes include, for example, a division into seven hazard groups instead of four, and the inclusion of CO_2 as a pollutant.

In a first phase of developing the methodology, the types of hazards to be considered were identified, grouped by typologies, taking into account their nature. The adopted hazards are grouped into seven different groups, making a total of twenty-eight distinct hazards, as shown in the Table 3.

Table 3. Groups and types of hazards adopted.

Hazard Groups (HG)	Hazard Identification (H)	Type of Hazard
HG1—hygrothermal conditions	H1.1	Growth of molds and fungi
	H1.2	Excessive cold [1]
	H1.3	Excessive heat [1]
	H1.4	Relative humidity [1]
HG2—pollutants (non-microbial)	H2.1	Carbon monoxide [1]
	H2.2	Carbon dioxide [1]
	H2.3	Formaldehyde [1]
	H2.4	Volatile organic compounds [1]
HG3—space, security, light and noise	H3.1	Overcrowding and space
	H3.2	Intrusion
	H3.3	Lighting
	H3.4	Noise
HG4—hygiene, sanitation and water supply	H4.1	Household hygiene, pests and waste
	H4.2	Food safety
	H4.3	Personal hygiene, sanitation and drainage
	H4.4	Water supply
HG5—falls	H5.1	Falls associated with baths
	H5.2	Falls at the same level
	H5.3	Falls on stairs
	H5.4	Falls between different levels

Table 3. *Cont.*

Hazard Groups (HG)	Hazard Identification (H)	Type of Hazard
HG6—electric shocks, fires, burns and scalds	H6.1	Electrical hazards
	H6.2	Fire
	H6.3	Flames and hot surfaces
HG7—collisions, cuts and collapses	H7.1	Collision and incarceration
	H7.2	Collision due to architectural features
	H7.3	Explosions
	H7.4	Location and operation of facilities
	H7.5	Structural collapse and/or fall of elements

Remark: [1]—parameters to be monitored.

As an example, exposure to molds or fungi poses a danger to occupants of dwellings. In Table 4, the main effects on human health resulting from this exposure can be found, as well as the aspects that affect its probability and risk of occurrence. This hazard is directly related to relative humidity.

Table 4. Health effects and aspects that affect probability and risk: hazard "H1.1—growth of molds and fungi".

Health Effects	Aspects that Affect Probability and Risk
Allergic reactions (rhinitis, among others), exacerbation of asthma symptoms or chronic obstructive pulmonary disease	Low energy efficiency—insufficient heating; Inadequate ventilation;
	Clothes' drying facilities—lack of ventilation for outside air; Waterproofing in poor condition;
	Poor or insufficient insulation resulting in moisture build-up or penetration;
	Floors, walls or ceilings that allow water penetration; Inadequately installed sanitary facilities or sewage pipes.

3.2. Model Structure

The model proposed in this article is based on several assumptions. Since the objective of the model is the assessment of risks for the occupants of the dwellings, more specifically with regard to their health, safety and well-being, it is considered important to evaluate a set of parameters that may interfere with such requirements. As such, in this model proposal, the risk factors are associated with the following points:

- Visual inspection;
- Measurements (parameter monitoring);
- Age of the occupants and the existence of serious mental illness or permanently conditioned mobility (information obtained through a survey);
- Location and age of housing (information obtained by survey).

To carry out the assessment through visual inspections, for each hazard, three risk factors will be assigned, scaled from 1–3, with the value 1 being the lowest risk factor (low influence for the occurrence of the risk), the value 2 for moderate risk and 3 for high risk of occurrence. This means that, based on the general characteristics of the dwellings, and according to the risks that the hazards can cause to the health, safety and well-being of the occupants, the risk factors will take into account the effects on health and the aspects that affect their probability and risk of occurrence. Overall, the visual inspection intends to evaluate the state of the house, its characteristics and the conditions of use and interior comfort (Table 5).

Table 5. Risk factors—visual inspection (examples).

Hazard Identification (H)	Type of Hazard	Risk Factor	Visual Inspection
H1.1	Growth of damp, mold and fungi	1	There is no evidence
		2	Sporadic existence (stains less than 0.010 m^2)
		3	Fungal and mold stains with an area greater than 0.010 m^2
H3.3	Lighting	1	Windows that are clear from the outside and of reasonable dimensions [1]; Correct placement of indoor artificial light
		2	Insufficient entry of natural light due to external barriers
		3	Windows obstructed from the outside by other buildings and inadequate position of artificial light inside the house
H4.2	Food safety	1	Sufficient and adequate space for storing and cooking food
		2	Existence of adequate but insufficient space for the storage and cooking of food, taking into account the number of occupants
		3	Lack of space for proper storage and cooking of food; Lack of water supply, a sink with a drainer, an adequate space for the fridge and freezer and free and sanitized surfaces
H5.2	Falls at the same level	1	Regular pavement; Adequate spaces with minimum free distances for the performance of tasks and the passage of occupants
		2	Floors susceptible to slipping; Presence of furniture that reduces the minimum safety distance for occupants to pass through
		3	Uneven pavement; Presence of sharp edges, heating installations or glass; Inadequate lighting; Insufficient surface water drainage
H6.3	Flames and hot surfaces	1	Protected hot surfaces, as well as all types of water heating appliances; Good layout of the kitchen
		2	Hot surfaces with poor protection; Existence of a door close to the location of the stove
		3	Unprotected hot surfaces; Poor layout of the kitchen; High temperatures from water heating appliances
H7.2	Collision due to architectural features [2]	1	Doors' headroom clearance and minimum ceiling height within regulations
		2	Occasional zones with low headroom
		3	Low headroom of doors, beams and ceilings

