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Assessment and Improvement of the Educational buildings' ventilation potential.

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Dedication

*I dedicate this project **To My Beloved Family**; who believed in me and everything I did and supported me all through to the completion of my education. To my Parents and siblings, who have stood by me and accorded me the love and support that has always been my beacon of hope. To all who made the completion of this project a success , and to all our dear inspiring brothers and sisters in occupied Palestine. A big Thank you.*

" If you can't figure out your purpose, figure out your passion. For your passion will lead you right into your purpose"
Bishop T.D. Jakes

✓ You are what you read.

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Last, but not least, I would also like to extend my heartfelt gratitude to all the contributors to this latest milestone work which provides a window into one of nowadays issues "Indoor air quality and energy use in context of ventilation".
Finally, For all who gave us this golden opportunity to do this research on the topic descriptive analysis of awareness about the importance of Air Quality and ventilation strategies to improve indoor environments in educational buildings; which also helped us in doing a lot of research and we came to know about so many new interesting things; we are really thankful to them.

Each in turn are contributing to the culture change being felt across the built environment and human experience. As Winston Churchill said, "We shape our buildings; thereafter they shape us."

Abstract

We live in a world where the impact of humans on the ecosystem is enormous and is becoming increasingly apparent and frightening, in a world where the natural resources have becoming scarce and energy demand has been increasing worldwide, which is generating harmful wastes, such as releases more dangerous GHG into the atmosphere threatening people's life by trigging unprecedented health problems and natural catastrophes (Roodman et al. 1995). In a world where the buildings represent very high energy consumption compared to the other economic sectors; about 30-45% of the global energy demand (Cox.2010). Mainly due to its indoor servicing systems and irresponsible practices. This latter is not only depleting natural resources, it's also notorious-labeled system that to blame for making people sick (SBS) (Seppänen et al. 2002) and increasing global temperature especially in cities (HUI) (Roodman & Lenssen.1995) by releasing hazardous gases, VOCs and PMs into the atmosphere. Therefore, promoting energy efficiency and environmentally friendly system in buildings is more than essential, which is also considered a key feature in green buildings.

Due to the disadvantages of these indoor environmental control systems ex.HVAC (Daisey et al. 2003) which associated with high energy consumption, greenhouse gas emissions, and poor indoor environment quality; there has been increasing studies interest on indoor environmental control using passive environmental control approaches in the development of energy-saving systems and environmentally friendly building strategies that achieve thermal comfort, saves valuable energy and leads to healthier indoor environment (Fisk et al. 2003, Zweers et al 1992, Roodman & Lenssen.1995).Amongst passive design techniques in buildings is the use of natural ventilation strategies which is demonstrated by many publications on the subject (Allard F (ed.).1998, Cook.J & McEvoy.M 1996).

In this work we investigate the potential use of natural ventilation strategies in educational buildings to improve indoor air quality as they lead not only to good indoor environmental quality and reduce the energy demand but also to enhance student's performance and comfort, thus improve academic achievement. (Mendell et al. 2005, Carnegie Mellon,2004, H.W. Meyer et al., 2005, Grün, G, & Urlaub, S. 2015, E & Sterling T 1983). In light of that, two adventitious ventilated classrooms in two different contexts have been selected to analyze.

keywords: Energy efficiency, Passive retrofit techniques, Air pollution, Natural ventilation, Indoor Educational building (carbon dioxide, comfort, health, performance..), CFD ...

”***We are making this work not only for marks but to also to increase your and our awareness and knowledge."***

ملخص

نحن نعيش في عالم بدا ظاهرا تأثير البشر فيه على النظام البيئي هائلاً وأصبح واضحًا ومخيفًا بشكل متزايد ، في عالم أصبحت فيه الموارد الطبيعية نادرة والطلب على الطاقة يتزايد في جميع أنحاء العالم ، مما نتج عنه نفايات ضارة ، مثل إطلاق المزيد من الغازات الضارة كغازات الدفيئة الخطيرة في الغلاف الجوي التي تهدد بدورها حياة الناس من خلال التسبب في مشاكل صحية غير مسبوقة وكوارث طبيعية هائلة، في عالم تمثل المباني فيه نسبة مرتفعة لاستهلاكها للطاقة مقارنةً بالقطاعات الاقتصادية الأخرى ؛تقدر بحوالي 30-45٪ من الطلب العالمي للطاقة. ويرجع ذلك أساسًا إلى أنظمة الخدمات الداخلية (نضام التهوية و التكيف..)و الممارسات غير المسؤولة. مما أدي هذا الأخير ليس فقط لاستنفاد الموارد الطبيعية فحسب ، بل أيضًا نظام اتهم بأنه المسؤول عن إصابة الناس بالمرض(SBS). وزيادة درجة الحرارة العالمية خاصة في المدن (HUI)عن طريق إطلاق الغازات الخطرة الملوثة والمركبات العضوية المتطايرة (VOCs) و (PMs) في الجو. لذلك ، يعد تعزيز كفاءة الطاقة والنظام الصديق للبيئة في المباني أكثر من ضروري ، والذي يعتبر يحد ذاته أيضًا سمة رئيسية في المباني الخضراء.

ونظرًا لعيوب تلك الأنظمة- أنظمة التكيف والتهوية السائدة و الممارسات غير المسؤولة والتي ارتبطت بارتفاع استهلاك الطاقة وانبعاثات غازات الضارة و الاحتباس الحراري وسوء جودة البيئة الداخلية ، فقد تزايد الاهتمام بالدراسات المتعلقة بالتحكم البيئي الداخلي باستخدام أساليب التحكم الطبيعية في تطوير أنظمة توفير الطاقة واستراتيجيات البناء الصديقة للبيئة التي تحقق الراحة وتوفر الطاقة وتؤدي إلى بيئة داخلية أكثر صحية. ومن بينها تقنيات التصميم السلبية في المباني كاستخدام استراتيجيات التهوية الطبيعية التي أظهرتها الكثير من الدراسات حول الموضوع.

في هذا العمل ، نبحث عن الاستخدام المحتمل لاستراتيجيات التهوية الطبيعية في المباني التعليمية لتحسين جودة الهواء الداخلية لأنها في الأخير لا تؤدي فقط إلى تحسين جودة البيئية الداخلية العامة وتقليل الطلب على الطاقة والمحافظة على البيئية ولكن أيضًا هذا الأخير يساهم في تحسين أداء ونجاعة الطالب في التحصيل الدراسي ،في ظل ذلك تم اختيار فصلين دراسيين بتهوية عشوائية في سياقين مختلفين تماما لتحليلهما.

الكلمات الأساسية: كفاءة الطاقة ، تقنيات التعديل التحديثي السلبي ، تلوث الهواء ، التهوية الطبيعية ، البيئية الداخلية (ثاني أكسيد الكربون ، الراحة ، الصحة ، الأداء) المباني التعليمية

"أن تضيء شمعةً صغيرةً خير لك من أن تنفق عمرك تلعن الظلام»

Résumé

Nous vivons dans un monde où l'impact de l'homme sur l'écosystème est énorme et devient de plus en plus apparent et effrayant, dans un monde où les ressources naturelles se raréfient et la demande d'énergie augmente dans le monde entier, ce qui génère des déchets nocifs, tels que des rejets plus dangereux (GES) dans l'atmosphère menaçant la vie des personnes en provoquant des problèmes de santé sans précédent et des catastrophes naturelles.
Dans un monde où les bâtiments représentent une consommation énergétique très élevée par rapport aux autres secteurs économiques ; environ 30 à 45 % de la demande énergétique mondiale. Principalement dû à des systèmes de services internes (système de ventilation et de conditionnement) et ses pratiques irresponsables. ces derniers non seulement à épuiser les ressources naturelles, mais aussi à un système qui a été accusé d'être responsable de rendre les gens malades (SBS) et d'augmenter la température mondiale en particulier dans les villes (HUI) en libérant des gaz dangereux, polluants, des composés organiques volatils (COV) et (PMs) dans l'atmosphère. Par conséquent, la promotion de l'efficacité énergétique et d'un système respectueux de l'environnement dans les bâtiments est plus qu'essentiel, ce qui est également considéré comme une caractéristique clé des bâtiments verts.

En raison des inconvénients et des défauts de ces systèmes de contrôle de l'environnement intérieur (ex. HVAC) qui sont associés à une consommation d'énergie élevée, des émissions de gaz à effet de serre et une mauvaise qualité de l'environnement intérieur, il y a eu un intérêt croissant des études sur le contrôle de l'environnement intérieur en utilisant des approches de contrôle environnemental passif dans le développement de systèmes d'économie d'énergie et de stratégies de construction respectueuses de l'environnement qui permettent d'obtenir un confort thermique, d'économiser de l'énergie précieuse et de créer un environnement intérieur plus sain. Parmi les techniques de conception passive dans les bâtiments se trouve l'utilisation de stratégies de ventilation naturelle qui est démontrée par de nombreuses études sur le sujet.

Dans ce travail, nous étudions l'utilisation potentielle de stratégies de ventilation naturelle dans les bâtiments scolaires pour améliorer la qualité de l'air intérieur, car en fin de compte, cela améliore non seulement la qualité globale de l'environnement intérieur, réduit la demande d'énergie et préserve l'environnement, mais aussi ce dernier contribue à améliorer les performances des élèves en matière de réussite scolaire. À la lumière de cela. deux salles de classe aérées fortuites dans deux contextes différents ont été sélectionnées pour être analysées.

Mots-clés : Efficacité énergétique, Techniques de rénovation passive, Pollution de l'air, Ventilation naturelle, Bâtiment éducatif (CO_2, confort, santé, performance..), CFD ...

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Part 3: CASE OF STUDIES

General Introduction

1.1.Introduction

Build environment and its operation fields can have extensive, direct and indirect impacts on the environment, on society, and the economy (Y. Boer 2007, UNDP 2007, Hanssen 1997). which are commonly referred to as *3 P's* describes the triple bottom line ('People', 'Planet', 'Profit') of the goal of sustainability (John Elkington,1994) . A new vision is needed to cater and balance of those pillars for granting an ideal building design for people, economy and their environment. As a part of solution, over the last 3 decades or so, interests has directed the focus on better building integrated and less energy consuming alternatives (James & James 1999, Ford 2002) A type of building is referred to as “green” or “sustainable” has been emerged as a key solution for balancing of those 3ps in this sectors (Frej 2005); and providing greater health and well-being by integrating principles of sustainability, passive design, and triple-bottom-line accounting(David et al. 2011). by using alternative sustainable construction technologies and operation approaches in order to reduce energy use, which account for up 40% of our total primary energy consumption (Andrew 2014) and at the same time, to maximize the utility of natural resources. One of the strategies that are widely applied in these building operation is to optimize the potential usage of natural ventilation.(Frej 2005); instead of mechanical ventilation systems, which represents great share of the building’s construction and running costs ,consumption of huge amount of resources, and thus a major cause of greenhouse gas emissions (Schrøder 2001, Vik 2003, Roodman et al. 1995, Craig et al. 1988)

A passive and adequate ventilation system has become an essential key to save energy, environment and offer an efficient indoor environment in buildings, especially we have become indoor generation spending most of the time within buildings 90% (Andrew 2014,EPA’s /NHAPS data 2001) and where air quality (IAQ) can be 4 to 5 polluted than outdoor ambient air, which adds up more serious implications directly to the health, well-being and work efficiency of occupants.(WHO 2020);Thus, this passive ventilation approach is increasingly becoming an attractive method for not only reducing energy use and cost, but also for providing good indoor environmental quality and maintaining a healthy, comfortable, and productive indoor climate rather than the more prevailing approach of using conventional or mechanical ventilation which is known by the so-called (SBS) (Seppänen, & Fisk 2002 , Fisk et al. 1993, Zweers 1992)

Educational buildings in my country” Algeria” account for 26.982 public schools, 488 privates and 110 universities dedicated to higher education(ONS),Unfortunately most of these facilities are not subjected to any environmental or energetic regulatory requirement plans or compliance to any recognized green building programs or codes, the parameters of the design are exclusively functional and architectural (DTR); whereas the environmental and energy aspects of ventilation /conditioning system for instance is often neglected.

In those building where the classroom microclimate is mainly influenced by adventitious ventilation practices not only has a great energy consumption and environmental impact, health and performance of students and teachers are always in question.

Natural ventilation as a promising solution; rely on natural driving forces, such as wind and temperature difference between a building and its environment, it can be achieved solely by operable windows and doors (E & Sterling T 1983, James & James 1999,Mendell & Heath 2005) or by enhanced architectural features such as atria, solar chimneys, double-skin facades and wind-towers(Wood & Salib 2013). all are ideal ventilation potentials techniques to improve classroom indoor environment and as alternatives to air-conditioning plants which could save between 13 and 40% of the building cooling energy use based on building types (Saber et al.2021), thus lead more to a sustainable building development in our cities by saving energy, cutting air pollution and of HUI (Evyatar et al. 2011).

