Journal of Engineering Sciences
Assiut University
Faculty of Engineering
Vol. 45
No. 5
September 2017
PP. 722 – 741

STUDYING THE INDOOR AIR POLLUTION WITHIN THE RESIDENTIAL BUILDINGS IN EGYPT: AS A FACTOR OF SUSTAINABILITY

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Received 25 July 2017; Accepted 29 August 2017

ABSTRACT

The paper aims to propose a framework, to study the indoor air pollution within the residential buildings in the architectural scope. This framework is handled in two phases. The first phase is the technical solutions, which divided into categories, subcategories, and strategies (solutions). The second phase is the framework's activation, which comes through an assessment tool's extraction. This tool is formed in a comprehensive, configurable, and multidisciplinary checklist. This checklist covers the overall technical solutions' categories and subcategories. Then, it conducts the strategies to specific & measurable indicators, by setting maximum points for each indicator. Assessment of indicators depends on the relative importance, which set depending on the specialists' teamwork.

The proposed checklist can help both designers and evaluators, in both design & assessment phases. Officially, it can be activated through a multidisciplinary of specialist's teamwork. Hence, certified licenses can be released. Activation needs to establish a specific & official authority to can assess the concluded indicators. Hence, it can be used as a part of the licensing requirements for new projects before its awarding regarding IAQ. Also, evaluators can use it to assess the existing projects. Then, the study findings represent a step to study the indoor air pollution and to promote sustainability.

Keywords: Indoor Air Pollution; Indoor Air Quality; Residential Buildings; Sustainability.

1. Introduction

Earlier researchers reached to that, People usually spend around 90% of their daily time at indoors. Related residential buildings, occupants spend between 53% to 82% on it. Therefore, the quality of the indoor environment is essential determinative of people's health [1]. Also, the indoor air pollution as a problem is important to be addressed. This refers to the pollution output rates, which reach tens of times compared with the outdoor pollution. The indoor air pollution increases due to rising use of manufactured building materials, finishes, furniture, HVAC systems, and various building chemicals, etc.

Apparently, the scientific outcomes, particularly in Egypt, the IAQ concerns in residential buildings still have slight care. So, the paper aims to study the aspects & factors of the indoor air pollution through a framework in two phases. Phase 1 proposes the technical solutions, which extracted to address the most repeated issues of the research problem.

The second phase aims to discuss the framework's activation. It comes from extracting a tool to summarize the strategies that addressed inductively, then reaching to the corresponding and concluded indicators. Hence, consentient specialist's teamwork can measure these indicators in more details. Where, it relies on scientific data and equipment, as it was executed in similar approaches abroad. The framework in two phases helps as a starting step in this scientific area in the Egyptian real scope. Fig. 1. illustrates the sequence of the study and the research skeleton.

2. Method

The trend of the research problem led to use the <u>Induction</u> method. Mostly, the research sections depended on the authoritative, professional, academic books & reports, specialized scientific journals, and academic theses. Chronologically, the references were chosen to be up to date, to understand the research problem with the existing relationships between the various sub-phenomena of the basic phenomenon. Also, <u>Deduction</u> method is used in extracting the proposed checklist which helps with concluding the indicators that based on the strategies of the most repeated aspects. Also, a <u>Mathematical</u> method is set to measure the indicators, depending on both points & relative importance's method.

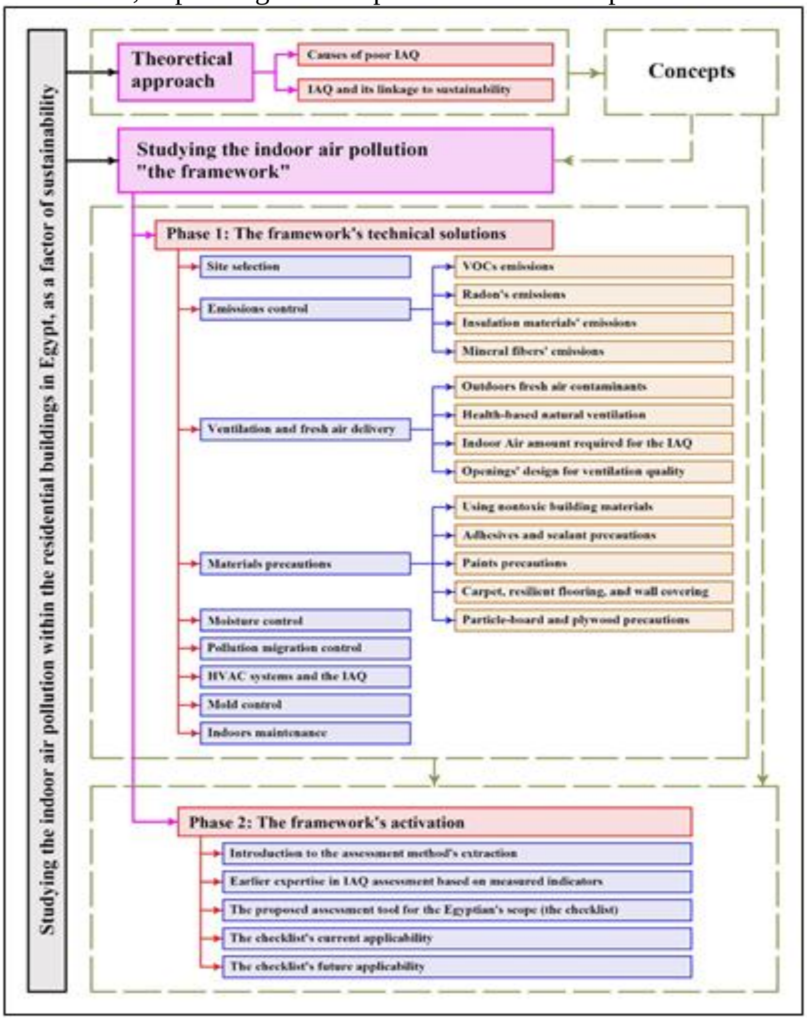

Fig. 1. The research skeleton

3. Theoretical approach

It comes in two brief approaches as a concise preface to the proposed framework.

3.1 Causes of poor IAQ

The studies in the last decades confirmed that the main causes of poor IAQ are:

52% inadequate ventilation, 16% contamination from inside buildings, 10% contamination from outside buildings, 5% microbial contamination, 4% pollution from building fabric, and 13% from unidentified sources [2].