Remarks: [1]—Portuguese legislation establishes a mandatory minimum of 10% for the area of windows and a recommended maximum of 15%, in relation to the area of the floor served; [2]—Portuguese legislation establishes that the minimum headroom clearance cannot be less than 2.40 m. Exceptionally, in corridors and sanitary installations, it is permissible that the minimum ceiling height is 2.20 m. In beamed or sloping ceilings, the minimum ceiling height must be maintained at least 80% of the ceiling surface.

Regarding the hazards considered in the parameter measurements, risk factors were also considered on a scale of 1–3. In this case, as these parameters are air quality and hygrothermal comfort, the maximum values, minimum or reference, recommended by the legislation in force, were considered according to the hazard under analysis. Ranges of values were defined for each of the hazards, with risk factor 3 always being the one that will correspond to the most unfavorable case, such as, for example, the registration of a concentration of carbon dioxide higher than the maximum value recommended by the regulations in force. In short, the measurement of these parameters intends to evaluate and validate the fulfilment of standard requirements, vis-a-vis the applicable regulations and the required conditions of use and interior comfort. As an example, Table 6 shows the risk factors of the hazard "relative humidity" (*RH*).

Table 6. Risk factors—measurements: relative humidity.

Hazard Identification (H)	Type of Hazard	Risk Factor	Interval (%)
H1.4	Relative humidity	1	$40 \leq RH \leq 60$
		2	$30 \leq RH < 40$ or $60 < RH \leq 80$
		3	$30 > RH > 80$

For the "occupants' age" parameter, three risk factors were also adopted for each hazard, on a scale from 1 to 3. The application to the "overcrowding and space" hazard is exemplified in Table 7.

Table 7. Risk factors—occupants' age: overcrowding and space.

Hazard Identification (H)	Type of Hazard	Risk Factor	Occupants [1]
H3.1	Overcrowding and space	1	Number of occupants lower than the conventional number admitted for the housing typology
		2	Number of occupants equal to the conventional number admitted for the housing typology
		3	Number of occupants higher than the conventional number admitted for the housing typology

Remark: [1]—Portuguese legislation establishes that the conventional number of occupants of a dwelling is as follows: T0 (without bedrooms): 2; T1 (one bedroom): 2; T2 (two bedrooms): 3; T3 (three bedrooms): 4.

To determine the risk factors associated with the "housing location", four categories were created, in line with the most common types of location in Portugal, typified in regulatory documents, as, for example, to quantify the action of the wind in buildings, which are as follows:

- Inside the urban perimeter—dwellings located in urban centres;
- Outskirts of urban areas—dwellings located on the outskirts of urban centres;
- Rural area—dwellings located in small/medium settlements (villages and towns);
- Very exposed area (to the wind)—isolated dwellings, with no other dwellings within a radius of 200 m.

The application to the hazard "water supply" is exemplified in Table 8.

Table 8. Risk factors—housing location: water supply.

Hazard Identification (H)	Type of Hazard	Risk Factor	Location
H4.4	Water supply	1	Inside the urban perimeter
		2	Outskirts of urban area
		3	Rural area; very exposed area

Regarding the influence of the "housing age" on the probability of the occurrence of hazards, five intervals of age of housing of the dwelling were adopted, to take into account how long ago it was built, which are as follows:

- 0 to 10 years;
- 11 to 20 years;
- 21 to 30 years;
- 31 to 50 years;
- ≥51 years.

These intervals were defined based on the most relevant factors that can determine the difference in the type of construction, such as the materials used, the types of frames and doors, the layout of the house and the types of ventilation systems.

To determine the risk factors associated with the "age of housing", five levels were thus adopted, which are as follows:

- 1.00—has a low influence on the occurrence of the risk;
- 1.25—has a low to moderate influence on the occurrence of the risk;
- 1.50—has a moderate to high influence on the occurrence of the risk;
- 2.50—has a high influence on the occurrence of the risk;
- 3.00—has a severe influence on the occurrence of the risk.

It should be noted that for the application of this evaluation proposal, the time interval between the last general rehabilitation/remodeling works of the dwelling should be taken into account, such as the replacement of water supply pipes, electricity wiring and telecommunications and the placement of new window frames.

In Table 9, the risk factors taking into account the influence of the "housing age" are presented.

Table 9. Risk factors—age of housing.