I.2. Problematic

The potential of natural ventilation in improving indoor environment in buildings greatly depends on climate and building types. (Chen et al. 2017) estimated NV potentials of1854 locations across the world, and they found subtropical and Mediterranean climates as the most favorable places for NV designs. They also conducted that there are potentials for NV design with a night purge strategy for the desert climate, yet in Algeria this approach is still neglected except a few vernacular buildings in Sahara.

The main focus of this work mainly revolves around "Good indoor environment quality through passive ventilation strategies in educational environment." Energy efficiency and good IAQ in context of ventilation are often seen as conflicting requirements in educational building. This complex indoor environment which is influenced by many factors; building design, the number and age of students, activities and behaviors, sources of pollution inside the building; outdoor pollutant concentration and other climatic and ventilation conditions; is concern nearly10 million school children and 2 million university students (480.000 teachers; and 60.000 university professors) across Algeria.(NES, M.H.E.S.R 2018-2019), Although it significantly impacts on both overall well-being and academic achievements(WHO 2020) of students on one hand, school budget and environment on the other hand; this important issue is still neglected subject in my country. Yet, it has been well-treated by many studies . (Goyal & Khare 2009; Goyal 2009; Clements-Croome et al. 2008; Hanssen 1993; Hanssen and Mathisen 1987; Lee and Chang 2000; Daisey et al. 2003).

So, the broad aim of this work is to answer to the following question; How to ensure a healthy and good indoor learning environment with energy-efficient and zero co2 emission ventilation techniques? And the other specific question is what is the retrofitting approach or technique has to be followed to achieve these passive ventilation techniques? and, How to select and integrate these passive retrofitting ventilation systems to be subjected to deferent microclimate contexts?

I.3. Hypothesis

With increasing environmental awareness, and IAQ problems, designers are putting more effort into the implementation of natural ventilation in non-domestic buildings ;the results have shown that natural ventilation could provide a comfortable condition inside the building. (Kolokotroni et al. 2001,Marvuglia et al. 2014, Zhang et al. 2012) Similarly, other several successful cases of naturally ventilated non-domestic buildings with an adequate comfort level for occupants in a temperate Mediterranean climate without mechanical means(Baxevanoua & Fidarosa 2017, Pracchi & Lucchi 2013).

In this work we attempt to use an integrated and a multidisciplinary approach by using Eco-friendly and clean energy intervention solutions in tier passive approach. Designing a building with natural ventilation requires knowledge of prevailing wind directions and weather data, as well as solar orientation and radiation intensity. To achieve a constant good performance which is not always can be guaranteed because of the unpredictable nature of wind.(Ulrike & Francine 2015). We think Well-harnessed and well-exploited of our natural elements and resources with passive and smart technologies can solve this intricate issue. Bioclimatic and climatic analysis outcome can be vital in our suggested approaches; the potential benefit of these approaches ,can cut energy bills "electrical and gas consumption which is the purpose of a sustainable building», can increase the efficiency of energy and material resources "which are the purposes of green building" and most importantly can provide health (free-toxic and free-infectious environment), comfort, and productivity advantages to the users and its physical environments ”which is the purpose of health-centric buildings and biophilic design philosophy."
As a feasible combined approach based on natural ventilation strategies either via sample architectural elements such windows and small vents or by enhanced ones such as solar chimneys and wind towers which it can be easily integrated into buildings and provides a healthier and more comfortable environment if integrated correctly (Allard 1998);a potential energy cost savings especially valuable to our educational building with low-budget compared to financially better-off private schools and where the capital and energy expenditure of mechanical system would account for a greater proportion of our educational building budget in particularly the privates ones , it can be used as an alternative to air-conditioning plants, saving 10%–30% of total energy consumption (Andrew 2014). Besides, where solar and wind energies are good potential as clean energy in Algeria which can back up our suggested natural ventilation system in generating hybrid ventilation (elasticity) in worst case scenarios. As already mentioned, (PMs) represent additional pollutants that can impair IAQ at school. (Mohammadyan & Shabankhani 2013) Actually, it was found that IAQ in the classrooms is influenced not only by internal factors such as crowding and microclimate (poor ventilation and overheating), but also by (PMs) attributable to road traffic emissions. (Braniš 2005) Besides, there is a huge amount of data linking bad ventilation with higher virus transmission rates. The “WHO” has compiled a list of over 65 studies which show this phenomenon. In Algeria, our adventitious ventilated classrooms (Pawel 2021).with poor ventilation may lead to a higher virus infection rate especially in our over-crowded classroom that in some cases account for more than 40 students in one classroom(MNE), in which set with no adequate plan design of ventilation overheated and poorly ventilated, or even contaminated by pollutants originating both from inside the school and outside (road traffic, domestic heating, intensive agriculture or industrial activities etc (WHO 2020).(Lee & Chang 1999) but by improving building ventilation and airflow may lower the spread of viruses like the corona virus in our classrooms. Thus, whether ventilation system can have a direct impact the probability of virus transmission for diseases like COVID-19. Then Natural Ventilation is a potential leading precaution to be taken in order to prevent indoor air contamination. (WHO 2020)

I.4. Research Objectives

The scope of this work is to investigate the potential use of natural ventilation strategies to offer a healthy and comfortable indoor environment with minimum energy use which means zero budgets and zero negative impact on environment for educational facilities.

Among few strategies of ventilations to obtain significant savings on energy consumption and to improve indoor climate simultaneously is adequate passive ventilation. This work examined the potentials benefits and barriers to retrofitting educational buildings with passive ventilation strategies in Algeria which has a favorable climate " Mediterranean climate", that supports the use of natural ventilation (Guedes et al. 2009, Conceição & Lúcio 2006). It also provided a new tools or multidisciplinary approach with a retrofitting natural ventilation within the selecting projects attempting to study the complexity of natural ventilation strategy and comfort in educational buildings settings through reviewing , multiple interactions between the site and the climate (microclimate), the building types and the occupant age and their activities , and energy use and (budget) economy. In this work those methods or approaches are represent in different retrofitting scenarios.

Good indoor air quality and energy efficiency are often seen as conflicting requirements when choosing a ventilation strategy. There are several ways to obtain significant savings in energy consumption in buildings and to improve indoor climate simultaneously.Thus implementation of these passive ventilation faces significant difficulties, such as concerns about providing consistently comfortable interior environments without admitting pollutants and noise. The next section comprises a thorough literature review on natural ventilation strategies that have been applied in two different educational buildings in two different contexts.

The main focus of this work is "Granting a healthy and comfortable indoor environment for educational facilities through natural ventilation strategies" By using environmentally friendly techniques that are cost-effective and low energy consuming based on the use of a wind tower, solar chimney, and biophilic elements which are not been commonly regarded as an efficient ventilation strategy and as a potential or promising solution to provide a healthy and comfortable indoor educational environment in Algeria; The other main focus is how to choose and apply those techniques or strategies for integrated sustainable designs and evaluate their responses in different contexts (micro-climate, available renewable energy resources...etc)

This work specifically focuses on natural ventilation strategies based on /or using climate-responsive natural elements and verifies the potential benefit of these strategies with and without the intervention of mechanical assistance to offer a healthy, comfortable, and performance educational indoor environment in school environment.

General Promising Objectives to attend:

- Equity health and grant healthy educational buildings./Public health
- Improve Productivity, Performance and Comfort /Economy and Education
- Zero-energy building and Save Energy Costs/Economy.
- Efficient and sustainable Building/ Economy and Environment
- Reduce Co2 emissions Footprint /Environment.

I.5. Methodological Approach

In order to achieve and meet the objectives of my theses. An extensive literature search has been done to shed light on my problematic statements to find prospective answers and solutions related to health, air pollution, and energy use issues as well as the context of the passive ventilation strategies in educational buildings.The following databases were searched : ISI Web of Science, ScienceDirect, PubMed, ERIC, Google Scholar, Additionally more papers were searched by hand: on the context of IAQ, Healthy Buildings, air pollution, infectious disease, natural and mix-ventilation, indoor environment quality, ...etc. as well as the following journals: Building and Environment, Energy and Buildings, biophilic architecture, healthy building, ventilation strategies in schools, sustainable and green buildings, Climate Responsive Buildings, renewable energy, Integrated Energy Design, Zero-net Energy (ZEN) Building, Passive and Green Building, public health, and Covid pathogen. educational building and energy use in Algeria...etc materials. In total, this search led to over 666 different publications, indeed some of them were not relevant as they have a different focus to this review, yet they were beneficial. The number of useful studies is indicated in the bibliography section.

Reviewing and analyzing national and international examples on passive ventilation strategies has shed some extra light on the use and the development of this strategy in different climate patterns, different types of projects, and different building users; post-occupancy evaluation results also play a definite key role in the result of our work.

As a last and important step of our methodology approach, climatic and bioclimatic research of our case studies have been conducted by analyzing meteorological data and reviewing the different influencing microclimate parameters. In order to interpret these results into adequate natural strategies, we have used different climatic and bioclimatic tools, *Climate Consultant*, *BcChart*, *Table of Mahoney*, and *Comfort Triangles of Evans* (bioclimatic diagrams). which makes it possible to determine project micro-climate characteristics, and evaluate the natural ventilation needs and specify the adequate proposed strategies to be adopted for each different selected type of our case studies. The final synthesis of the results will be presented in form of general recommendations and then use these recommendations and plethora of data and information to elaborate my conclusions along my simulation models CFD (ANSYS, IESV,..) outcomes to cover my case studies.

Thesis Development
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I.6.Thesis Structure

In order to meet the objectives set and to verify the validity of our hypotheses, we have organized our research work around an introductory chapter and two other parts:

The "Introductory Chapter" where I present my general introduction to my research, the general and specific problems of my case study, the objectives of my research, and the presentation of my working methodology.

The First Part "State of Art", consists of the understanding of the different concepts and key notions related to our research, it results from bibliographical research, It is divided into six chapters. where I will be discussing ventilation in general, in the First chapter; in the second chapter will be discussed comfort, air quality, and its relation with occupants health; in the third and fourth chapter we will shed light on natural and passive ventilation principles and strategies; the Fifth chapter we will be addressing the comfort of occupants and low energy ventilation strategies in general and in educational environments in particular, In this chapter, I will be presenting examples in various context; this chapter will be useful for my next part; the six chapter will be presenting sustainable development guidance for retrofitting existing buildings. An approach that can solve or mitigate the colossal impact of the built environment on public health, economy, and environment, where we will be focused on natural ventilation and climate-responsive elements to enhance indoor air quality and indoor environment quality as a whole.

The Second Part "Case study "consists of two chapters the first chapter will be dedicated to the climatic and bioclimatic analysis of the case studies regions; the second chapter we will present our simulation of our selected case study models.

The "General Conclusion" presents the conclusions drawn from this research and all architectural and technical recommendations that will be set to improve comfort and indoor air quality in indoor environments in general and in indoor educational facilities in particular by using passive and low energy ventilation strategies.

I.7. Limitations of the Study

One of the major limitations of my thesis is meager data and resources on natural ventilation and biophilic design which often are overlooked in my country “Algeria”. Especially about, solar chimneys and wind towers as types of enhanced natural ventilation strategies and potential solutions to improve IAQ and IEQ, yet it’s time to explore and invest in these promising natural strategies to be part of the solution to public health concerns, environmental and the economic crisis in the near future.

Another limitation is choosing user-friendly and precise software for the modeling and conducting the research is quite challenging. (IESVE, ANSYS, AIOLOS, Autodesk Ecotect, Green Building Studio, and Computational Fluid Dynamics-CFD). The difficulty of conducting thorough field research and post-occupancy investigation during the Covid pandemic is almost impossible. And with lacking apparatus and tools such as PM2.5 sensors and Co2 monitors, the results may be not accurate as supposed to be.

State of the Art

Ventilation, Comfort and Low Energy ventilation Strategies

This section is organized into six chapters. Each chapter deals with specific issue; issues addressing the following:

1.Ventilation

2.Hygrothermal comfort and cooling

3.Air change and standards

4.Natural ventilation

5. Passive Ventilation Strategies and Materials Used in Natural ventilation

6. Passive retrofitting guidance and efficient protocols for ventilation

2.1. Ventilation *"Dilution is the solution. When all else fails, ventilate"*

2.1.1 Overview:

Ventilation is the process of supplying air to and/or removing air from a space for the purpose of controlling air contaminant concentrations, humidity, or temperature within the space.(ASHRAE, 2013a) In other words, ventilation moves outdoor air into a building or a room, and distributes the air within the building or room. Ventilation is not only the main means to introduce fresh quality air into spaces and extract stale and polluted air out of the space, but also a major means to transport energy within a building.(Ulrike & Francine 2015)

Buildings are usually classified according to their ventilation system as mechanically, naturally or mixed (hybrid) ventilated. The general purpose of ventilation in buildings is to provide healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it (Etheridge & Sandberg 1996,Awbi 2003,2007); In this context, microclimate refers to thermal environment as well as air quality. These two factors must be considered in the design of a ventilation system for a room or a building, as they are fundamental to the comfort and well-being of the human occupants or the performance of industrial processes within these spaces.