Pollutants cause poor IAQ from varieties of the sources, including outside air. It can be considered as any cause that reduces the comfort and health standard of the IAQ. And it includes overheating through solar gain, humidity, dust, and microbes, etc. As shown in Fig. 2 [3].

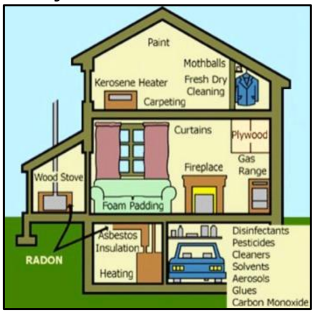

Fig. 2. causes of poor IAQ

3.2 IAQ and its linkage to sustainability

Integration of the IAQ considerations in sustainable designs suffers from insufficiency of comprehensive and information-based assessment methods. Guidance and rating systems for "green" buildings fail to handle the compromises necessary for assessment of the of the building performance [4].

Lately, different tools are developed to assess the ability to measure the greenness of buildings [5]. It depends on setting the different efficiency's aspects, design's points, and indices. It is typically classified into six main categories, which are site planning, water management, energy management, material use, indoor air quality, and Innovation & design process. Therefore, it explains the importance of the IAQ as a significant pillar of the Indoor Environmental Quality (IEQ), and in this way for encouraging sustainability.

4. The framework of "studying the indoor air pollution"

It comes in two phases. The first phase is the framework's technical solutions, and the second is the framework's activation. The two phases are detailed as follows:

4.1 The framework's technical solutions

Technical solutions are the first phase of the framework. It attempts to arrange guidance on materials, designs, and procedures for avoiding the indoor air pollution. It comes with main nine technical solutions (categories). It handles the main concerns and explores the most repeated approaches for preventing or minimizing the indoor air pollution. So, it is divided into main nine categories, which branched into subcategories that detailed through strategies (technical solutions). This phase details can be explained in Fig. 3.

4.1.1 Site selection

It is the first category. It handles the following factors of the site's circumstances which affect the IAQ. These are [6]:

- Local geography, regarding the site ridges, mountains, and water masses.
- The ambient rural context through agrarian abuses, gardens, arid soils, and irritant, etc.
- Urban context through the remains, vicinity to trash dustbins, and adjoining building exhaust which influences the fresh air intakes, Fig. 4.
- Transportation runs out from streets, low emitting & fuel efficient vehicles, parking garages' capacity, railway tracks, and terminals, etc.
- Public transportation access and bicycling [7].
- Industrial enterprises with its ingredients and impacts & pollution reduction control.
- Undesired soil gases & fumes, as radon, leakages, and earlier harmful usage of the site.
- Passive adjacent construction activities with a threat or semi-hazardous materials, like bitumen and asbestos.

So, the urban forest concept can be considered about urban and site solutions, to reduce particles at the air [8].

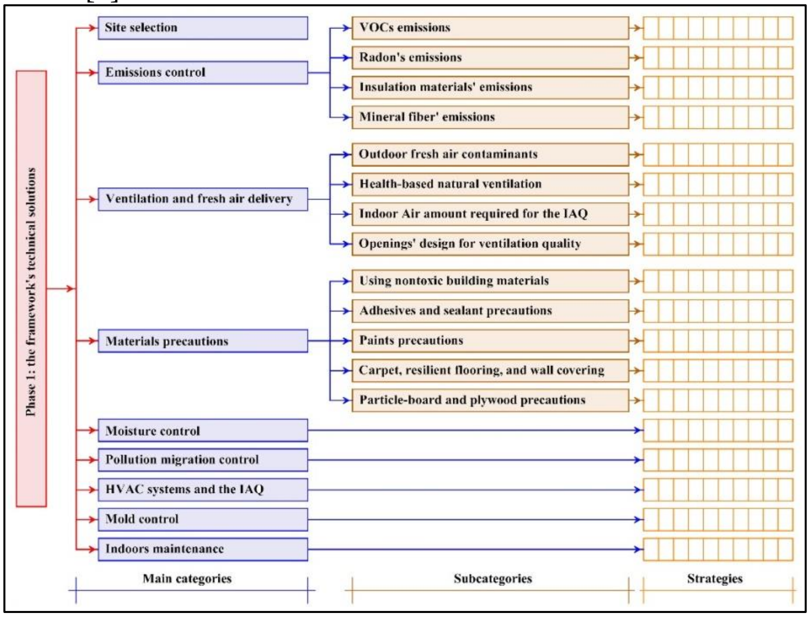

Fig. 3. Phase 1: the framework's nine technical solutions

4.1.2 Emissions control

It is handled in four subcategories as follows:

4.1.2.1 VOCs emissions

The Volatile Organic Compounds (VOCs) contain all chemicals that have carbon and hydrogen. Types of indoor decorations, coats, and other building materials can produce it, through paints, solvents, adhesives, matters, fabrics, and fibers. Odors associated with an increase of VOCs resemble those linked to the above matters. The increasing variety of possible causes and contents renders it impractical to test the concentrations of each chemical alone. So, the way of total VOCs attempts to deal with this practical control. A simple test of the total VOCs can be executed without the separation between individual compounds [9].

Controlling the VOCs concentrations poses a specific difficulty where filtration and source control are crucial. This refers to the existing of the many origins of VOCs in buildings, including construction materials, furnishings, and cleaning supplies. The wide potential of VOCs inside buildings makes individual measurement difficult and expensive. As a result, the most common way of handling is to end their sources. Then, it should be decreased, whatever concentrations stay with outdoor air.

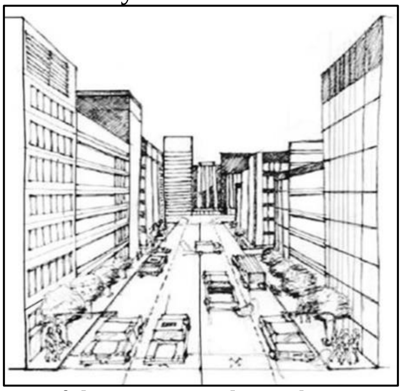

Fig. 4. effects of dense surrounding urban context on the IAQ

4.1.2.2 Radon's emissions

Radon can enter the indoors as shown in Fig. 5, through [10]:

A. Cracks in concrete.	B. Spaces behind walls.	C. Pores & cracks in blocks.
D. Floor.	E. Wall joints.	F. Exposed soil as in a sump.
G. Weeping tile.	H. Mortar joints.	I. Penetrations of a loose-fitting pipe.
J. Walls' open tops.	K. Foundations.	L. Well water.