Hazard Identification (H)	Risk Factor	Age of Housing (Years)
All hazards	1.00	0 a 10
	1.25	11 a 20
	1.50	21 a 30
	2.50	31 a 50
	3.00	≥51

After the risk factors' identification, the *HRC* will be determined. To establish this classification, the following parameters and respective weighting factors will be used:

- Average rating of visual inspection risk factors (ARVI)—0.20;
- Average rating of measurement risk factors (ARM)—0.25;
- Average rating of occupants' age risk factors (AROA)—0.25;
- Average rating of housing location risk factors (ARHL)—0.10;
- Average rating of age of housing risk factors (ARAH)—0.20.

It should be noted that, if there is more than one campaign to collect data and measurements, the most unfavorable classifications will be used, in another words, the worst cases recorded will be the ones considered.

Greater weight was given to "measurements" in view of their objectivity and "occupants' age". In the case of the latter, the added weight was due to the greater probability of the occurrence of safety and health risks, namely for the oldest and youngest occupants.

Bearing in mind all that has been outlined, the following expression is proposed to determine the *HRC*:

$$HRC = \mathrm{ARVI}\cdot 0.20 + \mathrm{ARM}\cdot 0.25 + \mathrm{AROA}\cdot 0.25 + \mathrm{ARHL}\cdot 0.10 + \mathrm{ARAH}\cdot 0.20 \quad (1)$$

After the *HRC* calculation, a classification by intervals will be used that defines the class of risk that the house presents, as illustrated in Table 10. The scores assigned to each degree of risk are based on the negative influence that the parameters can have on the health, safety and well-being of the occupants of the dwellings.

Table 10. Housing risk class (*HRC*): classification ranges, risk class and description.

HRC	Risk Class	Description
$1.6 < HRC$	Low	Low risk to occupants, with no likelihood of suffering any type of harm or injury
$1.6 \leq HRC < 2.0$	Moderate	Moderate risk to occupants, as they may sustain injuries that may lead to the need for medical assistance
$2.0 \leq HRC < 2.6$	High	Elevated risk to occupants as they may sustain serious injuries that will lead to the need for urgent medical assistance
$HRC \geq 2.6$	Severe	Severe risk to occupants, as they may suffer very serious injuries that will lead to the need for urgent medical assistance or even death.

4. Model Application

The application of the proposed evaluation model for the assessment of safety and health in housing (MASHH) allows for the evaluation of the functioning of the model and the validation of the quality of the results obtained.

The application of the model follows the sequence of the flowchart shown in Figure 1.

As the parameter "measures" is fundamental in the application of the method, the main measurement conditions (preferred) are as follows:

- Measurement of six parameters—relative humidity, carbon monoxide, carbon dioxide, formaldehyde, volatile organic compounds;
- Selection of the most significant months in relation to the heating seasons (e.g., December and January) and cooling (e.g., July and August)—measurement in the 4 months;
- Selection of the day of the week most representative of the occupants' activity (excluding weekends)—measurement on the chosen day every week for 4 months;
- Selection of the most representative compartments (e.g., kitchen, living room and bedrooms)—measurement in all selected compartments;
- Choice of measurement period on the chosen day (e.g., if the occupants eat lunch at home, the measurement time must cover before and after lunch)—measurement at least 5 h;
- Measurements must be taken at 30 s intervals.

For the purposes of calculating the risk factor, one should consider the following factors:

- The maximum temperature in the cooling season and the minimum temperature in the heating season;
- The minimum and maximum relative humidity in each season;
- The maximum value of the concentration of pollutants in each station.

For the purposes of calculating the housing risk class (*HRC*), one must consider the highest risk factor between the two stations.

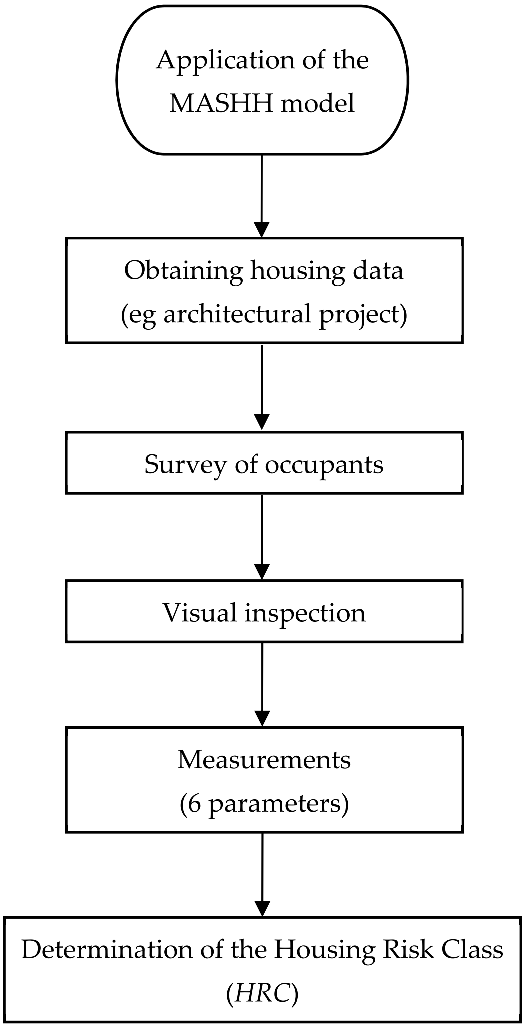

Figure 1. Flowchart of application of the MASHH model.