Building ventilation has three basic elements: (Shittu Abimbola 2010)

• *Ventilation Rate:* the amount of outdoor air that is provided into the space, and the quality of the outdoor air;

• *Airflow Direction:* the overall airflow direction in a building, which should be from clean zones to dirty zones; and

• *Air Distribution or Airflow Pattern* : the external air should be delivered to each part of the space in an efficient manner and the airborne pollutants generated in each part of the space should also be removed in an efficient manner.

1.2.2.Definition

Ventilation is defined in (ASHRAE Standard 62.1) as the process of changing or replacing air in any space to provide high indoor air quality (to control temperature or to remove moisture, odors, smoke, excess heat, dust, airborne bacteria, carbon dioxide and to replenish oxygen). Ventilation is used to remove unpleasant smells, introduce fresh air, to keep interior building air circulating, and to prevent stagnation of the interior air. The principle role of ventilation is to provide an appropriate level of indoor air quality (IAQ) by removing and diluting airborne contaminants. Guidance on achieving adequate levels of IAQ (to avoid mould growth and health hazards) Approved Document F(4). **(**CIBSE 2010 & E.R.D.D 2016)

2.1.3. Importance and reasons for ventilation:

In the past, the primary and almost the only reason for ventilation was to remove or dilute the indoor-generated pollutants and to supply fresh air for human beings; There are several types of pollutants that must be removed from the building: pollutants related to human occupancy (human effluents) and to human activities (combustion, smoking, cooking, etc.), as well as pollutants related to the building itself (building materials), its content (furniture), its maintenance (cleaning products) and its environment (ingress of soil gases such as Radon).

Ventilation is also needed to reduce the exposure to airborne microbes causing infectious diseases, and to control pressure levels in the building to prevent pollutants from spreading. Other reasons for ventilation may be, for example, humidity control to:
(1) Prevent growth of dust mites;(2) Prevent microbiological growth in building structures (walls, floors and ceilings); and (3)Prevent building constructions from damage.
Since the beginning of the 1990s, ventilation has received increased attention in the context of summer comfort control by so-called 'free cooling'. In practice, one observes an increased need for treating this kind of cooling strategy in standards and regulations. (Kevin P.2009)

2.1.4.Ventilation Fundamentals

Ventilation can be defined as the movement of air through a building and the circulation of air within internal spaces (DW Etheridge, M Sandberg 1996) The two key aims of ventilation:
-To provide thermal comfort for building occupants. Working in conjunction with heating and/or air-conditioning systems, ventilating flows can be used to control heat flows into and out of occupied spaces and thereby deliver the desired thermal environment.
-To provide good indoor air quality (IAQ) by removing airborne pollutants including carbon dioxide, odors, excess moisture, particulate matter and any other substances whose build-up could have a detrimental effect on building occupants. (Andrew 2014)
The ventilation systems used to achieve the above aims fall into three categories:

- *Mechanical (active) ventilation*, where air is supplied to and extracted from a building and the internal circulation of air within spaces achieved, by fans, pumps or other powered air handling units. (ASHRAE) defined forced ventilation (or mechanical ventilation) as *"intentional movement of air into and out of a building using fans and intake exhaust vents"*.

- *Natural (passive) ventilation*, where air flows through a building are driven by pressures generated by the wind acting on the external surface of the building (wind-driven ventilation), and/or by the buoyancy forces which arise as a consequence of the differences in air temperature between internal spaces and the external environment (stack effect, or buoyancy-driven ventilation or both driven forces). (Allard F 1998, Cook.J & McEvoy.M 1996)

- *Hybrid (mixed-mode) ventilation*, Hybrid ventilation is where air flows are achieved by a deliberate combination of natural and mechanical means. In recent years with the increased environmental awareness interest has grown in using the two methods together to achieve better indoor climate and energy efficiency. (Heiselberg 2002)

2.1.5.Forms of ventilations and ventilated buildings:

For most of the buildings, the air exchange from outside to inside happens in these ways:
1. Intentional (controlled) via natural ventilation, through opening windows/doors grilles, and other planned building envelope penetrations. It is ensured by air inlets and evacuations (vertical ducts with natural draft). This system works by natural thermal draught. It is usually controlled to some extent by the occupant. Or mechanical/ hybrid ventilations, by adding additional and controllable airflow in the buildings to provide a good indoor environment. In other words it's forced ventilation; it is the intentional movement of air into and out of a building using intake and exhaust vents (fans).

2.Unintentional (uncontrolled)via air leakages (infiltration) from windows, doors, aperture and various holes such as joints and cracks in the building envelope;' air leakage' or " Infiltration/exfiltration " into a building."(A. Bhatia 2007)

Based on these two forms of ventilations, ventilated buildings categorize as follow:

2.1.5.1.- Mechanical ventilated buildings : The most conventional and utilized one in most building in the world. In a mechanically ventilated building, ventilation is provided by powered equipment, such as motor-driven fans and blowers; this system depends on: Overpressure, Balanced Ventilation and Under Pressure Ventilation; Mechanical ventilation systems consist of four major components. fans, openings, heaters, and controls. Fans and openings control the amount of air exchange in a mechanical ventilation system. The openings also have an impact on the air distribution and mixing in a mechanically ventilated poultry barn. Heaters provide supplemental heat to maintain desired indoor temperatures during cold. Controls are needed to adjust ventilating rates, supplemental heating rates, and the air velocity through openings as weather, bird age and size change. (Panjkov et al. 2013)
In the past, when buildings were less airtight, ventilation was obtained by infiltration through the building envelope, shafts, or operable windows (adventitious ventilation); today, it is usually achieved by specially designed systems that not always but predominantly are mechanical. (Pawel 2021)

Advantages of mechanical ventilation: The primary advantage of this approach is the consistency and controllability of the rate of ventilation; Other advantages include :
-The opportunities for air filtration and possible heat recovery.
-Provide positive ventilation at all times irrespective of outside conditions.
-They can ensure a specified air change.
-The air under fan pressure can be forced through filters.
-Use of electrically driven fan or fans to provide the necessary air movements

Disadvantages of mechanical ventilation:
-When outdoor air is less humid than indoor air, e.g., during cool winter weather, more ventilation decreases the indoor humidity.
-Mechanical systems do not dehumidify sufficiently to counteract the effects of increased moisture entry.
-Other disadvantages are the capital costs, the running costs, the noise, and continuous maintenance. (A. Bhatia 2007)

a. Adventitious ventilated buildings:
The term "adventitious ventilation" is not new. It has been used, mainly in the seventies and for residential buildings, as synonymous of infiltration and natural ventilation (Harris-Bass, J et al. 1974) "Noncompliant ventilation." mean that the ventilation system may not comply with a specific standard or a version of a standard but it may comply with other guidelines or standards._"unknown ventilation" "agnostic ventilation" These name terms also could mean the same notion,. "adventitious ventilation." occurring as a result of an

external factor or of chance, rather than by design.” It is the most prevailing mode of ventilation especially in developing countries. (Schiavon, S 2014,Harris-Bass, J et al. 1974)
This definition does not exclude that sufficient or abundant outdoor airflow rate could occur or that adventitiously ventilated buildings have higher, equal or lower performance compared to naturally ventilated buildings (i.e. buildings provided with a designed system). The definition underlines the point that, for an adventitiously ventilated building, the issue of ventilation was not considered by the designers, where the researcher, engineer or architect does not find reasonable evidence to show that a natural ventilation system was designed, then she should classify the building as adventitiously ventilated.
Thus In the absence of appropriate design, it seems wrong for the default building classification to be “naturally ventilated.” If buildings without designed ventilation should not be classified as “naturally ventilated", thus in an adventitiously ventilated building, ventilation is incidental and the ventilation system has not been taken into account and designed to achieve any particular code, standard or best practice. This definition does not exclude that sufficient or abundant outdoor airflow rate could occur or that adventitiously ventilated buildings have higher, equal or lower performance compared to naturally ventilated buildings (i.e. buildings provided with a designed system). (Schiavon,S 2014)

b.Smart ventilated buildings : Since occupants are usually not good sensors of air quality in buildings, Smart ventilation system is the answer to questions like: what are important contaminants, how do we measure harm from them and how do we mitigate that harm? Smart ventilation is a process to continually adjust the ventilation system in time, and optionally by location, to provide the desired IAQ benefits while minimizing energy consumption, utility bills and other non-IAQ costs (such as thermal discomfort or noise). One feature of this system is BMS and IOT design. It can be illustrated in Fig.1,2
The definition given by (AIVC) for smart ventilation in buildings is a process to continually adjust the ventilation system in time, and optionally by location, to provide the desired IAQ benefits while minimizing energy consumption, utility bills and other non-IAQ costs (such as thermal discomfort or noise). (François, D & Rémi,C 2018)

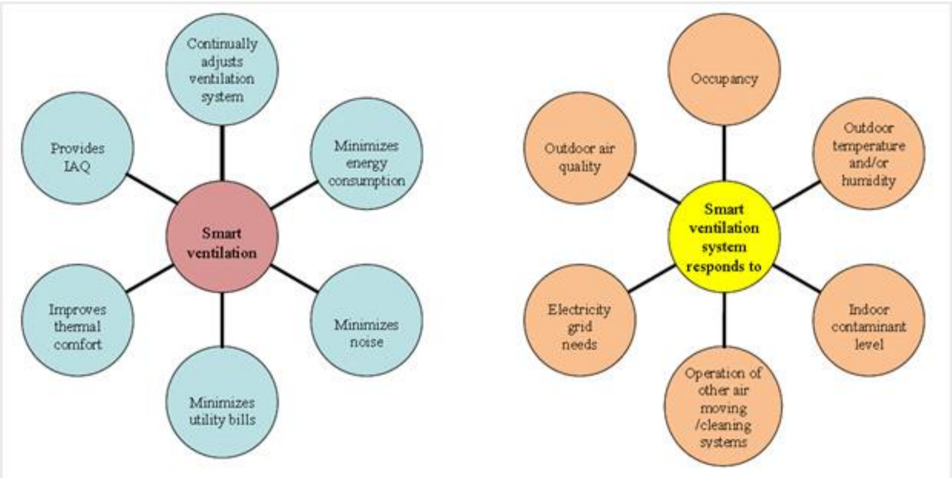


Fig.1. Main features and parameters of smart ventilation system.(François, D & Rémi,C2018)

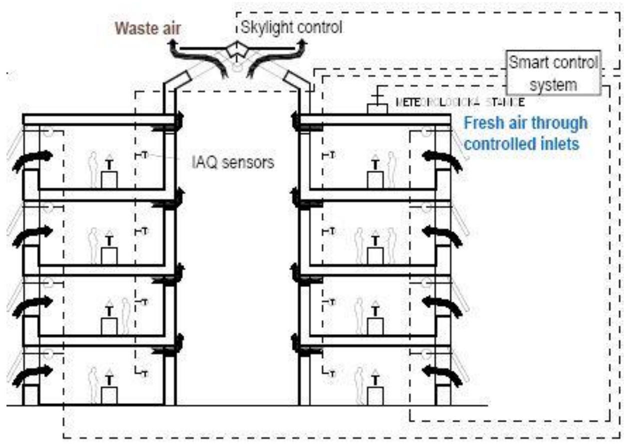


Fig.2. Principle of automatic control of natural Ventilation (A’zami, A., (2005)
(Evaluation of indoor air quality – Sensors-Meteorological data- Smart control system)

Some of the benefit of the smart ventilation system:
A smart ventilation system adjusts ventilation rates in time or by location in a building to be responsive to one or more of the following: occupancy, outdoor thermal and air quality conditions, electricity grid needs, direct sensing of contaminants, operation of other air moving and air cleaning systems. In addition, smart ventilation systems can provide information to building owners, occupants, and managers on operational energy consumption and indoor air quality as well as signal when systems need maintenance or repair. (François, D & Rémi,C 2018)
- Reducing the energy consumption and the total resulting CO2 emissions.
- Having a good thermal comfort during summer and winter.
- Using free cooling by introducing night cooling.
- Reducing the amount of material used compared to mechanical ventilation, which is beneficial for a building’s life cycle assessment.
- Reducing the capital cost compared to mechanical ventilation, which is beneficial for a building’s life-cycle cost.
- Giving a precise and accurate control of the actuators.
In addition, smart natural ventilation is a major contributor to achieving a green profile and certification of the building. Several sustainability rating systems exists to guide the design of sustainable, high-performing buildings and they recommend natural ventilation as the best solution to air quality and minimal environmental impact.(WindowMaster 2019)

Ex ; San Diego Continuing Education Mesa College Campus, San Diego Using smart ventilation with *WINDMASTER* (See Appendices)

2.1.5.2-.Natural ventilated buildings: According to (2009 ASHRAE) fundamentals, “Natural ventilation is the flow of outdoor air caused by wind and thermal pressure through intentional openings in the building’s shell (doors, windows, or other intentional openings in the building).”While historically all buildings employed natural ventilation, this practice has been disregarded due to developing electrical cooling and heating devices. (ASHARE 62.1)
There are other different definitions of natural ventilation:
• Using local wind and temperature differences between the inside and outside of the building to move air through the structure. (Chastain, J.P. 2000)

•Natural ventilation is the process of air changing caused by pressure differences between the enclosed space and the surrounding. (Nick Baker 2013)

•Natural ventilation occurs when there are pressure or temperature differences between the building and its surrounding to provide ventilation and space. (RIBA 2013)

(ASHRAE, 2013a) specifies that a natural ventilation system should be "designed." This specification implies that there should be a professional who takes responsibility for designing openings and methods for their control according to standards or best practices, e.g. CIBSE AM 10 (CIBSE, 2010). The designer may take into consideration parameters that affect the performance of the natural ventilation system, like wind speed and direction, indoor and outdoor temperatures, and location and size of the designed and controlled openings.