Hence, radon-resistant can be handled through:

A. Gaseous porous layer.	B. Plastic sheeting.	C. Sealing and caulking.
D. Vent Pipe.	E. Junction box.	

Also, other radon reduction techniques can include sealing, room pressurization, and heat recovery & natural ventilation, as illustrated in Fig. 6 [11].

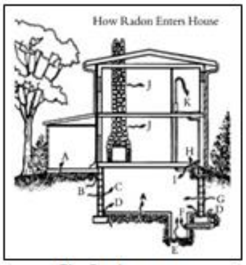

Fig. 5. radon sources

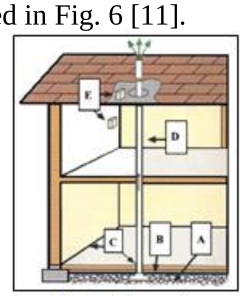

Fig. 6. Radon resistant (construction techniques)

4.1.2.3 Insulation materials' emissions

Insulators are one of the most common health problems in buildings. Especially, those are responsible for high levels of formaldehyde. Industrial foam produces many highly toxic gases when heated or burned. It forces people to use protective masks when exposed to the incineration of such insulators or the occurrence of indoor fires. Most of the deaths from building fires are due to carbon dioxide released from the insulation components' incineration. So, most of the construction's requirements & codes need to keep the insulation materials away from the occupants. Also, fire-resistant's material should be considered . For example, gypsum is advised [12].

4.1.2.4 Mineral fiber's emissions

Fine mineral fibers include mineral fiber emissions from facilities, manufacturing or processing, glass, rocks or slag fibers. It is embodied in this description the synthetic vitreous fibers, which consist of, glass wool, rock wool, slag wool, glass filaments and ceramic fibers.

Acute short-term influences of fine mineral fibers in people did not go on after exposure ceased. Hereabouts, the investigations have reported a rise in lung tumors in animals exposed to ceramic fibers by inhalation. While, no increase in tumors was recorded from exposure to glass wool, rock wool, or slag wool. Environmental Protection Agency (EPA) has classified refractory ceramic fibers as probable human carcinogens.

The National Toxicology Program (NTP) [13] categorized glass wool fibers as moderately predicted to be a cancer cause [14]. So, using these fibers needs a certain attention to design, solutions, and details, etc. to manipulate these emissions to the outsides through natural ventilation.

4.1.3 Ventilation and fresh air delivery

In this context, ventilation can be defined as the air supply from outside to indoors for reducing the indoor air pollution and treating the Sick Building Syndrome (SBS) [15]. That depends on the occupation and the pollution ratio (ventilation rate/capita) through the fresh air quality. Both quantity of air & precautions of mechanical devices and also the design of the architectural openings can adjust the ventilation. This category is addressed through four subcategories as follows:

4.1.3.1 Outdoors fresh air contaminants

It is around 10% of total cases of SBS. Overzealous energy-saving procedures are often the direct cause of inadequate fresh outdoor air which enters ventilation systems.

Smog is a large-scale outdoor pollution which primarily caused by an automobile exhaust and industrial emissions. Cities are significantly considered as centers of these kinds of activities. It suffers from the impacts of smog, especially, during the warm months.

The precise reasons of pollution in cities may be different relying on temperature, the geographical location, wind & weather factors, and the pollution, which are scattered differently. Occasionally, it does not occur and the air pollution can increase to risky ranks [16].

Contaminant sources as sanitary vents, cooling towers, vehicular waste from parking garages, landing docks, and traffic should be obviated. Also, a special care should be taken to avoid types of moisture drift from cooling towers into the makeup air and building vents. Even, the outdoor air of acceptable quality can become contaminated if brought into the building through contaminated outdoor air intakes and duct-works [17].

4.1.3.2 Health-based natural ventilation

Noteworthy, inadequate ventilation causes around 52% of SBS [18]. Human comfort and ventilation can be considered by the heat balance through indices and models. At indoors, the required amount of oxygen is necessary to stop the increase of carbon dioxide & unwanted odors. Additionally, to reduce the amount of carbon monoxide & other products of combustion to a level below the level that harms health. Then, smoking's pollution should be considered.

As known, air quality results from a range of factors, as the concentration of carbon dioxide. Calculating the amount of fresh air per person per hour (Q), on condition that the concentration of carbon dioxide does not increase over than 0.5% needs the following equation [19]:

Q = q.100 / (0.5- 0.05) ×1000 = q / 4.5 m^3 / h per person. Where, (q) is emission rate (m^3/h).

If the production of carbon dioxide is about 18 l / h in the case of dormancy, then:

Q = 4 m^3 / hour / person.

But, with manual labor, the production of carbon dioxide is 54 liters/hour.

Then, Q = 12 m^3 / hour / person.

These rates aren't enough for the odors Impact's mitigation. The aim of ventilation is not to have unacceptable odors in a significant amount of buildings, but to ensure minimum ventilation requirements which are important in kitchens, bathrooms, and toilets. So, connection to the outdoors is needed.

Last, by taking carbon monoxide into account, the smell's standard is not the only matter needed, but also more ventilation is required where carbon monoxide gas is still toxic, even if at little concentrations. Then, limiting it in the residential building is considered as 0.01% [20].

4.1.3.3 The indoor Air amount required for the IAQ

It is considered through studying contaminants, ventilation rates, and the effectiveness of air change & age of air, the ventilation systems, and energy needs for ventilation. Calculating air infiltration need taking air leakage characteristics of buildings, modeling studies, and measurement steps [21].

Unsatisfactory ventilation can occur if the HVAC systems do not passably distribute air in buildings. Till about the middle of 1900's, building ventilation standards defined around 7.08 liter/s of outside air /person, to reduce & remove odors. Later, a decrease in the outdoor air provided for ventilation reached to 2.36 liter/s/person to achieve satisfactory IAQ with reducing energy amount used. Lately, ventilation standard is changed by ASHRAE, to be a minimum of 7.08 liter/s of outdoor air /person. Up to, 28.137 liter/s/person may be needed in the zones like the smoking lounge that depending on the activities in these spaces [22].

