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The Architectural Design Role in Mitigating VOCs Concentration in Educational Buildings

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The Architectural Design Role in Mitigating VOCs Concentration in Educational Buildings

دور التصميم المعماري في الحد من المركبات العضويه المتطايره في المباني التعليميه

Aliaa A. Mahmoud, *Alaa M. Eleishy* and Ahmed El-Tantawy

KEYWORDS:
VOCs emissions, VOCs Mitigation process, Natural ventilation, Architect role, low-VOCs materials, Educational environment

الملخص العربي:- هناك وعي متزايد في مجال إستدامه البيئات الداخليه فيما يختص بالمركبات العضويه المتطايره المنبعثه من مواد التشطيبات الداخليه كمصدر أساسي للتلوث في البيئه التعليميه نظرا لحساسيه الأطفال الزائده تجاه الملوثات عن البالغين ولزياده الفتره الزمنيه المنقضيه في المدارس. إن العلاقه مازالت مبهمه بين تقليل مستوي تركيز المركبات العضويه المتطايره في البيئه الداخليه وبين دور المعماري . ومن المتعارف عليه أن تقليل هذا المستوي يمكن أن يتحقق بتقليل مصادر المركبات العضويه المتمثله في إختيار مواد مستدامه أو مواد منخفضه الإنبعاثيه. هذه الاستراتيجه تأتي كمرحله متاخره في عمليه التصميم المعماريه، لكن في الحقيقه فإن عمليه التقليل يجب ان تؤخذ في الإعتبار من المراحل المبكره . هذا البحث يهدف الي تسليط المزيد من الضوء علي عمليه تقليل نسب الملوثات من خلال مناقشه أهم عاملين موثرين في هذه العمليه ألا وهما : إختيار مناسب لمواد البناء وتحقيق تهويه طبيعه كافيه . ولذلك تم إختيار سته مدارس في هذا البحث بناء علي معايير محدده لكي يتم تحليلها فيما يختص بهذين العاملين . ومن خلال التحليل المفصل لكل مثال في كيفيه تحقيق نسب مقبوله لتركيز المركبات العضويه المتطايره اصبح واضحا وجليا أن كل إستراتيجيه مستخدمه لإختيار مواد منخفضه الإنبعاثيه وتحقيق تهويه مناسبه تسببت في نتائج في التصميم المعماري فيما يتعلق المدارس .

***Abstract*—There is a growing awareness in indoor environment sustainability concerning Volatile Organic Compounds (VOCs) emissions from interior finishing materials as a major source of pollution in the educational environment; owing to children sensitivity to pollutants than adults and the large time spent in school. The relationship between mitigation VOCs concentration levels in indoor and the architect role is still ambiguous. It's generally accepted that mitigating this level can be achieved by eliminating the sources of VOCs embodied in selecting sustainable or low-VOCs materials. This strategy comes as the last step in the architectural design process, but in fact, mitigation process must be taken into consideration from the very beginning. The objective of the paper is to shed more light on the mitigation process through discussing the two most effective factors in this process; suitable materials selection and achieving adequate natural ventilation. For that the paper selects six schools with specific criteria to be analyzed concerning these two factors. From the detailed analytical study of each case in fulfilling accepted VOCs concentration levels, it has become clear that every used strategy in selecting low-VOCs materials and ventilation results in different architectural consequences with regard to school design.**

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I. INTRODUCTION

INDOOR environments in schools have already been of public concern, as children have greater susceptibility to environmental pollutants than adults. Indoor air pollution especially VOCs pollution effects on the comfort, productivity and academic performance of students in schools. (Mendell & Heath, 2005). Studies by the U.S. Environmental Protection Agency (U.S.EPA) and other researchers have identified that VOCs are common in indoor environments and that their levels may possibly be two to a thousand times higher than outdoors. There may be from 50 to hundreds of individual VOCs in indoor. (Davis, 2001)

VOCs concentrations vary widely between indoor spaces and may also vary within a single space as a function of location and time. The extent of such variations depends on factors such as the emission characteristics of sources (including ongoing activities), occupant behavior and the ventilation conditions or other environmental conditions. The large variability of most these factors causes indoor air pollution and human exposure to be an extremely dynamic process. (Lundgren, 1995)