Natural ventilation, as the name implies, is a system using natural forces to supply fresh air for comfort and heat dissipation. As an alternative to mechanical (fan-forced) ventilation, this approach relies on the natural forces of wind and buoyancy to deliver fresh air to indoor spaces. Natural ventilation may be divided into two categories:

1. *Controlled natural ventilation* is intentional displacement of air through specified openings such as windows, doors, and ventilators. It is usually controlled to some extent by the occupant.

2. *Uncontrolled ventilation* (Infiltration) is the random flow of air through unintentional infiltration through cracks, gaps or crevices in the building structure. It is less desirable and can be controlled only by plugging the gaps. (A. Bhatia 2007)

From a technology viewpoint, NV may be classified into simple natural ventilation systems and high tech natural ventilation systems. The latter are computer controlled, and may be assisted by mechanical ventilation systems (i.e. hybrid or mixed mode systems). High-tech natural ventilation may have the same limitations as mechanical ventilation systems; however, it also has the benefits of both mechanical and natural ventilation systems.

The elements of natural ventilation include openings on facades (windows), chimneys, double-skin facades, atriums and ventilation chambers. It is possible to integrate more than one of these elements into a building depending on the form and organization as well as the design strategy and the environmental factors.

More explication on this type of ventilation will be thoroughly developed in the next section.

Advantages of Natural Ventilation (Emmerich. et al. 2001, Shittu A 2010,Romina M 2009)

Some benefits of having a naturally ventilated building are to provide indoor air quality and comfort, which leads to healthier and more productive building occupants. (McEneaney 2005). It has the potential to reduce first costs and operating costs for some Commercial buildings while maintaining ventilation rates consistent with acceptable indoor air quality.(McEneaney 2005); Natural ventilation comes with many advantages ranging from environmental benefits to improved design and lastly an enhanced indoor air quality that battles high levels of CO2, VOCs and humidity. (WindowMaster 2019)

- Removal of mechanical air handling systems and reducing cooling energy consumption.
- Providing quantitative health, comfort, and productivity advantages.
- Providing qualitative advantages of 'fresh air' in the minds of most occupants.
- Having better control of their environments and less restrictive comfort criteria.
- Reducing significant fraction costs of conventional mechanical ventilation systems.

- Eliminating the large spatial requirements that conventional mechanical systems demand.
- Avoiding the duct cleanliness dilemma, and its attendant costs.
-Simple and maintenance- free, quiet and does not require electrical power.
-No generation of power from warmed air rising during the spring, summer and autumn.
- Can provide a high ventilation rate more economically, due to the use of natural forces and large openings and can be more energy efficient, particularly if heating is not required.
- Well-designed natural ventilation could be used to access higher levels of daylight.
-The avoidance of large ventilation plants with belonging components and vertical and horizontal ductworks may in itself result in architectural possibilities and a greater freedom in the design.

In general, the advantage of natural ventilation is its ability to provide a very high air change rate at low cost, with a very simple system. Although the air-change rate can vary significantly, buildings with modern natural ventilation systems (that are designed and operated properly) can achieve very high air-change rates by natural forces, which can greatly exceed minimum ventilation requirements.

Disadvantages of Natural Ventilation (Panjkov et al. 2013,Romina M 2009, Emmerich et al. 2001,Tommy K A & Grete H,2003)

Despite benefits, natural ventilation systems have a number of drawbacks that are important to be aware of when designing naturally ventilated buildings. Natural ventilation can save space necessary for plant rooms and duct networks, but due to its strong dependence on weather conditions, occasionally, non-domestic buildings require vertical shafts such as atria or solar chimneys to improve the air flow rate, when wind speeds are low. In this case, minimizing the efficient use of floor space in commercial buildings may be unfavorable from a commercial viewpoint Furthermore, it is difficult to control NV and it only works for relatively narrow floor plans (Wood & Salib 2013).

-Difficult of integrating and maintaining NV systems; and to comply with the various norms that exist
- If the air inside is at the same temperature as the air outside, and if there is no wind, NV will not occur; beside to unnecessarily high air flows wintertime and draught problems.
- Difficult to control when natural driving forces are small.
- Lack of filtration capabilities particularly urban, with high outdoor particle and gaseous contaminant concentrations; air and noise pollution in urban areas and city centers.
- Unable to control humidity especially in hot and humid climates and extracting humidity from wet places. And combating summer overheating.
-Variability of weather around buildings and the dependence on these variable driving forces.
-Recovering heat from NV systems (especially countries with very cold winters).

The utilization of natural ventilation in modern buildings is almost without exception done in conjunction with a mechanical driving force that assist the natural forces in periods when they do not suffice. The combination of natural and mechanical driving forces is most commonly referred to as hybrid or mixed mode ventilation in the literature. (Heiselberg, P 1999 ,Tommy K & Anne Grete H 2003)

2.1.5.3. Hybrid/Mixed ventilated buildings : Hybrid ventilation is a new ventilation concept that utilizes and combines the best features of natural and mechanical ventilation systems. Hybrid ventilation provides opportunities for innovative solutions to the problems of mechanically or naturally ventilated buildings:

Natural and mechanical ventilation have developed separately over many years and the potential for further improvements is limited. But the combination of natural and mechanical ventilation opens a new world of opportunities. (Kevin P 2009)

In the third mode, mixed or hybrid ventilation the two strategies natural and mechanical are alternated spatially or temporally) (Heisenberg, P 2002). Hybrid Ventilation is a two-mode system which is controlled to minimize the energy consumption while maintaining acceptable indoor air quality and thermal comfort. The two modes refer to natural and mechanical driving forces.(IEA .(2002). Through proper design and control, a hybrid system can provide improved occupant satisfaction, reduced energy use, lower life-cycle costs and sometimes lower initial costs “solutions that simultaneously improve the indoor environment and reduce energy demand “. (Arnold 1996)

Mixed or Hybrid ventilation refers to a hybrid approach to space conditioning that uses a combination of natural ventilation from operable windows (either manually or automatically controlled), and mechanical systems that include air distribution equipment and refrigeration equipment for cooling. "Two strategies are alternated spatially or temporally, it combines both natural and mechanical ventilation systems." If natural ventilation is not able to provide required air flow rate, than supporting mechanical element starts it operation. It's a controlled combination of mechanical and natural ventilation including also night cooling,

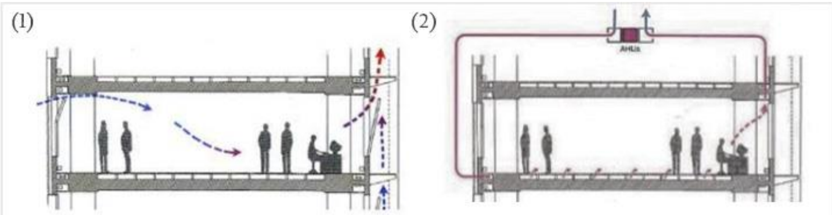


Fig 3. Operation while natural ventilation provides sufficient pressure difference (1).Transient states operated by mechanical system (heat recovery)2 .(source; A’zami, A. 2005)

A Mixed-mode building begins with intelligent facade design to minimize cooling loads. It then integrates the use of air-conditioning when and where it is necessary, with the use of natural ventilation whenever it is feasible or desirable, to maximize comfort while avoiding the significant energy use and operating costs of year-round air conditioning.

When external conditions are favorable, the natural ventilation system operates and conserves energy. When conditions are unfavorable for natural ventilation alone, windows close and the mechanical system takes over, or windows remain open and the mechanical system augments natural ventilation. The increased first costs of this best-of-both-worlds approach should be compared with maintenance costs and energy savings via life cycle cost analyses(E.R.D.D 2016).

a-<u>Mixed-mode strategies</u> There does not seem to be a “standard” mixed-mode approach in practice today each building continues to be unique. Yet there are a number of classification schemes that describe the integration of NV and air-conditioning control strategies, usually in terms of whether they exist in the same space, or operate at the same time.

1-Concurrent Strategy (Same space, same time): Concurrent mixed-mode operation is the most prevalent design strategy in practice today, in which the air-conditioning system and operable windows operate in the same space and at the same time. The HVAC system may serve as supplemental or “background” ventilation and cooling while occupants are free to open windows based on individual preference. Typical examples include open-plan office space with standard VAV air-conditioning systems and operable windows, where perhaps perimeter VAV zones may go to minimum air when sensor indicates that a window has been opened. Fig 4

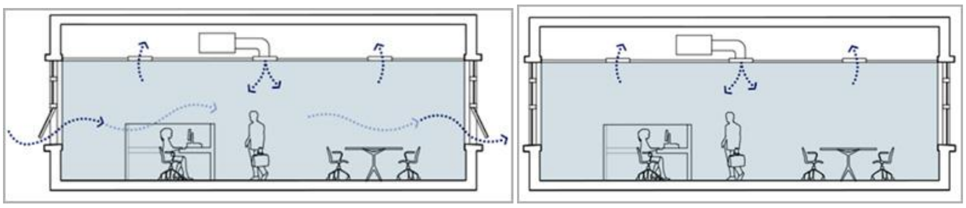


Fig.4. Concurrent mixed-mode Operation/ Change-over design mixed-mode Operation
(Source; Center for the Built Environment (CBE). University of California, Berkeley.)

2-Change-over designs strategy Change-over (Same space, different times) are becoming increasingly common, where the building “changes-over” between natural ventilation and air-conditioning on a seasonal or even daily basis. The building automation system may determine the mode of operating based on outdoor temperature, an occupancy sensor, a window (open or closed) sensor, or based on operator commands. Typical examples include individual offices with operable windows and personal air conditioning units that shut down for a given office anytime a sensor indicates that a window has been opened; or a building envelope where automatic louvers open to provide natural ventilation when the HVAC system is in economizer mode, and then close when the system is in cooling or heating mode.Fig 4

3-Zoned (Differed spaces, same time) Zoned systems are also common, where different zones within the building have different conditioning strategies. Typical examples include naturally ventilated office buildings with operable windows and a ducted heating/ventilation system, or supplemental mechanical cooling provided only to conference rooms. For many mixed-mode buildings, operating conditions sometimes deviate somewhat from their original design intent (e.g., a building originally designed for seasonal changeover between air-conditioning and natural ventilation may, in practice, operate both systems concurrently).Fig 5

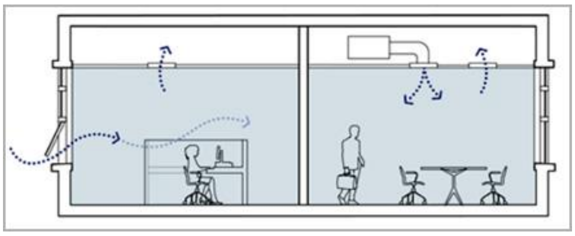


Fig.5. Zoned system mixed-mode Operation

b.Some features of this system: Hybrid ventilation, which is the combination between natural and mechanical ventilation, represents another potential worthy strategy to achieve energy efficiency, thermal comfort, and satisfying IAQ (Yoshino et al., 2003; Tovar et al. 2007). Indeed, buildings equipped with hybrid ventilation systems can achieve significant reductions of energy needs and CO2 levels compared with conventional air conditioning designs. (Fu & Wu, 2015)

Advantages of Hybrid ventilation

-Reduced HVAC energy consumption; A well designed and properly operated mixed-mode building can scale back or eliminate the use of mechanical cooling and ventilation systems throughout much of the year, with associated reductions in pollution, greenhouse gas emissions, and operating costs. Ventilation with cool outside air can reduce a commercial building's energy use by 15 to 80%, depending on climate, cooling loads, and building type.

-Higher occupant satisfaction; occupants typically want windows that can open. Mixed-mode buildings have the potential to offer occupants higher degrees of personal control over their local thermal and ventilation conditions, as well as a greater connection to the outdoors, which should lead to increased occupant satisfaction and reduced potential for IAQ problems. Past research has found that building occupants prefer a wider range of indoor thermal conditions when they are provided with some measure of personal control.