4.1. Case Studies—Characterization

The six houses used in the pilot study are located in the area of the city of Covilhã, which is situated on the southeastern slope of Serra da Estrela (the tallest mountain in continental Portugal). The city of Covilhã is the municipality's seat and it has an area of more than 555 km^2. The population, according to the 2021 census, is estimated at about 46 thousand inhabitants.

Portuguese thermal regulations [34] indicate approximately 2000 heating degree days (base 18 °C) for the town of Covilhã (average elevation = 750 m).

Table 11 shows the characterization of the six case studies, identified as Houses A to F, ordered by the decade of increasing construction, as well as the number of sampling points defined in each of the dwellings (compartments most representative of housing occupancy), where measurements of the six parameters were performed [33].

Table 11. Characterization of case studies.

House	Number of Inhabitants: Age Group	Housing Typology	Housing Location	Representative Decade of Construction	No. of Sampling Points in Measurements
House A	1: 41–60 years old 2: 21–40	T3 typology apartment in a multifamily building	Inside the urban perimeter	1960	5
House B	2: ≥61 years old	T3 typology apartment in a multifamily building	Inside the urban perimeter	1970	6
House C	2: ≥61 years old	Single-family dwelling of type T3	Very exposed area	1980	5
House D	2: 41–60 years old 1: 21–40	Single family habitation T4 semi-detached	Outskirts of urban area	1990	10
House E	1: 0–10 years old 1: 11–20 2: 41–60	Single-family dwelling of type T3	Very exposed area	2000	7
House F	1: 41–60 years old	T3 typology apartment in a multifamily building	Inside the urban perimeter	2010	6

4.2. Application of the Model to the Six Case Studies

Two times of the year were chosen to carry out the measurements of the six adopted parameters. To this end, two representative campaigns were designated, the summer campaign (cooling) and the winter campaign (heating), and measurements were recorded from May to July 2015 and from January to March 2016, respectively (spanning 9 weeks for each campaign). Measurements were recorded by parameter and by representative compartment in each case study.

Data relating to visual inspection, occupants' age and housing age were considered to be the same between the two measurement campaigns. Thus, for the determination of the *HRC*, only the classifications of the parameters that involved measurements were changed.

Table 12 presents the results obtained for *HRC* calculation, as well as the risk class assigned to each of the dwellings under study.

Table 12. Housing risk classes (*HRC*)—application of the MASHH model.

House	*HRC*	Risk Class
House A	2.38	High
House B	2.21	High
House C	1.85	Moderate
House D	1.76	Moderate
House E	1.65	Moderate
House F	1.48	Low

The analysis of the results of Table 12 shows that the classifications for the *HRC* vary between 1.48 and 2.38, with the risk class increasing with the increase in the construction's age. In this way, when applying the model to this sample, it can be concluded that, the higher the age of the dwelling, the higher the *HRC* score (reflected in its classification), and, consequently, a more unfavorable risk class for the occupants. It is also concluded that there is no case with a severe risk class and that House A is the worst classified (2.38), fitting into the high risk class. House F obtained a rating of 1.48 points, falling into the low risk class, with this housing being representative of the most recent construction decade.

Table 13 shows the average ratings of risk factors in House A and F, respectively, including the worst and best classified.

Table 13. Housing risk class (*HRC*)—parameters for Houses A and F.

House	Visual Inspection (ARVI)	Measurements (ARM)	Occupants' Age (AROA)	Housing Location (ARHL)	Age of Housing (ARAH)
House A	1.52	3.00	1.96	2.36	3.00
House F	1.00	2.29	1.07	2.36	1.00

The most serious risk factor for House A (worst classified) is that associated with "measurements", with a classification of 3.00 points, and the lowest was "visual inspection" with 1.52 points. In House F, the risk factor associated with "housing location" was the one with the highest rating (2.36 points), followed by the rating of the parameter "measurements".

Since the "measurements" parameter was one of the most unfavorable, Table 14 presents the values obtained for each house, in each of the campaigns. When using the methodology to determine the *HRC*, as already mentioned, the most unfavorable case between the two campaigns was the one to be considered. The measurement conditions were as follows:

- Measurements on a day of the week in the most representative compartments of each dwelling, obtained mostly in the afternoon;
- Measurements performed in 5-min periods, with 30 s intervals (five measurements) in each compartment.

Table 14. Risk factor "measurements"—Houses A and F.