4.1.3.4 Openings' design for ventilation quality

Openings and their shapes should be studied to ensure efficient performance in terms of transition or thermal insulation, lighting, and effective solar radiation treatment. So, reference can be made relying on several of the climatic control's studies to prove its impacts on the indoors. It can come in terms of shapes, measurements, and orientation, etc.

Noteworthy, the typical windows (solar, glass, and wire mesh) deal with this point successfully. Particularly, if many other criteria are taken into consideration, such as IAQ, ventilation, shading, air conditioning control, privacy, and preventing harmful insects.

Also, the windows with fine details, Fig. 7, can also control both indoor and outdoor air, where openings can be used in some cases, as:

- Increased outdoor pollution at a high rate.
- There is over one source of pollutions, such as high outside noise.
- Confronting spread of fungi and chemical contaminants, or others which caused by microorganisms from the ambient environment.

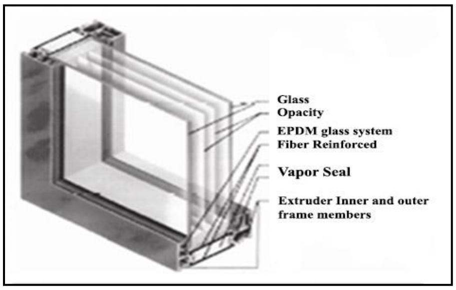

Fig. 7. openings details for ventilation

4.1.4 Materials precautions

According to LEED, the Indoor Environmental Quality (IEQ) takes 15/69 points. Only materials as a specific indicator take 4/15 points of them. The material takes 13/69 (total possible points) [23]. So, it gives a clear result by its importance. Hence, for the IAQ, it can be detailed in 4 basic points as follows:

4.1.4.1 Using nontoxic building materials

The environmental effects should be studied over the life-cycle where that material emits the contaminants that may be shortened or extended to the whole age of the buildings. For example, adhesives, types of glue, chemicals, formaldehyde, benzene, and ammonia which can cause unhealthy impacts to occupants [24]. So, products that contain: solvents, glues, and plastics are not preferred.

Noteworthy, there are an increasing number of commercial sources of natural paints, glues, materials, and systems. Economically, it can be substituted, but it has a dangerous impact as a building material, for example, particleboard, wafer board, carpet, foams, and paint. Also, decreasing the entire VOCs intensities with considering the size needs may need, for example, using the natural (and unpainted) lime-cement plaster, sand, and solid wood as wall finishes. Similarly, concrete, linoleum, solid wood, and ceramic tiles for floor finishes can be used as well.

It is safer to use the organic adhesives with less VOCs and chemically based emissions. It includes aromatic solvents that have little or no odor during manufacturing, construction, and disposal stages [25]. Finally, about occupants and maintenance staff, they must also avoid material and products that might affect the IAQ.

4.1.4.2 Adhesives and sealant precautions

It can be used wet and dry, or for curing on the premises, wherever the solvents used in of preparation of these materials are directly related the produced VOCs. The resins used in the base of adhesives are natural or synthetic, and it ranges from low to high rates of emission. Also, Sealants which consist of putties, caulking compounds, rubber, acrylic latexes, and silicones should be carefully taken about emissions. Similarly, paints, stains, sealers and varnishes which used in coatings should be considered [26]. Cracks and joints are weak points in the IAQ handling. It requires adhesives and sealant to decrease infiltration & conditions contributing to pest access and mitigates the radon’s impact as well [27].

So, in some architectural works, as, wood flooring, carpet pad adhesives, rubber floor, ceramic tiles, subfloor, asphalt, multi-purpose construction, drywall & panel, and structural glazing, for all these VOCs Limits must be considered according to the standards [28].

4.1.4.3 Paints precautions

These precautions should be taken in handling architectural paints, coatings, and primers, also, anti-corrosive, anti-rust paints, clear wood finishes, floor coatings, stains, and shellacs, all of these must follow low VOCs emissions and recommended that paints should be implemented during empty periods and fast-drying paint as workable. It is recommended that keeping lids on paint containers when not in use.

Also, it should keep building ventilation with significant quantities of outside air during and after painting, to ensure a complete building flush before occupancy. As a recommendation, using more than normal outside air ventilation for the period after occupancy and avoiding spraying when possible should be taken. Hence, it is preferable to use water-based or natural materials or composite materials with lower emission ratios.

4.1.4.4 Carpet, resilient flooring, and wall covering

Using of adhesives to attach the material to various surfaces can bring VOCs into the indoors. Now, the floors are usually poured concrete, and often covered with vinyl tile, terrazzo or carpet. Vinyl and asbestos tile was widely used lately in new buildings; floor coverings are glued-down industrial-grade carpeting. Emissions from carpeting and associated adhesives have been the of the IAQ complaints in buildings where carpeting becomes a sink for a wide diversity of organic particles [29].

Acoustic treatment materials, carpets, upholstery fabrics are considered of most absorbers for organic compound emissions /unit area. So, some details for floors Fig. 8. can be done to achieve the integration between ventilation studies and the IAQ through lifted floors technique where it can be covered with natural materials or any other suitable coverages [30].

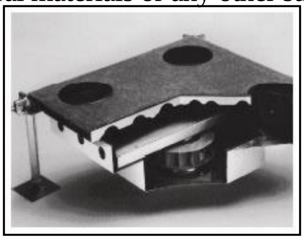

Fig. 8. VOCs emissions control through floor ventilation's details

4.1.4.5 Particle-board and plywood precautions

Particleboard is a composite product made from wood chips or residues that are bonded together with adhesives. Typically, it comes from milling or woodworking waste. Plywood is made up of about thin sheets or layers of wood which glued with adhesive. It is categorized to softwood & hardwood. Substantially, the IAQ is affected by softwood and hardwood where its characteristics are varied with the adhesives [31].

Hardwood unusually has more effects to IAQ compared with softwood. Hardwood is glued with urea-formaldehyde adhesives, which releases formaldehyde for months or years later of production. Phenol-formaldehyde adhesives, commonly used in softwood, are steadier and have minor formaldehyde emissions. Usually, softwood can be used in the exterior [32].

4.1.5 Moisture control

Moisture control in building assemblies can be done through limiting penetration of liquid water into the building envelope, and also by limiting water of vapor condensation. Also, it can be done on interior surfaces, through maintaining proper building pressurization, controlling humidity, selecting suitable materials, equipment, and assemblies for unavoidably wet areas. That also considers the impact of landscaping and indoor plants for moisture and contaminant levels.