-Highly "tunable" buildings Mixed-mode strategies provide inherent flexibility and redundancy in the space conditioning systems of a building, resulting in potentially longer life, greater adaptability to changing uses, and reduced lifecycle costs. With the careful application of mixed-mode cooling and ventilation, one can anticipate somewhat smaller mechanical systems and extended HVAC equipment life. (A'zami, A. 2005)

-Simpler system, low required service and maintenance with heat recovery -usually not used, heat pipes heat exchanges are possible; All air inlets and outlets low pressure drop.

-Fans and other motorized devices low energy input; Fans-auxiliary function.

Disadvantages of Hybrid ventilation

-Mixed-mode strategies also have the potential to add cost and complexity to a building, and in the worst case might yield frustrated occupants and excess HVAC energy consumption. Because there is less familiarity, more design time might be needed than with conventional buildings with standard HVAC systems. There is a concern in the industry that concurrent mixed-mode schemes may result in wasted energy if air-conditioning and natural ventilation are occurring in conflict with one another, yet there have been no studies to determine under what situations this might occur. The need for humidity control in some climates may also exacerbate this conflict between the benefits of a sealed and permeable envelope. In addition, it is recognized that natural ventilation may be undesirable in some situations due to air-borne pollutants and allergens, or outdoor noises.

c.Example of hybrid ventilation system Haute Vallée School Jersey. US (1998)

A 750 schoolchildren secondary school is a design brings together a number of low energy technologies into a simple and yet innovative configuration. Appearance, initial cost, durability and long term maintenance costs were all important considerations in the choice of external materials. The scheme combines the use of wind towers - Stack ventilation through the "chimneys" on the roof of the building keeps fresh air circulating around the school Fig.6, thermal mass, passive solar heating, external shading and good daylighting Fig7, all controlled electronically to provide a well balanced ecological environment. Haute Vallée was awarded a 1999 RIBA Award for Architecture.

Fig.6. Different views show the wind tower of the HAUTE VALLE school.

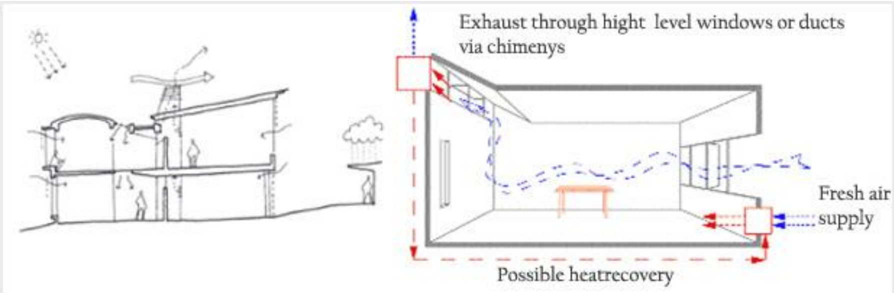


Fig.7 Diagram shows ventilation design of a typical classroom chimneys

2.2. Hygrothermal Comfort and cooling

2.2.1.overview

Major steps towards the definition of thermal comfort parameters were conducted in climate chambers in the 1960s and 1970s by Ole Fanger's research team. They determined the *predicted mean vote* or *predicted percent dissatisfied* (PMV/PPD) model (Seppänen, O. & Fisk, J. 2002) through studies conducted in tightly controlled climate chambers. Further research (Fisk et al. 1993) conducted by de Dear and Brager in the USA as well as Nicol and Humphrey in the UK indicated that this model was not suitable enough for thermal comfort understanding in natural ventilation spaces. The PMV/PPD model is not dynamic enough for the environment created in naturally ventilated buildings as it defines a too narrow band of temperatures considered comfortable by users. (Ulrike & Francine 2015)

2.2.2.Predicted Mean Vote (PMV)

Is an index that predicts the mean vote of a group of people voting on how comfortable they are in an environment. While PPD is a function of PMV. The PMV refers to a thermal scale that runs from Cold (-3) to Hot (+3) where zero is optimal comfort. The research Subjects a large number of people to different conditions in a climate chamber and then having the subjects select a position on the scale that best described their comfort level. The result relates the thermal factors to each other through heat balance principles and produces the following scale. The recommended acceptable PMV range for thermal comfort from ASHRAE 55 is between -0.5 and +0.5 for an interior space. (Ulrike P & Francine B 2015)

Fig 8: Predicted Mean Vote [PMV](Source: Adopted Author, (Ulrike & Francine 2015)

2.2.3.Predictive Percentage of Dissatisfied (PPD)

Index that establishes the percentage of thermally dissatisfied people who feel too cool or too warm and It predicts the number of thermally dissatisfied persons among a larger group of people.PPD increase as PMV moves away from 0. ASHRAE 55 recommends an acceptable PPD is less than 10% as it is impossible to account for everyone's optimal thermal comfort as each person has their own unique influencing factors such as activity and clothing.

Clothing	Clo	Activity	Met
Panties, t-shirt, shorts, light socks, sandals	0.30	Seated, relaxed	1.0
Underwear, shirt, trousers socks, shoes	0.70	Sedentary activity (office, dwelling, school laboratory)	1.2
Panties, stockings, blouse, long skirt, jacket, shoes	1.00	Standing, light activity (shopping, laboratory, light industry)	1.6
Underwear with short sleeves and legs, shirt, trousers, vest , jacket coat, socks shoes	1.50	Standing, medium activity (shop assistant, domestic work, machine work)	2.0

Table 1: Thermal Comfort Indices left, clothing /right, activity (Panjkov et al 2013)

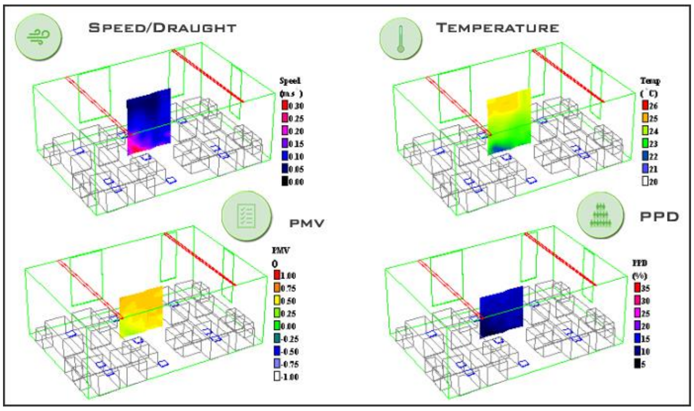


Fig 9 A simulation example shows the link of draught and temperature on PMV, PPD index.

2.2.2.Passive Cooling measures:

Passive cooling systems use no electricity. They can be used to cool homes and other indoor environments when electricity or air conditioning is not available, or to reduce the need for air conditioning. Three main approaches include: (Saber et al.2021)

2.2.2.1.Blocking the Heat: Limiting the heat absorbed by a building through the use of insulation, reflective barriers and shading can significantly reduce summer heat gain and reduce cooling needs. Exterior shading with trees or barriers, and interior shading through window blinds and shades will effectively reduce indoor heat gain. Light colored exterior wall and roof colors (e.g. cool roofs) can reflect the sun and prevent your home from absorbing as much heat, thereby keeping it more comfortable inside.

2.2.2.2.Limit Interior Heat Sources Limiting the use of heat producing appliances, incandescent lights, and indoor cooking can reduce indoor temperatures.

2.2.2.3.Removing Interior Heat Removing heat through thermal creation of siphoning effects (pull heat up and out), roof vents, natural ventilation (open windows and doors), and use of ceiling fans is important when indoor temperatures are higher than outdoor temperatures . Approaches to maximize cooler nighttime temperatures by ventilating a house at night, and using shading techniques during daytimes can significantly reduce indoor temperatures. However, Increased outdoor noise levels, pollution, and security issues can make relying on open windows a less attractive option in some locations.

2.2.3.Thermal Comfort Parameter

Thermal comfort is a multi-faceted experience, which is governed by four variables of the thermal environment: *air temperature*, *relative humidity*, *mean radiant temperature* (the temperature of the surrounding surfaces), and *air velocity*. Clothing as well as activity and the metabolic rate of occupants are personal conditions, which also influence comfort perception. (Ulrike P & Francine B 2015)

2.2.4.The effect or the role of ventilation on hygrothermal comfort

The concept 'thermal comfort' describes a person's psychological state of mind and is usually referred to in terms of whether someone is feeling too hot or too cold. According to (ISO 7730 or ASHRAE) the thermal comfort definition is: "that condition of mind which expresses satisfaction with the thermal environment". (Seppänen, O. & Fisk, J. (2002)

Thermal comfort is not easy to define because it is needed to consider different environmental and personal factors when trying to decide what will make people feel comfortable. These factors make up what is known as the *'human thermal environment'*. The best that you can realistically hope to achieve is a thermal environment that satisfies the majority of people in the workplace, or put more simply, *'reasonable comfort'.*

(HSE) considers 80% of occupants as a reasonable limit for the minimum number of people who should be thermally comfortable in an environment. Thermal comfort is measured by the number of people complaining about thermal discomfort. It is important to analyze all *six factors* listed below to understand why it is needed more than air temperature as a valid indicator of thermal comfort. (Panjkov et al 2013)

Beside acoustic, light and air quality, thermal comfort plays a major role in good IEQ. *Dissatisfaction can be caused* by warm or cool discomfort of the body as a whole or by an unwanted cooling or heating of one particular part of the body. A person's perception of indoor comfort is influenced by a number of factors, including:

1. Occupants' activity :What activities the building occupants are doing.
2. Clothing : The thermal factor of the clothing worn by the occupants.
3. Air temperature : Temperature of the air within the occupied space.
4. Relative Humidity : Percentage of water vapor in the air.
5. Radiant T :The average temperature of the surfaces within the occupied space.
6. Airspeed : The speed at which the air is moving.

Air velocity (m/s)	0.2		0.5		1		1.5		2		3	
Air temperature (℃)	27	29	29	31	29.5	32.5	31	33.5	31.5	36	32	36.5
Relative humidity (%)	80	50	80	50	80	50	80	50	80	50	80	50

Table 2. Subjective response to air motion (Tanabe and Kimura. 1989) (Ahmed A. et al. 2017).

Air velocity (m/s)	Occupant reaction
0 - 0.05	Complaints about stagnation
0.05 - 0.26	Generally favorable
0.25 - 0.5	Awareness of air motion but maybe comfortable
0.5 - 1.02	Constant awareness of air motion, but can be acceptable
1.02 - 1.5	Complaints about blowing of papers and hair but can be acceptable in living activities

Table.3 Required air velocity according to both air temperature and relative humidity to achieve thermal comfort. (Ahmed A. et al. 2017).

Source	Description
Givoni (1994) [1]	Direct passive cooling can be achieved only when outdoor air temperature equals or less than 26℃ and indoor air temperature is more than 26℃. Airflow rate between the two opposite openings are main indicators besides outdoor air temperature.
Kang and Carillo (2007) [16]	Comfortable indoor air velocity can be determined based on human skin. Minimum indoor air velocity equals 0.3 m/s. Comfortable indoor air velocity is 1 m/s. Possible maximum indoor air velocity in 1.5 m/s. This maximum value is a limit of air velocity even though thermal comfort needs more than 1.5 m/s.
ASHREA (2004) [18]	Thermal comfort can be extended from 26℃ to 29℃, at indoor air velocity of 0.7 m/s and up to 33.5℃, at indoor air velocity of 1.5m/s as the upper possible limit. Air velocity is the main indicator in this definition.
Rofail (2006) [13]	Indoor air velocity can decrease the apparent temperature by 10℃ if air velocity equals 3.5 m/s. Thermal comfort is preferable more than uncomfortable air velocity in the hot times.
Maarof and Jenes (2009) [19]	Continuous air movement is more important than undesirable conditions of air draft in particular at indoor relative humidity ≥70%.

Table 4.. A summary of recommended indoor air velocity (Ahmed A. et al.,2017)

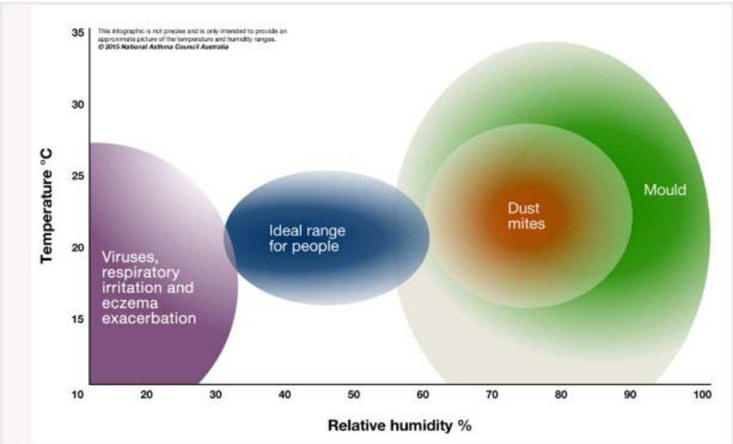


Fig. 10 Temperature and relative humidity correlation with air quality(Source: SenvitiveChoice.com)

Air movement for human comfort when air movement in occupied spaces is less than 0.075 m/s it generally causes a feeling of air stagnation and above 0.4 m/s it is felt as an unpleasant draught Table 2,3. To maintain comfort conditions in the workplace it is generally desirable to maintain an air movement between 0.1 and 0.3 m/s. (ASHRAE Handbook)
Attaining optimal thermal comfort it can be improved by giving the influencing factors the attention they deserve in the design phase of a project. Sustainable building design can optimize energy use by focusing on the most important human comfort factors in a specific climate and for particular occupant activities.