The VOCs indoor pollution dynamics are mainly caused by two factors: (a) the significant variety of VOCs emission characteristics from finishing materials for interior finishing and furnishing, (b) the broad range of ventilation conditions. (Lundgren, 1995)

Most materials used in the finishing of interior school spaces are potential sources of VOCs. These include paints, adhesives, sealants, caulks, carpets, vinyl floor and wall coverings, composite wood products, and furniture finishing products. Furnishing materials, such as furniture and interior panels, are also likely VOC sources. (Alevantis, 1996)

Evaluation and selection of low-VOC- impact building materials are the most critical step in mitigating occupant exposure to this kind of pollutant. A number of guidelines come up such as California Department of Health Services to define a low- VOC-impact building material. The guideline for the procedure consists of a four-step process as indicated in Figure 1. (Alevantis, 1996)

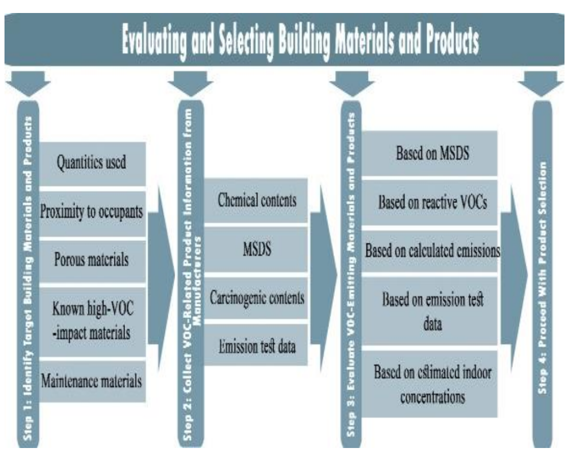

Figure 1: Four-Step Strategy for Evaluating and Selecting Building Materials and Products. (Alevantis, 1996)

On the other side, Dilution and removal of VOC concentration via ventilation are common approach to managing these concentrations from indoor sources (Willem, 2014). It is commonly assumed that increasing the air exchange rate can be an effective factor to reduce indoor concentrations of VOCs that are emitted from materials as shown in figure 2. If the emission characteristics are known, it is possible to calculate the ventilation rate necessary to prevent these concentrations from exceeding a pre-defined threshold concentration (Kleiven, 2003).

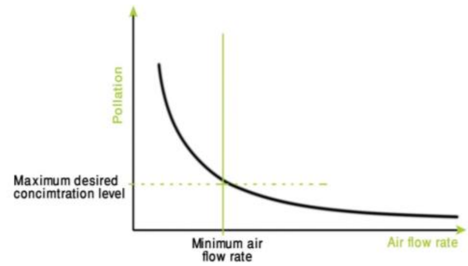

Figure 2: The pollution level decreases exponentially with airflow rate. (Kleiven, 2003)

II. Methodology

In an attempt to highlight the role of the architect in mitigating VOCs concentration levels in educational buildings, a number of cases studies will be analyzed. In order to ensure that relevant and appropriate building cases are selected, specific criteria were used in the selection process as follows:

a. The buildings, in particular, should cover as much as possible the variety of natural ventilation and low-VOCs material selection strategies.
b. The building should be evaluated by international organizations and achieve awards such as LEED and other international rating systems.

Taking these criteria into consideration a systematic search through various schools, eight buildings were found to match them sufficiently as mentioned in table 1 below

Table 1

The eight Selected school for the investigation.

SH.1	**SH.2**
Sidwell Friends Middle School	Greensburg Schools/ Kiowa County Schools
SH.3	**SH.4**
Ben Franklin Elementary School	Samuel Brighouse Elementary School
SH.5	**SH.6**
Ergolding Secondary school	Academy of St Francis of Assisi

III. Natural Ventilation Aspect Analyzing

3.1 SH.1:

Climate description: Washington DC is in the humid subtropical climate zone which characterized by hot, usually humid summers and mild to cool winters (Wikimedia Foundation, 2016).