	Campaign 1—Summer				Campaign 2—Winter			
	House A		House F		House A		House F	
Hazards	Measure.ts	Risk Factor	Measure.ts	Risk Factor	Measure.ts	Risk Factor	Measure.ts	Risk Factor
T (°C)	31.3	3	28.9	3	9.9	3	12.0	3
RH (-)	44.6/18.1	3	50.1/29.8	3	88.3/47.9	3	78.9/37.7	2
CO (ppm) [1]	2.1	1	0.4	1	17.4	3	0.6	1
CO_2 (ppm)	1014	3	845	2	1225	3	611	2
CH_2O (ppm) [2]	0.20	3	0.11	3	0.29	3	0.08	3
TVOC (ppm)	0.16	2	0.00	1	0.38	3	0.02	1

Remarks—according to Portuguese legislation at the time [35], the "protection threshold in existing buildings" are: [1]—to CO, 9 ppm; [2]—to CH_2O, 0.08 ppm.

For the purpose of calculating the risk factor, in the nine weeks and in all compartments, the following were considered:

- The maximum temperature in summer and minimum temperature in winter;
- Minimum and maximum relative humidity;
- The maximum value of the pollutants' concentration.

Some of the values presented in Table 14 are clearly concerning, namely in relation to the measurements of CH_2O and CO. It should also be noted that in 22% of the records obtained in the first campaign (summer), the concentration of formaldehyde was higher than the reference value (0.08 ppm). It is also worth mentioning, due to its especially hazardous nature, that an excessive value of CO was registered in the second campaign in House A.

As an example of the measurements carried out, Figures 2 and 3 show the average minimum temperature of all compartments (winter) for Houses A and F, and the average concentration of formaldehyde (summer), respectively, for all the houses.

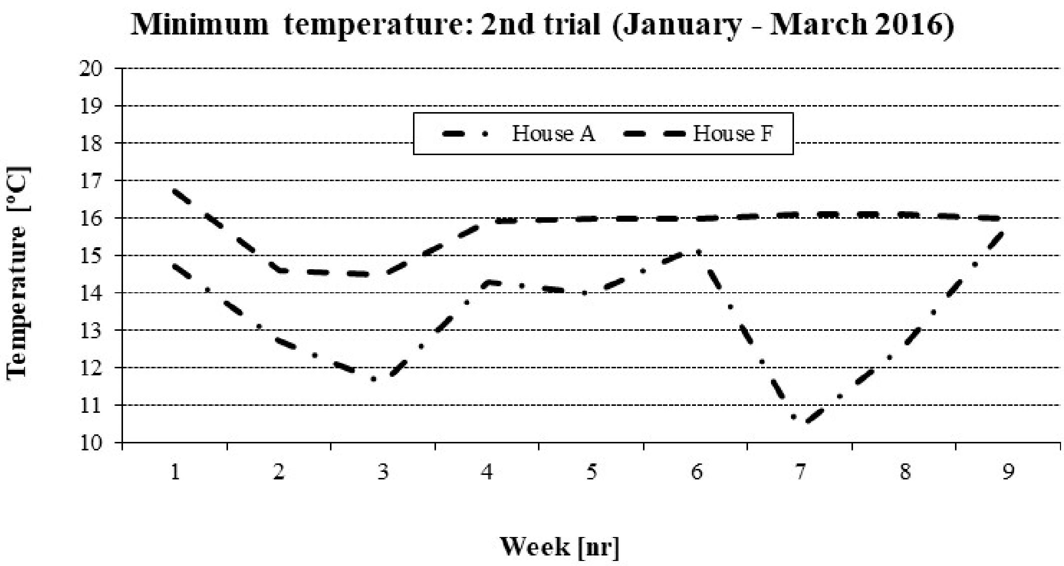

Figure 2. Average minimum temperature (winter)—Houses A and F.