2.2.5.Standards (thermal comfort):

Thermal comfort considerations in the USA are guided by ASHRAE standard 55,3 in the UK by CIBSE,4 and in Germany by the ISO standard EN ISO 7730.5; Other national and international standard bodies are also relevant. (Benjamin M. J 2010)
Thermal comfort standards and comfort expectations over the past 50 to 80 years have changed significantly, and the responsibility to provide indoor environmental conditions that meet the required comfort standards has generally been passed from the architects to the building service engineers, with the result that the requirements are mostly met with active mechanical HVAC systems and not necessarily through spatial design. Thermal comfort is rarely taught in the design studio, but is addressed in the environmental forces and systems classes and thus is often considered detached from spatial or visual design concepts and considerations. (Ulrike P & Francine B 2015).
-*BS ENISO 7726* ,Ergonomics of the thermal environment –Instruments for measuring physical quantities*; BS EN ISO 7730*, the standard regarding the ergonomics of thermal comfort suggests that it can be expressed in terms of (PMV) and (PPD).Professor Fanger developed equations that would help predict comfort levels, taking into account the *six factors* that influence thermal comfort.(Ulrike P & Francine B(2015)

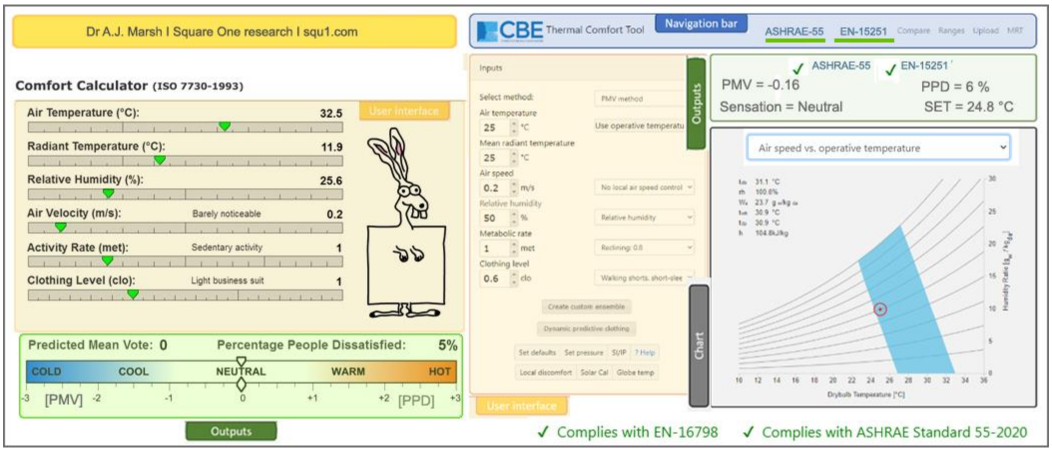


Fig.11 Screenshot of online comfort calculator tool CBE*. (Reference: comfort.cbe.berkeley.edu)

**Thermal Comfort Tool* (CBE) is a free online tool for thermal comfort calculations and visualizations that complies with the ASHRAE 55–2017, ISO 7730:2005 and EN 16798–1:2019 Standards. It incorporates the major thermal comfort models, including the (PMV).

2.2.8. Hygrothermal comfort and productivity

Many researchers have shown a positive correlation in business environment between lowering temperature during cooling period and increase in productivity, 10-12 year old students have shown to have an improved performance by increasing ventilation rate and lowering temperature. Ventilation rate had a positive impact of 8-14%, while cooling 2-4%.

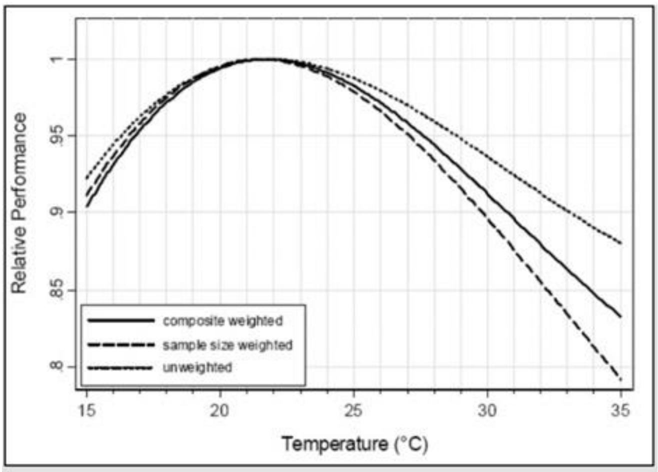


Fig 12. Relative performance and temperature (Source: Thermco,2009)

In a study by (Fisk 2000) estimated the “discomfort cost” ;it showed that for the U.S. improved indoor environment could:

- Save 6-14 b$/a from reduced respiratory disease
- Save 2-4 b$/a from reduced allergies & asthma
- Save 10-30 b$/a from reduced building syndrome symptoms
- Generate extra 20-160 b$/a due to improved personnel performance

In other study (Nikolaou V,et al.2014) claim that UK medical treatment cost due to poor housing is 2,5b£/a out of which 700m£/a stem from poor energy efficiency/fuel poverty .

Type of building/space	Activity W/m² (met)	Category	Operative temperature °C		Maximum mean air velocity ᵃ m/s	
			Summer (cooling season)	Winter (heating season)	Summer (cooling season)	Winter (heating season)
Single office Landscape office Conference room Auditorium Cafeteria/restaurant Classroom	70 (1.2)	A	24,5 ± 1,0	22,0 ± 1,0	0,12	0,10
		B	24,5 ± 1,5	22,0 ± 2,0	0,19	0,16
		C	24,5 ± 2,5	22,0 ± 3,0	0,24	0,21 ᵇ

Clothing: Winter = 1 clo (suit), Summer = 0.5 clo (trousers & short-sleeve shirt)

Table 5. Example design criteria for spaces in various types of buildings. (Source: Thermco,2009)

Standard	Winter	Summer
ISO 7730	22±2°C	24.5±1.5°C
CIBSE 2006*	22±1°C	23±1°C
ASHRAE 55**	22.5±2.5°C	25.5±1.5°C
BCO 2005	20±2°C	22±2°C

* Clothing: Winter = 0.85 clo, Summer = 0.7 clo, Activity = 1.2 met
** Clothing: Winter = 1.0 clo, Summer = 0.5 clo, Activity = 1.0-1.3 met, humidity = 50%

Table 6. Standards and Guidance but no upper temperature Legislation (Source: cchs.ca)

2.3.Air change and standards

2.3.1.Overview

The advent, development and widespread deployment of mechanical HVAC systems over the course of the 20th century provided engineers and building occupants with direct control over the indoor environment. The desire for increased levels of control, coupled with a growing awareness of the need to reduce the energy demand of buildings - particularly in the wake of the 1970s energy crisis -led to the construction of increasingly airtight buildings, and the reduction of ventilation rates. SBS arose as a consequence of a desire to improve the energy efficiency of buildings; poor IAQ, build up of airborne pollutants and excessive dryness or humidity associated with poorly designed or maintained HVAC systems, and noting that 'treatment involves both the patient and the building'. (Redlich et al.1997, Redlich, C. A., Sparer, J. & Cullen, M. R.1997) The conflicting challenges of mitigating SBS whilst simultaneously improving the energy efficiency of buildings sparked a renewed interest in natural ventilation. (Andrew A 2014).

Reducing energy consumption is even more of a concern today than it was in the 1970s. This is reflected by current energy policy and legislature such as the *Climate Change Act (2008)*, (Awbi 1998) reviews the historical variation in ventilation rates and notes that between 1936 and 1989, recommended ventilation rates were 2-5$l.s^{-1}$ per person (ASHRAE (1981), for example, up to five times lower than the 8-10$l.s^{-1}$ per person recommended by modern standards such as the CIBSE guide A (CIBSE, 2006) and ASHRAE standard 62.1. (ASHRAE, 2007) (Ulrike P & Francine B 2015)

Reduced ventilation rates led to higher concentrations of airborne pollutants in indoor spaces which, coupled with an increasing amount of time spent indoors, led to building occupants presenting with symptoms such as headaches, fatigue, eye and throat irritation and respiratory problems, a condition known as Sick Building Syndrome (SBS).

2.3.2. Air changes and standards

The control of air flow is important for several reasons: to control moisture damage, reduce energy losses, and to ensure occupant comfort and health. Airflow across the building enclosure is driven by *wind pressures*, *stack effect*, and *mechanical air handling equipment* like fans and furnaces. A continuous, strong, stiff, durable and air impermeable air barrier system is required between the exterior and conditioned space to control airflow driven by these forces. It has long been recognized that the control of air flow is a crucial and intrinsic part of heat and moisture control in modern building enclosures. That this statement is true for all climates. Fig.13 showing how ventilation rates changed over time.

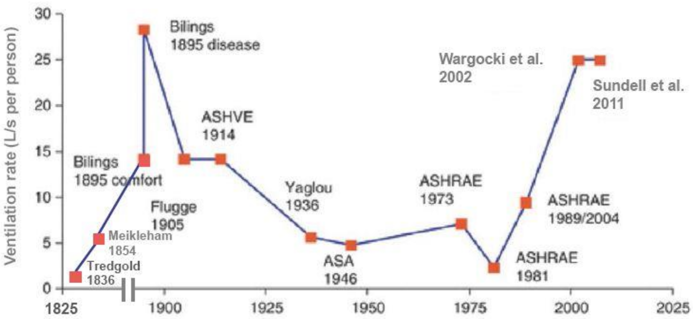
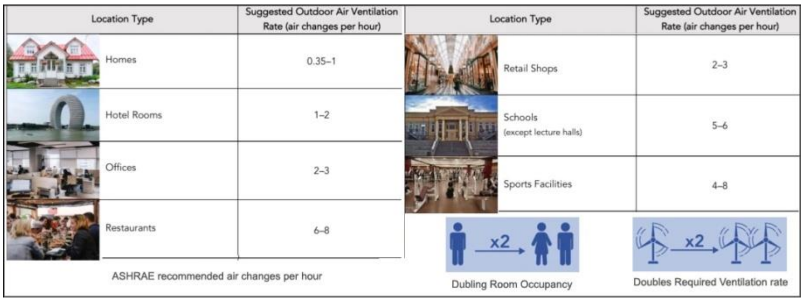


Fig.13 Ventilation requirements ;historical perspective (adapted from Nielsen and Li). (Saber et al.2021),

It is difficult to define one ventilation requirement that will satisfy all demands and conditions. Fig 13 . The reason is quite simple: different approaches were used to define ventilation requirements, different sources were controlled, and different outcomes were managed. If comfort (sensory perception of indoor air quality) is a design parameter and the target is 20% dissatisfied (80% acceptability) and humans are the major source of pollution, the ventilation rate would be about 10 ℓ/s per person as reflected in the current ventilation standards; this supports the widely accepted CO_2 concentration of 0.1% (1,000 ppm) proposed by Pettenkofer. (Li, L. & Mak, C.M. 2005).However, if health is considered, the rates required can be much higher and as high as 28.5 ℓ/s per person, as proposed by Billings. Setting ventilation requirements is only part of the problem. Scientific and technical literature shows that the design, operation, and maintenance of systems providing the air for ventilation have not always been adequate, resulting in the ventilation systems themselves becoming a strong source of pollution that can increase exposures and consequently increase health risks. (Pawel 2021)

The table below gives approximate air changes per hour for schools, homes, hotels, shops and restaurants. Exact ventilation rates for a given space should be calculated based on the (ASHRAE 62.1)standard. But the rules below are helpful staring points for calculating the recommended air changes per hour for any space.



Location Type	Suggested Outdoor Air Ventilation Rate (air changes per hour)	Location Type	Suggested Outdoor Air Ventilation Rate (air changes per hour)
Homes	0.35–1	Retail Shops	2–3
Hotel Rooms	1–2	Schools (except lecture halls)	5–6
Offices	2–3	Sports Facilities	4–8
Restaurants	6–8		

Table 7 A summary of the ASHRAE recommended Ach/h for common building types.(Source: ASHRAE)

To sum up, The recommended ventilation rates for schools, offices, shops, restaurants and homes varies from 0.35 – 8 air changes per hour. When dealing with places that may contain viruses, the recommended air changes per hour are higher, approximately 6-12.