Ventilation strategy: High-performance operable windows, solar chimney, and skylights

Strategy mechanism: Solar chimney is a small glass tower on the roof with south-facing providing passive ventilation. The sunlight heats air within the glass chimney tops, creating convection current that draws cooler air into the building through north-facing open windows in classrooms. Then the hot air rises from the classrooms to enter the chimneys and exits through vents at the top of the towers (see figure 3,4). Mechanically assisted ventilation utilizes the return ductwork and exhaust fan in something called an air handling, located in the basement that brings in fresh air. (AIA, 2007)

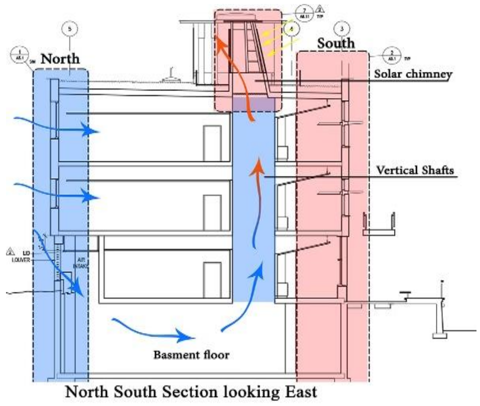

Figure 3: The mechanism of natural ventilation in Sidwell Middle School. (AIA, 2007)

Figure 4: The solar chimney in roof. (AIA, 2007)

3.2 SH.2

Climate description: Greensburg is situated in one of the windiest parts of the United States, with consistently high wind speeds throughout the year. (Architects, 2008)

Ventilation strategy: Building Orientation, Low operable window, Clerestories in the sloped roof, and saw-teeth Gym roof.

Strategy mechanism: The two single-loaded academic wings are oriented to East-West in order to optimize prevailing Southwesterly breezes. The GYM placed in the North of classrooms finger to avoid blocking air circulation in this area. The sectional shape of the classes represented in Southwest-low operable window and North-facing clerestories in classrooms and saw-teeth GYM roof which provide a path for ventilation (see figure 5). The team emphases on the strategy in the site through using deciduous trees in order to strengthen the wind driven to the building and prevent from the undesirable wind. (AIA, 2011)

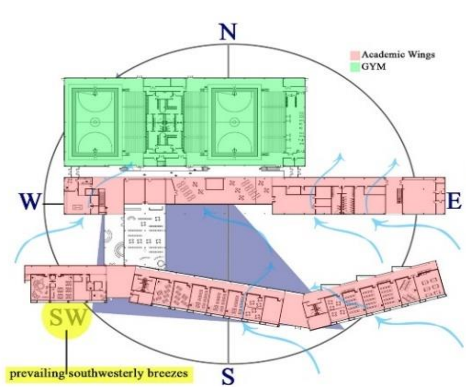

Figure 5: Greensburg make use of the prevailing breezes in the strategy. (AIA, 2011)

3.3 SH.3

Climate description: Kirkland city has the Pacific Northwest's climate which is ideal for passive ventilation systems. Maximum temperature ranges are between 45 and 75 degrees Fahrenheit. (AIA, 2006)

Ventilation strategy: courtyards, Low-perimeter louvers, and clerestories in sloped roof.

Strategy mechanism: The concept of thermal buoyancy and pressure differentials cause because of the two courtyards, as part of air flow moving up and part of it down, to form a large vortex leading to a very high-pressure build-up surrounding the building. This concept emphasis drawing fresh air through low-level perimeter windows and louvers located behind the heating units and venting it through high-level clerestories in the sloped roof (see figure 6). (AIA, 2006)

In 80% of the building, Carbon dioxide sensors and occupancy sensors automatically adjust louvers to control ventilation and conserve energy. In heating mode, the air passes over fin-tube water heating elements located at the perimeter louvers before it is introduced into the classroom spaces. (AIA, 2006)