Also, for mechanical systems and Bath's zone, moisture control should be considered, where dirt in air handling systems, piping, plumbing fixtures, and duct-works should be examined. Besides, facilitating access to HVAC for inspection, cleaning & maintenance and control of legionella in water systems that need more care [33].

As well, possibly to rely on porous materials without covering or coating it with paints that fills their pores. So, it helps in retaining the moisture in its pores at night and releases it at daytime. Also, it helps in improving the IAQ and causing thermal comfort as well. For example, of the materials which not covered with paints, as bricks, natural stones, and wood, especially if the relative humidity of indoors within 85% [34].

4.1.6 Pollution migration control

The architect should conceptualize the indoors' zones to limit their effects on each other. For example, as shown in Fig. 9, the kitchens should be protected of fumes, odors, and emissions related the food preparation systems [35]. As well, the disposal of waste from bathrooms should be separated from the living & the sleeping zones to prevent odors and unhealthy & undesirable emissions emitted by them. These spaces' placement should be set under wind influence. Then, leakage can be directed to outdoors.

Residential buildings may also include certain needs in terms of tools & activities such as imaging tools, computers or those based on radiation. These can impact on the IAQ and its characteristics. So, the environmental aspects of that equipment about its technical specifications and methods of use should be taken over the choice of species having certificates or licenses. Using it later than passing the tests of the quality & performance is important.

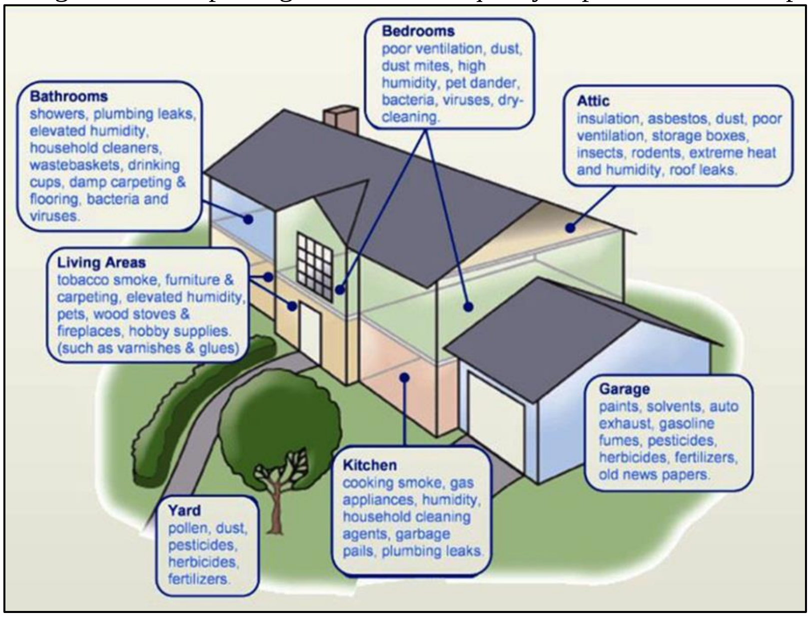

Fig. 9. The IAQ particulate sources

4.1.7 HVAC systems and the IAQ

Operation and maintenance of HVAC systems play a critical role in maintaining the acceptable IAQ and the thermal comfort as well at a reasonable energy cost. Fail of its design, install, commission, operation, and maintenance may lead to IAQ complaints.

Then, supplying conditioned air to indoors at an adequate outdoor air delivery rate is needed. The quantity or distribution of outdoor adequate air, which serves the ventilation, is needed. Under conditions of inadequate outdoor air ventilation, human bio-effluents and other indoor contaminants may build up in the indoors to levels that may affect health or comfort.

HVAC systems can also play a role in distributing contaminants to the occupied spaces from external sources or other internal sources. Also, it can be a cause of pollution, if not well preserved. Internal rusting, debris accumulation and deterioration of internally insulated surfaces can lead to infiltration and distribution of these contaminants into the supply air stream. Stagnant water sources can also cause a microbial growth. So it is important to maintain the HVAC systems regularly [36].

Prevention or remediation of indoor air pollution requires ability in optimizing geometrical configurations, understanding of HVAC systems, perceived or anticipated contaminants, source areas, and economics [37]. Generally, achieving HVAC quality needs [38]:

- Establishing a maintenance plan.
- Inspection of HVAC Systems regularly.
- Checking, cleaning, and changing filters according to the manufacturer's instructions, and ensuring that condensation pans are draining.
- Providing outdoor air ventilation according to ASHRAE standards or local codes.
- Cleaning of air supply diffusers, return registers and outside air intakes.
- Keeping the unit ventilators clear of book, papers and other items.

4.1.8 Mold control

For mold and other allergens, the indoor humidity should be kept at roughly from 30 to 50%. Also, using dehumidifiers to reduce moisture can also help. Exhaust fans should be used when cooking, bathing, fixing leaks, and other water problems right away.

Some precautions about architectural elements:

- Hidden leaks behind walls must be fixed in the living rooms' walls.
- Using exhausts fans or openings' windows for showers and excessive moisture needs.
- Care should be given to fixing leaks or water damage quickly for roofs, wet spots, or water stains.
- Paint must not be done over wet or moldy walls at bedrooms' corners.
- Water from a roof leak seeped into the walls causes the paint to buckle and peel.
- The stove exhaust hood should be used to draw heat, moisture, and other contaminants at kitchens' walls.
- Drain gutter length should have a suitable length to pump out the rainwater away to keep water away from the foundations.
- The ground near buildings should be sloped downward away to drain water away from it at yard [39].

4.1.9 Indoors maintenance

Maintaining buildings' hygiene is important to ensure the IAQ healthy. Regular cleaning of the building is necessary to avoid the accumulation of debris and particulate matter buildup. The cleaning material may contribute to indoor air pollution if based on chemical or solvent. In addition, the scheduling of maintenance activities should occur during periods in which the buildings are unoccupied [40].

In general, some particular elements need maintenance, e.g. filters & air cleaning devices, outdoor air dampers & actuators, humidifiers, dehumidification coils, drain pans and other adjacent surfaces. That is subjected to the outdoor air inlet louvers, which cause wetting, bird screens, fog eliminators, and nearby components. Likewise, air handling systems except for units under 2,000 cfm (944 liter/s), cooling towers, and floor drains are taken as a guide [41].