2.3.3. Important of control air flow: there are three primary classes of reasons why the control of air flow is important to building and occupant performance: .(Strabe,J.F 2001)

Moisture control – water vapor in the air can be deposited within the envelope by condensation and cause serious health, durability, and performance problems.

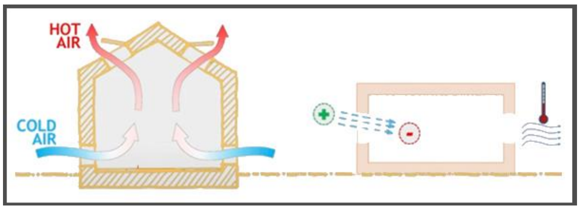
Energy savings –air leaking out of a building must be replaced with outdoor air which requires energy to condition it. Approximately 30% to 50% of space conditioning energy consumption in many well-insulated buildings is due to air leakage through the building enclosure. Convective circulation and wind .washing both reduce the effectiveness of thermal insulation and thus increase energy transfer across the envelope.

Comfort and health – cold drafts and the excessively dry wintertime air that results from excessive air leakage directly affect human comfort, wind-cooled portions of the interior of the enclosure promote condensation which supports biological growth which in turn affects indoor air quality, airborne sound transmission control requires good airflow control, and odors and gases from outside and adjoining buildings often annoy or cause health problems. There are other circumstances that require the control of air flow; for example, to control smoke and fire spread through air spaces and building voids and shafts, but these are situations that deal with extreme events, not typical service. This document will emphasize airflow control and the avoidance of related moisture problems.

2.4.Natural ventilation

2.4.1.Overview

Ventilation of buildings can very roughly be simplified as 1) getting fresh air into the building from the outside, 2) directing the air through the interiors to provide them with fresh air and to pick up heat and pollutants on its way, and finally 3) getting the exhaust air out of the building. The three points are useful when attempting to sort out the architectural possibilities associated with natural ventilation. (Tommy Kleiven &Anne Grete Hestnes,2003)
Passive ventilation can improve comfort, offer occupants more control over their comfort, and reduce operating costs. Building costs can be reduced even further when the HVAC system can be eliminated or reduced in size. (David et al. 2011)
As mentioned earlier before NV based on natural forces is quiet, requires no electricity, does not create global warming gases, and works even when the power is off is the process of supplying and removing air through an indoor space by natural means (Roulet et al. 2002).
There are three major spatial principles that enhance natural ventilation; they are represented in three iconic buildings of the Modern Movement: the *wind catcher*, *the stack effect*, and *cross-ventilation* as represented by the Affleck House by *Frank Lloyd Wright* (1940) (an example of a Usonian House), also represented by the How House by *Rudolph M. Schindler* (1925) and the Esherick House by *Louis Kahn* (1961). (Ulrike P & Francine B 2015).
These three breathing houses utilize all basic spatial themes: the stack chimney, the wind catcher, and cross-connections, as well as a combination of all three. Depending on the outside conditions, the chimney and wind catcher can reverse within the same space, if designers are not careful or act without proper guidance. Whether a tall space acts as a wind catcher or a stack chimney depends on multiple factors: wind catchers always have to be directed towards the windward side and stack exhausts to the leeward side, where low pressure zones can pull the hot air out of the stack space. But wind direction can frequently change and so inlet and outlet might also change and reverse the flow path.
Second, it is important to understand the density difference (temperature difference). The hotter the air will be at the upper end of the space, the more it is likely to act as a chimney, not a wind catcher.. (Ulrike P & Francine B 2015)



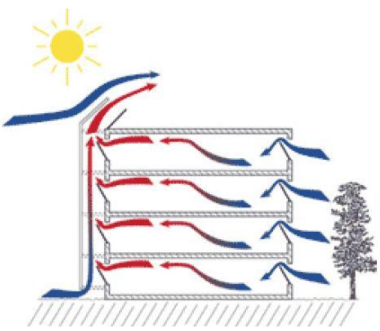


Fig 14.1 : Natural ventilation affects   Fig 14.2 Natural Ventilation (Dyer Environmental Controls, 2010).

The importance of fresh air in buildings cannot be overemphasized; it offers better thermal comfort and ensures an abundant supply of oxygen for respiration. The change in pressure may be due to a change in humidity or the buoyancy effect created by temperature differences or wind. Irrespective of the cause, the opening sizes and placements determine the amount of ventilation a building gets.

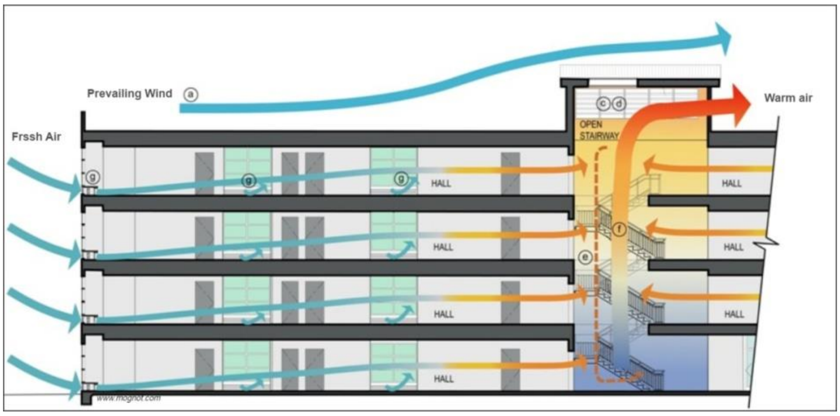


Fig 15: Comfortable Airflow in a Building by Using NV (Tommy K A & Grete H 2003)

2.4.2.Wind at the atmospheric scale (Types of wind) : (Ulrike P & Francine B 2015)

Wind is a horizontal movement of air generated by pressure differences between air masses; the air flows from areas of high pressure (anticyclone) to areas of low pressure (depression). Wind is by far the most significant component of the driving force in natural ventilation, particularly in hot seasons. The wind flow over the earth's surface is a very complex phenomenon that is governed by a number of variables such as: earth's rotation; temperature differences between oceans and land and polar and tropical air; geographical location and landscape. In meteorology, the following scales are used for describing climatic models: *global scale*, *regional scale*, *local scale* and *micro-climate scale*.

2.4.2.1.The global scale concerns astronomical factors that relate to the size, shape, and self rotation of earth and its elliptic rotation around the sun and this covers a range of thousands of kilometers. These factors create the diurnal and seasonal variations according to latitude, as well continental variations due to the distribution of land and oceans.

2.4.2.2.The regional scale relates to regional climatic features such as geographic landscape (e.g. the influence of mountains, hills, valleys, etc.), proximity to ocean and location of region with respect to zones of general wind circulation. This scale covers wind flows over hundreds of kilometers; it's also called *Prevailing winds.*

- *Seasonal Winds* are winds that blow seasonally. The air masses over the continents are warmer in summer and colder in winter than the air masses over the neighboring oceans. In summer, the continents become low pressure areas, with winds coming from the colder oceans. In winter, the continents become high pressure areas, with winds directed towards the warmer warmer oceans.

2.4.2.3.The local scale relates to local geography or water mass (such as hills, valleys, lakes, large rivers, etc.) and urbanization (such as heat islands) and how the local climate, including the wind flow, is affected by these factors. This stretches over a distance of about 10km. The local climate is of course influenced by energy balance at the regional scale.

- Land and sea breezes are specific local winds that occur near coastlines. They are generated by the difference in temperature between the surface of the land and the surface of the sea.

2.4.2.4.The micro climate scale relates to small towns or districts where local features used in their construction could have influence on the wind flow, such as nature of town planning, presence of artificial climate modifiers (e.g. windbreaks, hedges, etc.), the presence of water, etc. This scale covers a few hundred meters and is greatly influenced by man's planning and activities.

- The wind can be measured in m/s or in km/h, it is variable and unstable, it has several directions and can be represented on what is called a *WIND ROSE.*

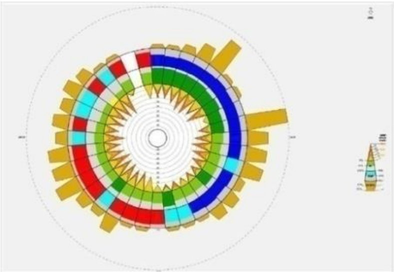


Fig 16.Example of Wind Rose illustrate the speed and direction of wind.(Source:wikipedia)

2.4.3. Wind /Air Movements Inside And Around Buildings

The wind is inherently variable. The wind pressure driving ventilating flows depends on numerous interacting factors such as wind speed and direction, positioning and orientation of vents and fa¸cades, and surrounding terrain and buildings. (Ulrike P & Francine B 2015)
Indeed, (De Wit & Augenbroe 2002) identify wind pressure calculations as the most important source of uncertainty in natural ventilation design, pointing towards the need for a probabilistic -rather than deterministic- design approach. Rather than taking a probabilistic approach, we will consider instead designing for a 'worst case' scenario in which no wind is available to assist ventilating flows. In this case, a naturally ventilated building should be designed to provide sufficient ventilation under the action of buoyancy only. The Contact Theatre, Manchester, "*always say stack before all*." (Andrew Acred 2014)
Air always moves naturally from a higher pressure zone to a lower pressure one. An air flow is called *laminar* when the speed is low and the fluid streamlines all move in parallel. Fig 17

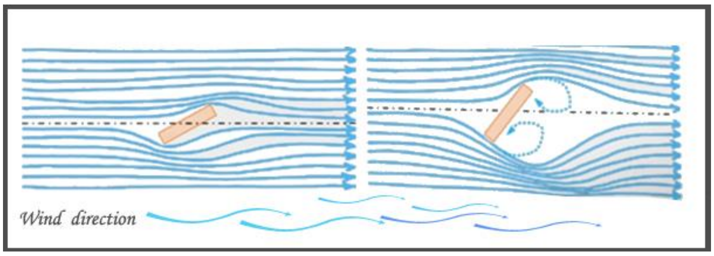


Fig.17: laminar and turbulent air flow (Benoit Cushman-Roisin 2019).

As the speed increases or a pronounced change of direction occurs, the motion becomes *turbulent*, and fluid streamlines ceases to move in parallel, given rise to significant changes in direction and to eddies. Fig. 18

Air is subject to the *BERNOULLI effects*, because of which there is a reduction of pressure when sped increases; this effect is exploited in the wind of an airplane, whose shape is such that it forces air passing above it. to follow a longer path, this resulting in greater speed than that of the air flowing beneath it; the pressure at the top is then lower than at the bottom and there is a push from the bottom to upwards.

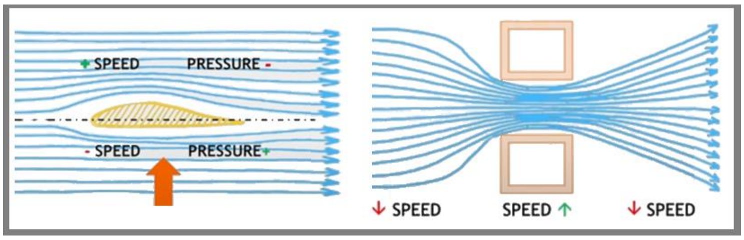


Fig.18: BERNOULLI and VENTURI effects (Benoit Cushman-Roisin 2019).

Because of the *VENTURI effect*, Fig 18 when an air stream is forced through a smaller section, its speed increases. An effect of a combination of the factors previously described, when the wind hits a building it causes areas of low pressure to be created along the sides parallel to its direction and on the leeward side.

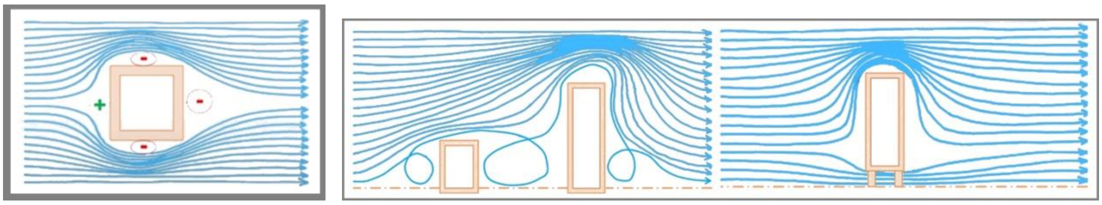


Fig.19: Pressure in and around building & windward of high-rise one and building on stilts

When the air inside a room is warmer than the outdoor air, it triggers the stack effect; the pressure inside is lower than it is outside due to the lower density of warmer air. It must be clarified that is not an easy task to predict the flow of air around and through buildings especially with regard to the path of the fluid streamlines. In a building on stilts leeward pressure is reduced and in correspondence to the stilts wind speed significantly increases.