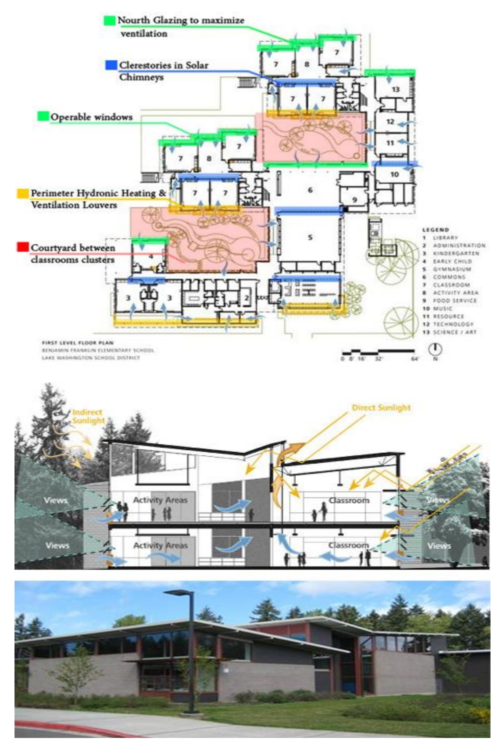

Figure 6: Techniques used to enhance natural ventilation in Ben Franklin School . (AIA, 2006)

3.4 SH.4

Climate description: Richmond city has a Mediterranean climate with dry warm summers with daytime temperatures around 20°C and mild winters. (WeatherSpark Beta, 2014)

Ventilation strategy: building orientation, Shifting floors, low-peek window, peak clerestories in wave roof.

Strategy mechanism: The stack ventilation concept has embodied in the orientation of the building and the shifting on various floors. In the 1stfloor, the classes are arranged along a double-loaded corridor which is a double height while in the 2ndfloor they are arranged along a single-loaded corridor. The prevailing wind enters from the low-peek window in the classrooms and left from a peak window in the opposite wall to the double height corridor and exists through windows at the peaks of the wave roof to the atrium (see figure 7). (Perkins+Will, 2012)

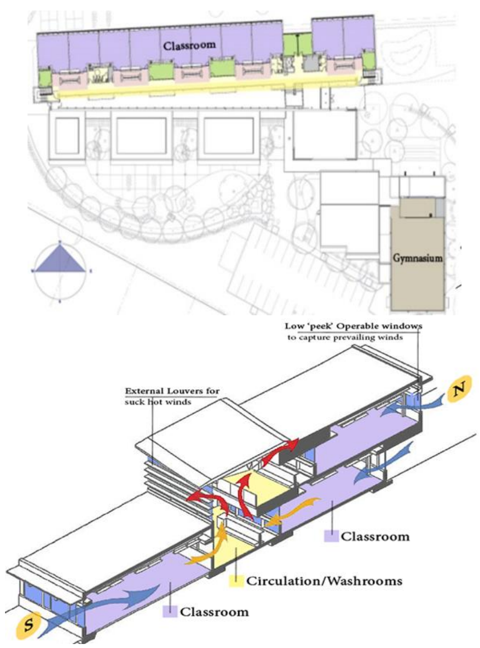

Figure 7: school section and plan show the ventilation mechanism. (Perkins+Will, 2012)

3.5 SH.5

Climate description: Most of the Germany has a temperate seasonal climate dominated by humid westerly winds. (ERYICA asbl, 2012)

Ventilation strategy: building orientation, hybrid air conditioning system, generous corridors, and atrium's skylights.

Strategy mechanism: Ventilation system takes advantage of the building orientation and the generous corridors, which vary in width from 8 to 10 ft. with louvers on interior façade. Supply air is directed from the north facing operable windows into the classrooms and can be supplemented by operable windows. Exhaust air is directed through the corridors (see figure8). (Pepchinski, 2015)

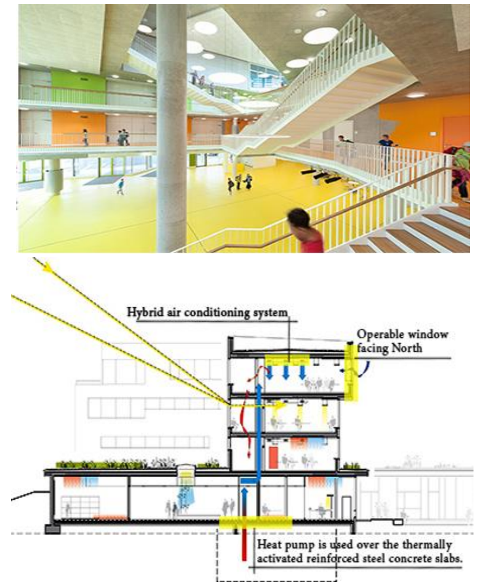

Figure 8: The whole ventilation technique use in Ergolding secondary school. (Architekten, 2014)

3.6 SH.6

Climate description: Liverpool experiences a temperate maritime (oceanic) climate, like much of the British Isles, with relatively cool summers and mild winter. (Wikimedia Foundation, Inc, 2016)

Ventilation strategy: Solar Chimney, Rotating Louvers, and North facing windows.