4.2 The framework's activation

To convey the above theoretical framework into activation phase, the paper directs it to be a tool. This tool is designed in a checklist method. It has some indicators, which influence on the research problem. This checklist can help in the performance's assessment about the indoor air pollution as follows:

4.2.1 Introduction to the assessment method's extraction

The environmental assessment aims to postulate, predict and degree the performance of the residential buildings. Where it can be highlighted in long-term operational benefits, and be given a valuable marketing tool for the construction industry. So, it can increase the demand for the environmental quality. Then, it can promote sustainability in this sector.

Globally, many environmental assessment methods are already in use. It varies in harmony with local conditions and stakeholders' concerns. These methods are sharing similar features & goals.

There are several preceding studies for the IEQ tools, assessment models, classification indicators, and schemes for evaluating the IEQ. Many countries already have or in the developing phase of preparing their domestic assessment methods, which need for international exchange and coordination in the same scope.

Apparently, most of the sustainability assessment systems do not contain conjoined social, environmental or economic principles. Although it has a various dialect, it goes ahead toward resources' regard and environmental standards. However, it dominates the socioeconomic problems and weighting credits. At the same scope, an earlier paper [42] provided an overview of sustainability assessment to rate the IEQ. It stated that "no best tool" is set for assessing sustainability where, Fig. 10. shows significantly varied weights of the IEQ in the different systems,. The differences range from 6.67% to 30.6%. So, these systems' assessment gives a clear difference in the final results. Moreover, it is uncertain and deficient.

Hence, assessment of the IAQ is so complex, because it contains broad criteria and many specialists that continuously vary over time and space. To address this complexity, the IAQ indicators can be used to classify, describe, and improve IAQ, through providing clear and comprehensive grades of IAQ points.

Over and above, sustainability is based on the three top pillars, which impose a change in the relative weights of the different criteria according to the assessment locality. So, the existence of unchanging global standards seems to be unacceptable. But, the criteria can be systematically defined and categorized in specific indicators, to allow both review and assessment. Hence, certification can be done, depending on various professional specialists in each category.

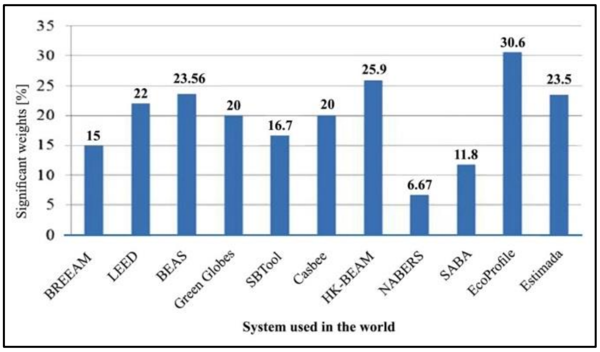

Fig. 10. percentage weights of the IEQ in the different systems

4.2.2 Earlier expertise in IAQ assessment based on measured indicators

In an earlier study, six measurements-based IAQ indexes were proposed in the USA, France, Taiwan, and Hong Kong. The assessment was based on nine parameters only [43].

This study aimed to make a comparison between the methods of IAQ assessment in these countries. Also, it compared every level related the specific six indexes, where levels are divided into classes. The study showed that only three indexes were repeatable while the other three indexes were more different regarding final findings. The cause refers to some levels of the indexes which contains classes were not associated with the classification of IAQ levels. So, it led to bias in the analysis. It can be understood through [44]:

- The objectives of the selected indexes, which were different and not consistent.
- Indexes dataset, which omits some parameters measurement. So, it partially evaluated these indexes. Therefore, more bias happened.
- Unclear recording of indexes' sampling period. Then, final assessment's calculation had an error.

Therefore, this study could not completely replicate the primary indexes, where above three defects led to an assessment calculation bias as indexes could not be quantified. Moreover, some indexes' challenges still remain, where the parameters should rely on the objectives, the parameters, and the indexes, which must be clearly defined.

In spite of the great efforts proposed by these specific and international teamwork, finally, the teamwork himself considered these findings just as an exploratory study and stated that it only up to now a phase to develop an integrative indicator for the IAQ defining, and to increase the awareness.

4.2.3 The proposed assessment tool for the Egyptian's scope (the checklist)

There is a strong necessity to develop tools for the IAQ assessment. So, the paper aims to benefit with the inductive handling of the IAQ in Phase 1 in formalizing a systematic and categorized tool in a hierarchical way. Also, it assembles the most repeated issues of the research problem within a configurable method.

This tool is represented in an execution checklist. It formalizes some extracted & detailed indicators (guidance) comprehensively in accommodation with the Egyptian's scope (activation of all the required multi-disciplines), through a configurable assessment method. Where the final record depends on the opinion of the specialists' teamwork, who sets the relative importance and the maximum available score of the indicators. So, the achieved score for each indicator can be measured individually. Lastly, the final assessment will come out, as shown in Table 1.

The emerged assessment result must be detailed in a report of the walk-through outcomes. It must also rank and categorize the records of the recommended improvements of the present IAQ shortages in the tested sample. So, it can act as a factor in improving the performance. Then, personnel can choose the most suitable decisions for the client, through the given recommendations. By that, the checklist through its professional teamwork can give a suitable participation in adopting that practice for improving the IAQ.

Table 1.