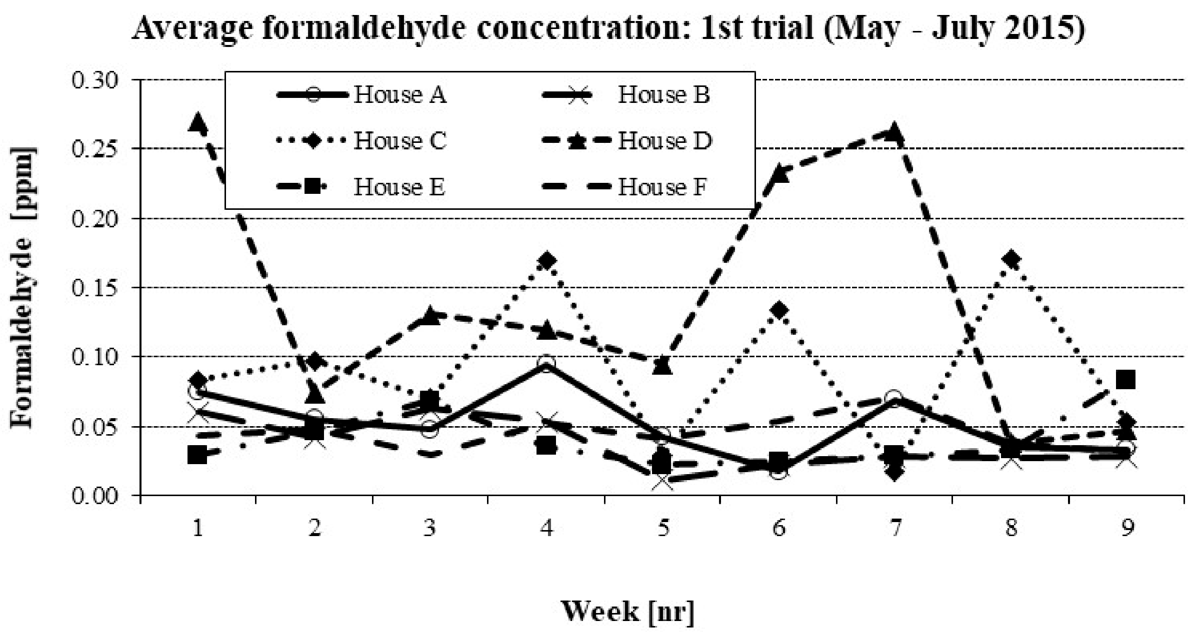

Figure 3. Average formaldehyde concentration (summer)—all houses surveyed.

From Figures 2 and 3, it can easily be concluded that Houses A and F present deficient comfort conditions in winter, with temperatures below the recommended minimum threshold (18 °C; House A has greater fluctuations in temperature, probably reflecting the outside temperature more easily), and that CH_2O concentrations have concerning values in Houses C and D.

4.3. Recommendations for Houses A and F

One of the applications of this method can be the adoption of recommendations to the occupants or owners. In this sense, Tables 15 and 16 present a summary of the records obtained by "visual inspection" and the survey applied to occupants for Houses A and F (Table 17).

Table 15. Visual inspection—Houses A and F.

House	Climate Control	Ventilation System	Energy Used in the Preparation of Meals; and in Domestic Hot Water	Exterior Walls; Blinds	Glazing: Type of Glass; Frame Material; and Opening System
House A	Intermittent heating with oil/electric radiators (only in some compartments during the day)	Natural ventilation in the kitchen; Natural ventilation of the bathrooms by opening a window	Gas and electricity; Gas	Single brick masonry without insulation; Plastic roller blind	Single glazing; Aluminum; Sliding (horizontal sash)
House F	Air conditioning	Intermittent mechanical exhaust in the kitchen; Natural ventilation in the bathroom	Electricity; Gas	Double brick masonry with insulation in the cavity; Aluminum roller blind	Double glazing; Aluminum; Tilt and turn

Table 16. Interior finishes of the main compartments—Houses A and F.

House	Compartments	Flooring	Walls	Ceiling
House A	Kitchen	Ceramic mosaics	Ceramic tile + painted cement plaster	Painted cement plaster
	Bedrooms	Wooden parquet	Painted cement plaster	Painted cement plaster
	Living room	Wooden parquet	Painted cement plaster	Painted cement plaster
House F	Kitchen	Ceramic mosaics	Ceramic tile	Painted stucco plaster
	Bedrooms	Wooden parquet	Painted stucco plaster	Painted stucco plaster
	Living room	Ceramic mosaics	Painted stucco plaster	Painted stucco plaster

Table 17. Survey of occupants—Houses A and F.

House	Type of Occupation?	Where Do You Eat Your Meals?	Have You Ever Noticed Moisture?	Is the Normal Temperature of Your Room Pleasant?	Activate the Blinds?	What Is the Frequency of Baths?
House A	Continuous	At home	Slightly—in glazed surfaces	Slightly. Unpleasant in summer and winter	Frequently	Daily shower in the morning
House F	Predominantly nocturnal	At home	No	Pleasant. Sometimes, in winter, it reaches 16 °C without heating	Frequently	Daily shower in the morning

For House F, as it is considered a recent construction with an adequate mechanical ventilation system and with glazed openings with good thermal insulation, only good practices of daily natural ventilation are recommended by opening windows, and the use of the (already installed) air conditioning equipment, whenever necessary, to reduce the negative impact that low/high temperature peaks have on the occupants of the dwelling.

In House A, it is recommended to check the air permeability of the frames and forms of shading, so that they promote the increase or decrease in the interior temperature of the house depending on the time of year, using simultaneously, if necessary, the heating system. However, it is strongly recommended to invest in the reinforcement of the thermal insulation of the exterior walls and in the installation of a more efficient heating system.

Regarding the CH_2O values recorded, these may be due to the by-products of the combustion of cigarettes and non-ventilated appliances that burn fuel, such as gas stoves and space heaters. It is important to reduce the concentration of this pollutant using, for example, the ventilation of spaces. The abnormal value of CO verified in the winter season implies a general review of the heating and cooking systems. In this case, especially in the corresponding smoke and gas exhaust system.

5. Conclusions and Future Work

This article presents a new model for assessing health and safety in housing, applicable in Portugal, although adaptable to other geographical contexts. Twenty-eight hazards and their risk factors were identified.

The application of the new housing safety and health assessment model (MASHH) to the six case studies made it possible to assess its applicability to dwellings and properties with different occupant profiles (number and age), different types of location and construction ages, and with different architectural characteristics. In other words, the application of the model made it possible to test and validate the evaluation proposal, using different inputs.