Strategy mechanism: The school is predominantly naturally ventilated; the prevailing winds enter from the north facing classrooms in the main block then the rising warm air extract to the manual rotating louvers in the solar chimney which located at the top of the corridor (see figure 9). (Britain, 2006)

Louvers for natural ventilation are manually operated, involving the building users in choosing their own environmental conditions. Craft and science rooms have an additional mechanical extract to maintain air quality while underground areas and the dining room have mechanical supply and extract. (Britain, 2006)

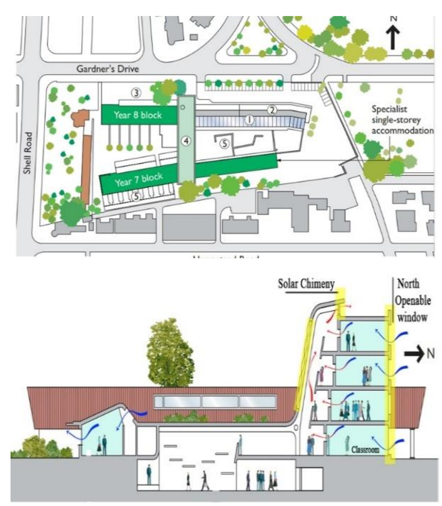

Figure 9: The north storey teaching block with a south-facing solar atrium is prominently positioned act as solar chimney. (Britain, 2006)

IV. MATERIALS SELECTION ASPECT ANALYZING

4.1 SH.1

When selecting materials to use in Middle School building, we included recycled, rapidly, renewable, and locally produced materials. Paints, carpets, and adhesives were selected for low VOC emissions. Much of the wood that is not reclaimed comes from environmentally certified sources (see table 2). So we can found that the strategy of selecting materials as follows: (Sidwell Friends School, n.d.)

A 78% of our building materials were manufactured regionally

B 11% of our building materials are from recycled sources.

C 60% of construction waste was diverted from landfills and recycled

4.2 SH.2

To avoid harvesting raw materials, a plentiful collection of locally sourced, recycled, and non-toxic materials was used on the project (see table 3) so we can found that the strategy of selecting materials as follow: (Charles S. Cassias JR., 2012)

A 46% of the wood (based on cost) is FSC certified.

B 24% of the materials (based on cost) are recycled.

C 27% of the materials (based on cost) are local/regional materials

TABLE 2
LIST OF MATERIALS USED IN SIDWELL MIDDLE SCHOOL
(SIDWELL FRIENDS SCHOOL, N.D.)

Type	Name	Description
Building envelope	Western Red Cedar	-Reclaimed materials made from 100-year-old western red cedar wine barrels.
Flooring	Linoleum Flooring	-Linoleum was used because it doesn't release a harmful chemical into the air, which vinyl flooring does.
	Carpet Tile	-The carpet tiles in the offices and library are made of recycled fibers.
	Wood Flooring	-The wood flooring is reclaimed from pilings from the Baltimore Harbor.
Ceiling	Acoustical Ceiling	-The ceiling tiles used in all the classrooms of the middle school building are made from recycled newspaper.
Wall	Gypsum Drywall	-The walls in the building are made of gypsum drywall. This is recovered from the scrubbers on the smokestacks of electric power plants electric power plants.

TABLE 3:
LIST OF MATERIALS USED IN GREENSBURG SCHOOL
(CHARLES S. CASSIAS JR., 2012)

Type	Name	Description
Building envelope	SIPs panels	-The structural insulated panel is a composite building material consists of an insulating layer of rigid core sandwiched between two layers of structural.
Flooring	Polished concrete floors (in high traffic areas)	-It makes use of the materials already present, low-maintenance, low levels of VOCs, reducing dust mite and allergen problems and extremely long life expectancy
	Wood Floors (in tactile areas)	-The reclaimed wood came from salvaged from cypress trees from Louisiana
Ceiling	fir board paneling	- Ceilings are made of 6-inch wide reclaimed Douglas fir board paneling which universally recognized for its superior strength-to-weight ratio.
Wall	Regional concrete masonry	-Masonry construction is energy efficient, made from local materials, durable, contain recycled materials and contains no (VOCs)
	Hemlock-fir furring strips	- FSC-certified wood tiles are lightweight and resistant surface. No mechanical fasteners are visible from the top, keeping the look clean.