The assessment checklist (technical solutions' categories & subcategories and Concluded indicators)

#	Technical solutions' categories & subcategories	Concluded indicators	Relative importance of the Indicators	
			Max. Points	Achieved
1	Site selection	▪ Local Geography		
		▪ Rural context		
		▪ Urban context		
		▪ Garbage dumpsters		
		▪ Transportation activities near buildings		
		▪ Industrial activities near buildings		
		▪ Soil gases around buildings		
		▪ Nearby construction activities		
2	Emissions control			
2.1	VOC emissions	▪ Furnishings		
		▪ Finishes		
		▪ Paints		
		▪ Solvents		
		▪ Adhesives		
		▪ Carpets		
		▪ Fabrics		
		▪ Concentrations remain		
2.2	Radon emissions	▪ Cracks in concrete slabs		
		▪ Spaces behind brick walls		
		▪ Wall joints		
		▪ Exposed soil		
		▪ Weeping tile		
		▪ Loose fitting pipe penetrations		
		▪ Open tops of block walls		
		▪ Building materials, such as the rocks and water from the wells		
2.3	Insulation materials' emissions	▪ Formaldehyde producers		
		▪ Toxic gases		
		▪ Carbon dioxide emitted		
		▪ Insulation materials		
2.4	Mineral fiber emissions	▪ Facilities manufacturing		
		▪ Glass wool fibers		
		▪ Glass filaments		
		▪ Rock wool fibers		
		▪ Slag wool fibers		
		▪ Refractory ceramic fibers		
		▪ Natural ventilation		
3	Ventilation and fresh air delivery			
3.1	Outdoors's fresh air contaminants	▪ Geographical location		
		▪ Enough fresh outdoor air		
		▪ Overzealous energy-saving procedures		
		▪ Smog (automobile exhaust and industrial emissions)		
		▪ The weather, temperature, and the wind		
		▪ Cooling towers		
		▪ Sanitary vents		
		▪ Vehicular exhaust from garages		
		▪ Loading docks		
		▪ Street traffic		
3.2	Health-based natural ventilation	▪ Adequate ventilation		
		▪ Amount of oxygen		
		▪ Carbon dioxide, monoxide, and unwanted odors		
		▪ Smoking impacts handling		

Table 1. (Continue)

#	Technical solutions' categories & subcategories	Concluded indicators	Relative importance of the Indicators	
			Max. Points	Achieved
3.3	Air amount required for IAQ	▪ Ventilation rates standards		
		▪ Types of ventilation systems		
3.4	Openings design for ventilation quality	▪ Openings' shapes		
		▪ Orientation		
		▪ Transition		
		▪ Thermal insulation		
		▪ Light and solar radiation		
		▪ Openings' details		
4	Materials precautions			
4.1	Using nontoxic building Materials	▪ Effects over the life cycle		
		▪ Solvents, glues, and plastics		
		▪ VOCs concentrations		
4.2	Adhesives and sealant precautions	▪ Natural vs. Synthetic		
		▪ Emission rates		
		▪ Total health effects		
4.3	Paints precautions	▪ VOCs emissions		
		▪ Drying period		
		▪ Ventilation precautions		
		▪ Natural vs. Synthetic		
4.4	Carpet, resilient flooring and wall covering	▪ VOCs emissions		
		▪ Emission rates		
		▪ Details		
		▪ Material used		
4.5	Particle-board and plywood precautions	▪ Adhesives		
5	Moisture control	▪ Penetration of liquid water into the building envelope		
		▪ Vapor condensation		
		▪ Proper building pressurization		
		▪ Controlling humidity		
		▪ Suitable materials		
6	Pollution migration control	▪ Indoors zones		
		▪ Kitchens separation		
		▪ Food preparation systems		
		▪ Bathrooms waste & odors		
		▪ Architectural spaces & the wind		
		▪ Tools & activities used in indoors		
7	HVAC systems and the IAQ	▪ HVAC design		
		▪ ASHRAE standards		
		▪ Local codes		
		▪ Maintenance Plan		
		▪ Maintenance details		
		▪ Ventilation		
8	Mold control	▪ Relative humidity		
		▪ Moisture control		
		▪ Leaks fixing		
		▪ Ventilation		
		▪ Paints materials		
		▪ Sanitary details		
9	Indoors maintenance	▪ Scheduling of maintenance activities		
		▪ Building hygiene & cleaning		
		▪ Cleaning Products (chemical or solvent)		
		▪ Building envelope details		

4.2.4 The checklist's current applicability

For individual or even teamwork of architects, sampling all above indicators is so unapproachable and overpriced specifically, when the scope of work extends to cover the whole country, as the Egyptian scope case where monitoring plan and a practical assessment strategy should be conducted as a base of air sampling. And it needs researching duties in both short and long-term in various disciplines.

Locally, regarding the IAQ assessment's literatures, just limited measurable parameters were selected according to its adverse impacts where Indoor air pollution indicators corresponded with distinctive parameters which have clear measures for the projects. The essential factor in the quantitative assessment is the period of measurements. It may cause incorrect results if it is inadequate. So, both long-term sampling and monitoring are needed, with heavy cost and time load [45].

Moreover, the greatest serious and critical part of the assessment is existed, not only on environmental and engineering criteria, but mainly, in the feelings and perceptions of occupants' needs. So, IAQ assessment must take into account the vagueness uncertainty and doubt resulted from singular partialities with its incorrect results.

Regarding the checklist, it has various indicators. So, it is so complex to be tested in a real case study by the individual effort that it surely needs a specific teamwork effort, with advanced & scientific equipment. This complexity comes as a result of the verity of biological, chemical, and physical indoor air aspects. Also, healthy, climatic, structural, mechanical, electrical and systems disciplines are also factors. With caring that analysis of the indicators can be branched into outside building causes, the building structure, and inside building causes. These are a very wide range, and can’t be done with only the architect’s efforts.

So, the checklist is founded on the collaboration of a wide range of issues to be activated in the field area. Thus, it conducts to the necessity of establishing a specific administration/ authority/ organization to cover all aspects in the activation phase, to be an official tool. Hence, it can release the official & scientific certificates, as a step to address and ensure the IAQ, as an approach to sustainability. This opinion here is based on:

Setting the technical solutions' categories, subcategories, and the concluded adjustable indicators, all of these are still some flexible pre-thoughts. It can be accommodated precisely according to the variable and final opinion of the professionals & the specialist’s teamwork. Then, setting the value of the relative importance of each indicator needs a special care and consensus opinions of them, particularly, for multi-discipline indicators. Taking into account that, projects locality is a key base in assessment.

So, the paper in the current phase is only aiming to summarize the indicators which influence on the research problem. And, it opens the scope to bigger efforts to complete the studying. Sure, it needs each specialist's sharing, where the measuring tools and missed data of architects will be replenished by others as well.

4.2.5 The checklist's future applicability

Globally, many institutes are growing the expertise on the IAQ concerns, specifying the urgencies, and aims that should be accomplished. These are activated through developing practical and methodical references of actions at each domestic level, considering the guidance that prepared by (WHO) World Health Organization.

Locally, by surveying, there is no single governmental organization; in any authority has an obligation for the IAQ. Also, for the outdoor air, there are no rules or protocols have been developed precisely for the IEQ in general associated with architects or licenses awarding.