Thus, with the application of the model to the various case studies, it appears that the same dwelling may have a different risk classification, depending on the ages of the occupants, since some age groups are more vulnerable. Likewise, houses with the same characteristics may obtain a more or less favorable risk class, depending on its location, taking into account the associated hazard factors. Or even, it may be the case where, for the same occupants, changing the dwelling for another with a higher age can worsen the negative effect on their health, safety and well-being.

Based on the work already carried out, and in order to test and improve this evaluation model, the following objectives are proposed:

- To study the influence of the penalization of the risk factor associated with the "housing location" parameter as a function of the climate (e.g., adopting a higher risk factor in areas with average outdoor temperature or degree days above a certain value);
- To study the influence of penalizing the risk factor for the "occupants' age" parameter in terms of the most vulnerable risk groups (e.g., adopting a higher risk factor for occupants under 5 and over 65 years old);
- To adjust the *HRC* calculation formula, so that it is possible to characterize a dwelling without occupants (new or uninhabited dwellings), thus simulating the classification according to the foreseeable occupancy;
- To analyze the weighting of risk factors and the weighting of the *HRC* calculation formula based on surveys (e.g., surveys of occupants, engineers and architects);
- To simplify the "measurements" parameter in order to implement a rapid assessment model, for example by creating the analogy between the energy efficiency class and the risk factors of the hazard "HG1—hygrothermal conditions";
- To promote medical studies on the occupants so as to confirm the relationship between their overall health status and the potential risks detected in their homes.

The application of a safety and health assessment model in housing could be especially useful, for example, for real estate companies and owners/developers (in an equivalent way to the existing energy certification). However, at the moment, the model still has some limitations, such as, for an effective and credible implementation, it will be necessary to harmonize the perception of inspectors in visual inspection and in the proficiency of applying standard operation procedures for the different apparatus used to obtain the parameter measurements, especially through training courses.

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Abbreviations

CO	Carbon monoxide, (ppm)
CO_2	Carbon dioxide, (ppm)
HRC	Housing risk class
CH_2O	Formaldehyde, (ppm)
RH	Relative humidity, (–)
IEQ	Indoor environment quality
PM_{10}	Particles less than 10 microns in size
$PM_{2.5}$	Particles less than 2.5 microns in size
SBS	Sick building syndrome
T	Temperature, (°C)
TVOC	Total volatile organic compounds, (ppm)
VOCs	Volatile organic compounds, (ppm)

References

1. Braubach, M.; Jacobs, D.; Ormandy, D. *Environmental Burden of Disease Associated with Inadequate Housing. A Method Guide to the Quantification of Health Effects of Selected Housing Risks in the WHO European Region—Summary Report*; World Health Organization: Copenhagen, Denmark, 2011.
2. WHO. *Health Co-Benefits of Climate Change Mitigation—Housing Sector*; World Health Organization: Geneva, Switzerland, 2011.
3. WHO. *Effects of Air Pollution on Children's Health and Development: A Review of the Evidence*; World Health Organization: Copenhagen, Denmark, 2005.
4. WHO. *Inheriting a Sustainable World? Atlas on Children's Health and the Environment*; World Health Organization: Geneva, Switzerland, 2017.
5. Ashmore, M.; Dimitroulopoulou, C. Personal exposure of children to air pollution. *Atmos. Environ.* **2009**, *43*, 128–141. [CrossRef]
6. Mendell, M. Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: A review. *Indoor Air* **2007**, *17*, 259–277. [CrossRef] [PubMed]
7. Mejía, J.; Choy, S.L.; Mengersen, K.; Morawska, L. Methodology for assessing exposure and impacts of air pollutants in school children: Data collection, analysis and health effects—A literature review. *Atmos. Environ.* **2011**, *45*, 813–823. [CrossRef]
8. INE. Census 2021. In *Release of Provisional Results*; INE (Instituto Nacional de Estatística—National Institute of Statistics): Lisbon, Portugal, 2021. (In Portuguese)
9. Bradshaw, S.; Playford, E.; Riazi, A. Living well in care homes: A systematic review of qualitative studies. *Age Ageing* **2012**, *41*, 429–440. [CrossRef] [PubMed]
10. Van Hoof, J.; Schellen, L.; Soebarto, V.; Wong, J.K.; Kazak, J.K. Ten questions concerning thermal comfort and ageing. *Build. Environ.* **2017**, *120*, 123–133. [CrossRef]
11. WHO. *World Report on Ageing and Health*; World Health Organization: Geneva, Switzerland, 2015.
12. Sharpe, R.A.; Thornton, C.R.; Nikolaou, V.; Osborne, N.J. Fuel poverty increases risk of mould contamination, regardless of adult risk perception & ventilation in social housing properties. *Environ. Int.* **2015**, *79*, 115–129. [CrossRef] [PubMed]
13. Magalhães, S.; Leal, V.; Horta, I. Predicting and characterizing indoor temperatures in residential buildings: Results from a monitoring campaign in Northern Portugal. *Energy Build.* **2016**, *119*, 293–308. [CrossRef]
14. Liddell, C.; Morris, C.; Thomson, H.; Guiney, C. Excess winter deaths in 30 European countries 1980-2013: A critical review of methods. *Public Health* **2015**, *38*, 806–814. [CrossRef] [PubMed]
15. WHO. *WHO Housing and Health Guidelines*; World Health Organization: Geneva, Switzerland, 2018.
16. WHO. *Large Analysis and Review of European Housing and Health Status (LARES)—Preliminary Overview*; World Health Organization: Copenhagen, Denmark, 2007.
17. Ormandy, D.; Véronique, E. Health and thermal comfort: From WHO guidance to housing strategies. *Energy Policy* **2012**, *49*, 116–121. [CrossRef]
18. Johner, N.; Roulet, C.A.; Oostra, A.; Foradini, F. Correlations between SBS, perceived comfort, energy use and other building characteristics in European office and residential buildings. In Proceedings of the 10th Indoor Air Conference, Beijing, China, 4–9 September 2005.