4.3 SH.3

The primary selection criteria for any public school project are durability and maintainability. Durable, non-toxic, low-impact materials were used throughout the project (see table 4). These include paint with low VOCs emissions, rubber resilient flooring… etc. (AIA, 2006)

4.4 SH.4

As the primary building material, locally harvested wood greatly contributes to the warm, supportive and inspiring physical environment. Materials from the demolished school were also salvaged and reused—such as concrete floors.... etc. (see table 5). (Perkins+Will, 2012)

TABLE 2
LIST OF MATERIALS USED IN BEN FRANKLIN ELEMENTARY SCHOOL (THE AMERICAN INSTITUTE OF ARCHITECTS, 2006)

Type	Name	Description
Building envelope	Fiber cement siding	-It a fire and insect resistant, durable, recycled, asbestos-free and non-toxic components material.
	Eco Concrete masonry	-It is a Regionally Durable, Recycled, Low Maintenance material. It also enhanced thermal performance
Flooring	Retro-plated concrete floor	-It is an extremely durable finish (three times harder than normal concrete), and improved indoor air quality (by avoiding applied adhesives and surfaces on which dust and mold could collect).
	Eco-Rubber resilient flooring	-It is the most widely used alternative to PVC flooring apart from linoleum, long wearing, suitable for high-traffic areas, slip resistant, relatively resistant to fire, low maintenance, and low-VOC content.
Wall	Regional concrete masonry	-It can contain recycled materials, is made from local materials, energy efficient, durable and long lasting, and contains no (VOCs) or other potentially harmful off-gassing materials.
	wool tackable wall coverings	-It is a100% renewable, warm, abuse-resistant material, composed almost exclusively of natural materials, containing no harmful components.

TABLE 5
LIST OF MATERIALS USED IN SAMUEL BRIGHOUSE ELEMENTRY SCHOOL (PERKINS+WILL, 2012)

Type	Name	Description
Building envelope	Locally mountain pine beetle wood	-It's an excellent environmental choice because it minimizes the use of energy, water and materials, and reduces impacts on human health and the environment.
Flooring	Eco-Resilient concrete flooring	-It is a perfect example of this synergy of beauty, sustainability, and economy, giving a durable, low-maintenance floor. It doesn't emit VOCs, can be finished with low-VOC sealers, and doesn't support the growth of toxic molds and bacteria
Ceiling	Acoustical Ceiling	-The ceiling tiles used in all the classrooms of the middle school building are made from recycled newspaper.
Wall	Non-Toxic Paints	-These paints are durable, cost-effective and less harmful to human and environmental health. Low-VOC products perform well in terms of coverage.

4.5 SH.5

Selection of materials for this project must be recycled, rapidly renewable, and locally produced materials (see table 6). To help with navigation, each floor is distinguished by a single color applied to flooring and walls which can be observed from outside and from the large central foyer. (Architekten, 2014)

4.6 SH.6

Material selection including FSC Douglas Fir externally and internally, mineral wall paints, recycled floor finishes and furniture laminates, have been selected to minimize environmental impact (see table7). (Design Build, 2104)

TABLE 6
LIST OF MATERIALS USED IN ERGOLDING SECONDARY SCHOOL (ARCHITEKTEN, N.D.)

Type	Name	Description
Building envelope	Alsecco, Quattro (thermal insulation system)	-Totally free-VOC content, high level of impact resistance, low material consumption, reliable protection and crack resistance and has a protection against algae and fungal growth.
Flooring	Linoleum Armstrong (hallways)	-Armstrong carpet uses natural ingredients made from 36% renewable raw materials and contains 35% recycled content. -FloorScore certified for low VOC emissions.
	Kugelgarn Fabromont Carpets (classrooms)	-It is economical in maintenance, regular brushing without water or any cleaning product, offers greater thermal comfort to hard or elastic coatings, contains at least 20% of recycled material. -Meet the criteria of (GUT) in relation to VOC emissions, the low capacity of harmful and environmentally friendly manufacturing.
Ceiling	Knauf Acoustic Ceilings	-It becomes apparent for example in energy efficiency and in climate protection.it supports low VOCs emissions and resource-efficient production by using natural gypsum extracting in an environmentally friendly way.
Wall	Brillux (Paints /coating)	-Incredibly durable and long lasting, reducing the need for maintenance, helping sustain the integrity of the build, maximizing efficiency, and contributing to protecting resources and reducing greenhouse gas emissions.