So, for setting the proposed checklist in activation phase, that needs also several of non-architects' specialists. Where every one of them will use his data to set:

a. The indicators: in extra details like principles, codes, and legislations.
b. The relative importance: which needs significant thoughts in harmony for formalizing the checklist as a tool, depending on more criteria, which varied from project to another?
c. Maximum points reserved for each indicator: it is an important decision. Where its importance comes from the final assessment result related the locality conditions and the renewable data.

So, the following recommendations can be emerged to activate the checklist:

- On the national governmental level, a suitable action should be taken in preparing a more detailed checklist or developing this one, through a specific authority or administration. It will be set for caring the IEQ at all. As a paradigm, experiences of EPA, ASHRAE, and WHO can be taken.
- Housing and Building National Research Center (HBRC), with its potential, can be a recommended affiliation. It can be either alone or in cooperation with other research authority. That depends on the available specialists of the IAQ field, the IAQ detailed criteria, and the set indicators.
- Also, Egyptian Environmental Affairs Agency (EEAA) can be recommended to adopt this tool. It can be done by focusing on the IAQ from the architectural point of view. Basically, it needs to emit a new administration containing specialists on both architectural and environmental science.
- Magnifying the role of environmental labs in the engineering researches & consultant centers, which exists at the faculties of engineering. And promoting it to the extent where it can achieve more detailed studies & results in this scope.

5. Conclusion

Concepts, categories, subcategories, strategies, and tradeoffs of IAQ depend on probable conflicts among various solutions can improve the building performance. The paper is a pushing step towards sustainability where it supports the IAQ study, with the special emphasis on local needs to global environmental interests.

Global IAQ assessment systems of both performance and sustainability as well, through its different packages contain standards, parameters, and indicators, etc. All of these are based on fine details, depending on the locality criteria. Generally, assessment methods heavily rely on both professionals in various disciplines and occupant’s claims, which international societies principally adopt it. Hence, this represents a starting point of preparing a similar handling for IAQ in the Egyptian's scope.

Subsequently, the extracted framework in its two phases aims to ensure the IAQ. It arises by the studying of the indoor air pollution, with considering of the local environment's criteria in a similar approach. The study proposes a theoretical approach, followed by the extracted framework. It comprises two phases. The first phase is the framework’s technical solutions (theoretical base). The second phase is the framework's activation. It comes with comprehensive, configurable, and a multidisciplinary assessment tool. It allows assessing the solutions' strategies through some concluded indicators where each indicator corresponds to a maximum number of points. Moreover, it corresponds to the number of points is achieved for each indicator. Basically. It also depends on the relative importance of each indicator which set relying on the overall vision of the multidisciplinary assessment teamwork. That conducts to a comprehensive and final digital assessment score for projects in terms of IAQ.

The proposed checklist can be activated officially, through a multidisciplinary teamwork, to release certificates. It can be implemented by a specific official authority or an administration. The certificates can be used as a part of the licensing requirements for new projects regarding IAQ. Also, the evaluators can use the checklist to assess the existing projects. Thus, its activation can magnify the integration of the key players that needed for studying the indoor air pollution at which, the residential buildings will move towards sustainability.

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دراسة تلوث الهواء داخل الفراغات السكنية في مصر كأحد عوامل الاستدامة

الملخص العربى

تعد الاستدامة حاليا أحد أهم التوجهات، ليس فقط على مستوى التنمية العمرانية والمعمارية بل على كافة مستويات التطور، وفيما يخص الفراغات السكنية بما لها من أبعاد بيئية واجتماعية واقتصادية والتي تمثل الركائز الثلاثة الأساسية للاستدامة بوجه عام فإن جودة الهواء الداخلي تمثل خطوة هامة في تأصيل الاستدامة من حيث ركائزها الثلاثة على المستوى المعماري، وتأتي هذه الأهمية مع الوعي الكبير مؤخراً بالآثار السلبية التي يسببها تلوث الهواء داخل الفراغات السكنية على الشاغلين.

وللاقتراب من تلك الإشكالية (دراسة تلوث الهواء داخل الفراغات السكنية في مصر) فقد تم التمهيد لها من خلال: اقتراب نظري موجز، ومن ثم ... تم طرح إطار عام مستخلص استقرائيا، يتكون هذا الإطار من مرحلتين، الأولى منهما عبارة عن: بلورة للمداخل التقنية الأكثر تكراراً وتأثيراً في تلك الإشكالية، وذلك بحصر جوانبها وتقسيمها إلى: مستويات رئيسية وأخرى فرعية، ومن ثم طرح بعض الحلول التقنية (استراتيجيات الحل). ثم الانتهاء إلى المرحلة الثانية والأخيرة من هذا الاطار العام، حيث تمثل تلك الخطوة مَخرجات البحث، والتي تبلورت بشكل أساسي في استخلاص استمارة فحص شاملة ومتعددة الاختصاصات كأداة تقييم مرنة، وذلك من خلال منهجية تسمح بتقييم استراتيجيات الحل التي انعكست في مجموعة من المؤشرات، حيث يناظر كل من هذه المؤشرات عدد أقصى من النقاط التي يمكن منحها لكل مؤشر، يناظره عدد النقاط المتحقق بالفعل بكل مؤشر، وذلك استنادا إلى الأهمية النسبية المطروحة لكل مؤشر على حده، والتي تتحدد في ضوء الرؤية الاتفاقية الشاملة لفريق التقييم المتعدد التخصصات، وللوصول في النهاية إلى تقييم رقمي شامل ونهائي للمشروعات من حيث جودة الهواء.

هذا ... ويمكن لاستمارة الفحص تلك أن تساعد كلاً من المصممين أو المقيمين على حد سواء، وذلك في كلٍ من مرحلة التصميم أو التقييم، كما يمكن إجراء التفعيل الرسمي لتلك الاستمارة في أرض الواقع من خلال فريق عمل متعدد التخصصات، ولتكون أداة تسمح بمنح الشهادات الموثقة التي تصدرها أحد الجهات أو الإدارات الرسمية المكرسة لهذا الغرض، حيث يمكن أن تكون جزءً من متطلبات تراخيص المشروعات قبل منحها، أو لتقييم المشروعات القائمة بالفعل، ولتمثل خطوة في دراسة تلوث الهواء داخل الفراغات السكنية في مصر كأحد عوامل الاستدامة.