19. Roulet, C.A.; Cox, C.; de Oliveira Fernandes, E.; Müller, B. Health, comfort, and energy performance in buildings. Guidelines to achieve them all. In *EU Programme: Energy, Environment and Sustainable Development (CONTRACT No: ENK6-CT-2001-00505)*; EU: Maastricht, The Netherlands, 2005.
20. Canha, N.; Lage, J.; Galinha, C.; Coentro, S.; Alves, C.; Almeida, S.M. Impact of biomass home heating, cooking styles, and bread toasting on the indoor air quality at Portuguese dwellings: A case study. *Atmosphere* **2018**, *9*, 214. [CrossRef]
21. Almeida, M.; Lopes, I.; Nunes, C. Characterization of indoor air quality in Portugal—HabitAR study. *Port. J. Immunoallergol.* **2010**, *18*, 21–38.
22. Madureira, J.; Paciência, I.; Cavaleiro-Rufo, J.; Fernandes, E.D. Indoor air risk factors for schoolchildren's health in Portuguese homes: Results from a case-control survey. *Toxicol. Environ. Health Part A* **2016**, *79*, 938–953. [CrossRef] [PubMed]
23. Santos, R. Indoor Air Quality in Nurseries: Study of Concentrations of Volatile Organic Compounds. Ph.D. Thesis, Lusófona University, Lisbon, Portugal, 2017. (In Portuguese).
24. Wierzbicka, A.; Pedersen, E.; Persson, R.; Nordquist, B.; Stålne, K.; Gao, C.; Harderup, L.E.; Borell, J.; Caltenco, H.; Ness, B.; et al. Healthy indoor environments: The need for a holistic approach. *Environ. Res. Public Health* **2018**, *15*, 1874. [CrossRef] [PubMed]
25. Lanzinha, J. Rehabilitation of Buildings—Diagnosis and Intervention Methodology. Ph.D. Thesis, University of Beira Interior, Covilhã, Portugal, 2006. (In Portuguese)
26. Vilhena, A. Method for Assessing the State of Conservation of Buildings: Analysis and Contributions to Its Improvement and Broadening of the Scope. Ph.D. Thesis, Higher Technical Institute (IST), Lisbon, Portugal, 2011. (In Portuguese)
27. Balaras, C. A special issue devoted to EPIQR. *Energy Build.* **2000**, *31*, 97–170. [CrossRef]
28. Caccavelli, D.; Gugerlib, H. TOBUS—A European diagnosis and decision-making tool for office building upgrading. *Energy Build.* **2002**, *34*, 113–119. [CrossRef]
29. *France 2003, Circulaire DGS/DGUHC/SD7C/IU H4 n.° 293 du 23 juin 2003*; Ministère de la Santé, de la Famille et des Personnes Handicapées: Paris, France, 2003. (In French)
30. *NEN 2006, NEN 2767-1:2006*; Conditiemeting van bouw- en Installatiedelen—Deel 1: Methodiek. NEN: Delft, The Netherlands, 2006. (In Dutch)
31. Pedro, J.; Paiva, J.; Vilhena, A. Portuguese method for building condition assessment. *Struct. Surv.* **2008**, *4*, 322–335. [CrossRef]
32. Office of the Deputy Prime Minister. *Housing Health and Safety Rating System*; Operating Guidance: London, UK, 2006.
33. Monteiro, M. Housing and Health. Methodology for Risk Assessment for Occupants. Ph.D. Thesis, University of Beira Interior, Covilhã, Portugal, 2020. (In Portuguese)
34. *Directorate-General for Energy and Geology, Order 6476-H/2021*; Building Energy Certification System Manual (SCE): Lisbon, Portugal, 2021. (In Portuguese)
35. *Ministries of the Environment, Ordination, Territory and Energy, Health and Solidarity, Employment and Safety Social, Ordinance 353-A/2013*; Energy Performance Regulation of Commercial and Services Buildings (RECS)—Ventilation and Indoor Air Quality Requirements: Lisbon, Portugal, 2013. (In Portuguese)