TABLE 7
LIST OF MATERIALS USED IN ACADEMY OF ST FRANCIS OF ASSISI (DESIGN BUILD, 2104)

Type	Name	Description
Building envelope	FSC Douglas Fir siding	-It is FSC-certified wood with 100% locally harvested material. It's also naturally resistant to rot, decay, and insects providing more aesthetic appeal than aluminum or vinyl siding.
	Raw brickwork	-Brick is made from naturally abundant materials, can include pre-consumer recycled content, do not emit off-gas VOCs or other toxic materials, durable, and having a life expectancy of hundreds of years.
Flooring	Eco-fair-faced concrete	-Solid concrete floor acts as a thermal store absorbing solar heat -The lifecycle of this building material is taken into consideration when using it.
Wall	Mineral wall paints	-It's a pigment made of some natural mineral substance, as red or yellow iron ocher. They are the healthy alternative to acrylic paints, completely Zero VOC, toxin-free, odorless, asthma-free, and naturally mold-resistant.

V. DISCUSSION

From the analyzing of the eight case study schools concerning the VOCs concentration mitigation through the most two effective factors; materials selection and achieving adequate natural ventilation, we found that:

a. Each characteristic ventilation strategy has a set of architectural consequences and certain architectural possibilities linked to it. The greatest of which are apparent on the facade, on the roof, in the plan layout and section, and in the interior spaces as shown in the analyzing table 8.

b. Each material selection strategy affects the architectural interior design of the building, so due care was given to consideration in selecting low-VOC impact, recycled, rapidly renewable, locally sourced, and nontoxic materials as shown in analyzing table9.

TABLE 8
THE ARCHITECTURAL CONSEQUENCES OF NATURAL VENTILATION IN EACH CASE STUDY

Type	SH.1	SH.2	SH.3	SH.4	SH.5	SH.6
Facade	✓	✓	✓	✓		✓
Roof	✓	✓	✓	✓	✓	✓
Plan and Section		✓	✓	✓	✓	✓
Interior Space				✓	✓	

TABLE 9
THE INTERIOR FINISHING MATERIAL CONSIDERATION FOR EACH CASE STUDY

School ID	SH.1			SH.2			SH.3			SH.4			SH.5			SH.6		
Finishing type	Floor	Wall	Ceiling	Floor	Wall	Ceiling	Floor	Wall	Ceiling	Floor	Wall	Ceiling	Floor	Wall	Ceiling	Floor	Wall	Ceiling
Protect IEQ																		
Use low VOC-emitting materials	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	
Materials Efficiency																		
Made from sustainable resources	✓												✓		✓		✓	
Made with recycled content	✓	✓	✓	✓	✓			✓	✓			✓	✓			✓		
Recyclable																	✓	
Movable and reusable																		
Other Environmental Considerations																		
Locally available	✓			✓	✓	✓		✓										
Durable	✓				✓	✓	✓	✓		✓	✓			✓				

VI. CONCLUSION

From the above discussion, it is found that VOCs mitigation process is a comprehensive one affecting obviously the architectural design of the building. Emanating from that, the role of the architect appears clearly in each design process stage from the early stage embodied in achieving adequate natural ventilation in an attempt to enhancement the IAQ and eliminating the VOC risk as possible as can to the final stage embodied in accurate selecting materials as an effective factor in VOCs mitigation.

This review article will be a guide for researchers in the next original paper named " Case Study on VOCs Mitigation Concertation's in Educational Interior Spaces: Glory International School in Mansoura ". This paper also will be a reference for the researchers in the applicable part in a Master thesis named " Architectural Design Role in Enhancing Sustainability of Indoor Environment: A Vision of VOCs Mitigation in Educational Buildings".

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