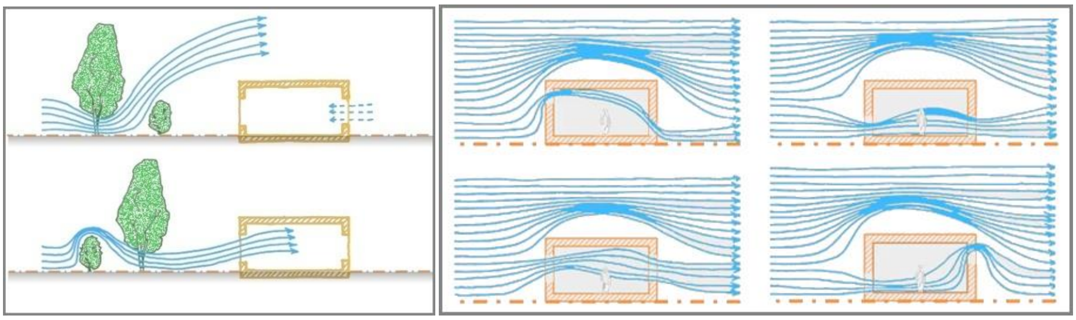


Fig.20**:** Effect of trees and bushes; Air flow and relative position of openings(Ahmed A. et al. 2017)

To maximize the cooling effect of wind, trees with high canopies should be used and bushes should be kept away from the building. The air flow pattern due to the wind depends on the relative position of the openings, and one of the best conditions are created when the outlet opening is higher and wider than the inlet (the idea is to have them of equal area). Fig 20
A horizontal overhand above the opening deflects flow upwards and in case of the overhand is spaced away from the wall, the flow is deflected at half height. Fig 21

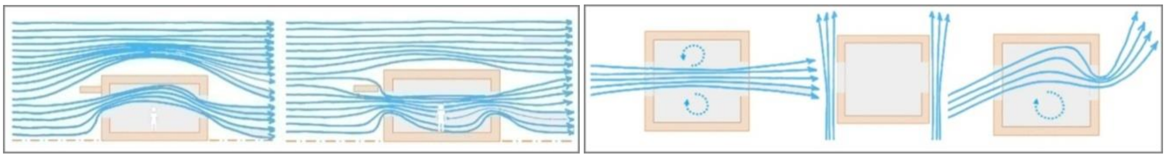


Fig.21: Effect of Slotted horizontal overhung; direct wind to the bottom of indoor space, as shown in Horizontal overhung at inlet openings & Wind direction openings on opposite wall.(Moore,F. 1993)

When inlet and outlet openings are aligned, cross ventilation is activated by wind. If the openings are aligned in the direction of the wind, the air flow passes right through the space influencing a reduced part of it and giving rise to modest induce air movements.

If the wind blows parallel to the openings, there is no significant air movement in the space. If the wind blows obliquely, however, the ventilation involves a wider zone and more air movement is induced. If the room has openings on adjacent walls, wing walls can significantly increase the effectiveness of natural ventilation. Fig 22 (Ahmed A. et al.,2017)

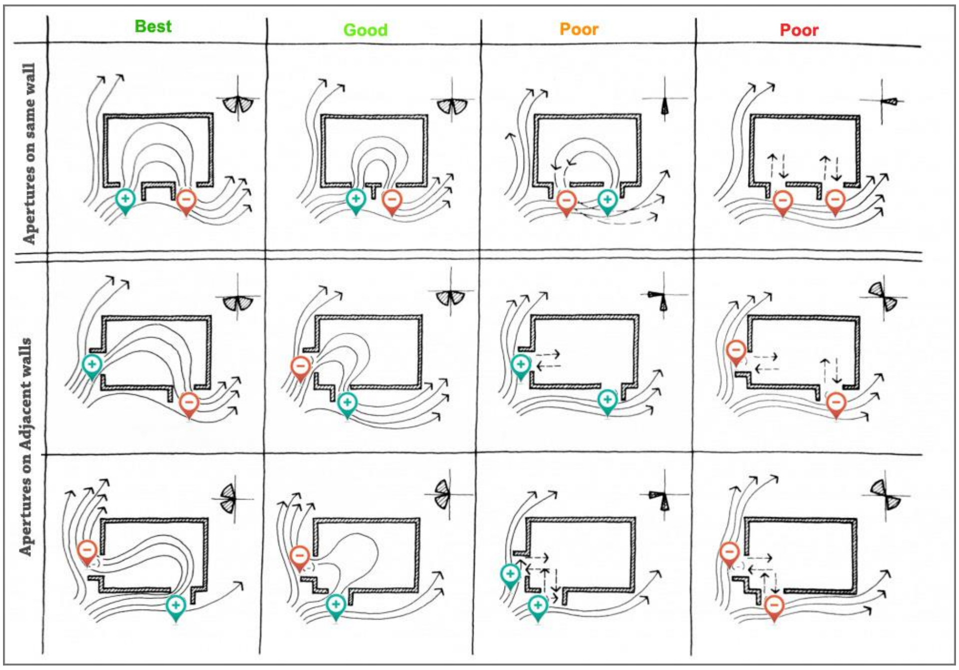


Fig.22: Openings on adjacent walls and wing walls (Source: Mechanical and Electrical Equipment for Buildings, 8th Ed. Stein, Benjamin; Reynolds, John S. published by Wiley Hardcover, December, 1991.)

2.4.4.The effects of natural ventilation :

2.4.4.1.Effect of ventilation on the indoor environment: Natural ventilation is mainly used for the control of indoor air quality and to provide thermal comfort in summer as well.

*2.4.4.2.***.***Effect of cross ventilation on the internal temperature:* Taking into account the position of the space in relation to the wind is important in the creation of the air movement, , thanks to certain differences in air pressure over the width and height of the openings, which are able to provide a suitable cross ventilation. Cross ventilation inside the building is the best strategy.

*2.4.4.3***.***Effect of night ventilation:* Givoni 1994 divides ventilation cooling into two types of ventilation of comfort and convective night cooling. The distinction between them is considerable, since some elements of the building, such as structural materials and thermal properties of the building thermal properties of the building require different designs for the effectiveness of these ventilation strategies. During the day, natural ventilation provides direct human comfort by seeking to increase the convective cooling of occupants by increasing the velocity of the internal air. (Ahmed A. et al.,2017)

The principle of night ventilation is interesting as soon as the outside air temperature lowers. There is an effect of lowering the temperature of the indoor air. The graph shows this effect for a building with average inertia where the interior temperatures are reduced by 3 to 4°C.

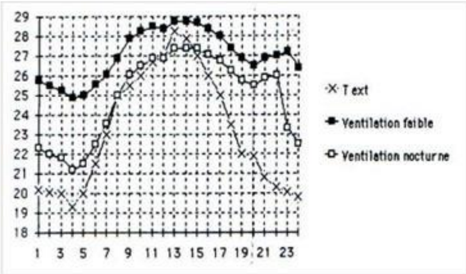


Fig.23. Effect of Night Ventilation.(Source: Bougriou, C. Hazem, A. et Kaouha, K.)

2.4.5.Driving forces for airflow in buildings: (Emmerich et al. 2001)

The pressure difference across the openings of a building is a major influence on the physical mechanisms for natural ventilation (Wood & Salib 2013). It is affected by the flowing of air, the differences of indoor and outdoor temperature, or a combination of both. Hence, natural ventilation can be grouped into 'wind-induced' and 'buoyancy-induced' ventilations. (Ulrike P & Francine B 2015).)

2.4.5.1.. Wind-induced ventilation: Wind exerts negative pressure on the leeward side of buildings and positive pressure on the windward side. This necessitates the need to equalize the pressure. And consequently, the fresh air enters via any windward opening and escapes via any leeward opening available; Fig 24. Wind supplies fresh air in generous amounts in the summer. However, the amount of fresh air available during the winter is only sufficient enough to get rid of excess pollutants and moisture. (Shittu. A, 2010)

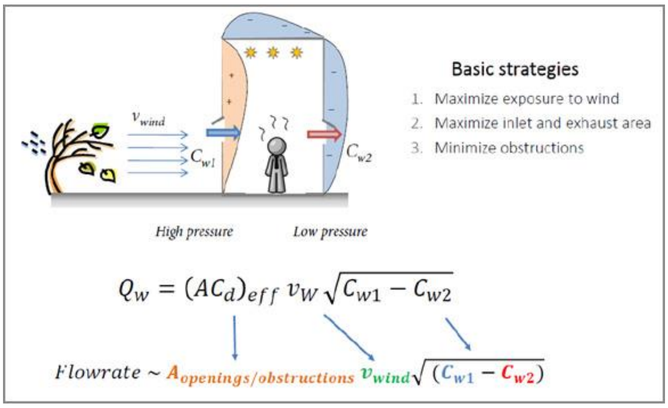


Fig 24. Wind driven ventilation (Source: CoolVen The NV Simulation Tool by MIT)

Wind flow generally in a direction that is perpendicular to the building. However, in cases where the flow is parallel, wind ventilation can be forced by incorporating certain architectural features or adopting casement window openings. In a situation where the wind blows from westwards from the east and along a wall facing the north, the first window opening out and hinging on the left-hand side serves as a scoop that redirects wind into the room. On the other hand, the second window would hinge on the right-hand side to ensure that the opening is down-wind from the open glass plane, with the negative pressure forcing air out of the room. There should be no obstructions between the leeward exhaust and windward inlet openings; No partition should exist in a room with a perpendicular orientation to the airflow. Conversely, the accepted design ensures that the outlet and inlet windows are not directly across each other. This is to provide improved mixing and more effective ventilation.

2.4.5.2. ***Buoyancy-induced ventilation:*** The buoyancy or stack pressure at an opening is due to variation in air density as a result of difference in temperature across the opening, and for openings at different heights, the difference in pressure between them is due to the vertical gradient in density. The presence of the existing heated air finding its way through the ceiling or roof openings allows fresh air to enter the lower openings to replace it. The effectiveness of the stack effect ventilation is maximum during the winter, considering that the temperature difference of the outdoor and indoor environment is at the peak Fig 25. Conversely, the effectiveness is reduced significantly in the summer because the requirement of the indoor being warmer than the outdoors cannot be met. (Ulrike, P & Francine, B. 2015). There are two forms of buoyancy ventilation *humidity-induced*, also known as the *cool tower*, and *temperature-induced*, also known as the *stack ventilation*. It is possible to integrate both, create a cool tower that can supply evaporatively cooled air low in space while relying on the increased buoyancy of the humid air to warm to exhaust air from the space via a stack. (Emmerich et al. 2001)

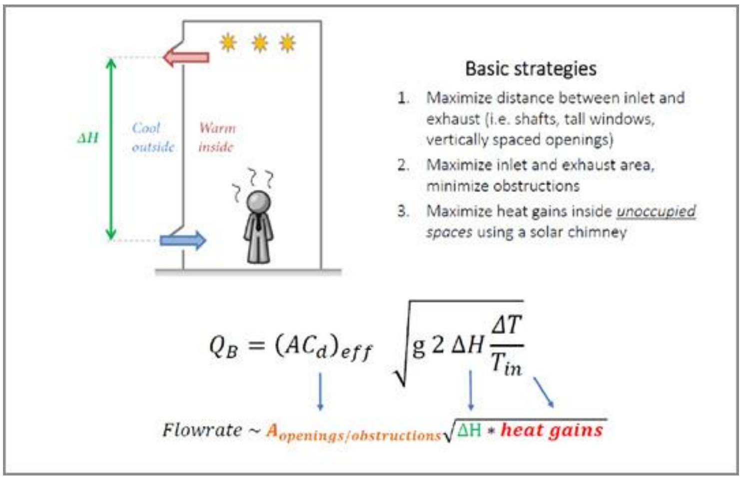


Fig 25. Buoyancy driven ventilation (Reference: CoolVent The NV Simulation Tool by MIT)

*2.4.5.3.****.Combined wind and buoyancy ventilation*** (Emmerich et al. 2001) When wind and stack pressure act simultaneously on a building, their combination will determine the air flow through building openings. If both pressures have the same sign then the two pressures will increase the air flow but if they have opposite signs the air flow will reduce and in certain circumstances the two pressures can cancel each other to produce no flow through the openings. The actual air flow in a building results from the combined action of stack effect and wind forces. The two effects may either reinforce or oppose each other, depending on the direction of the wind and on whether the internal or the extermanl temperature is higher. When acting simulataneously, the resuling air fow rate through the buildig can be calculated as square root of the sum of the two squared air flow rates Fig 26.

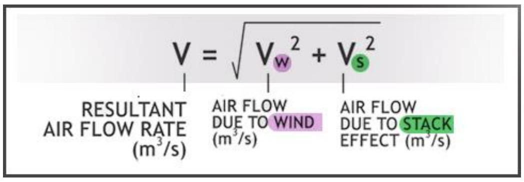


Fig 26: Combined Effect of Wind and Thermal Forces(Source: CoolVent The NV Simulation Tool by MIT)

2.4.6.The different types of natural ventilation (Architectural Ventilation)

There are three methods to carry out natural ventilation Fig.27, 28 (1)Single-sided ventilation,(2)Cross-ventilation, (3)Stack effect and top-down ventilation (i.e. windcatcher systems). : (Allocca et al., 2003; Dascalaki et al., 1999).

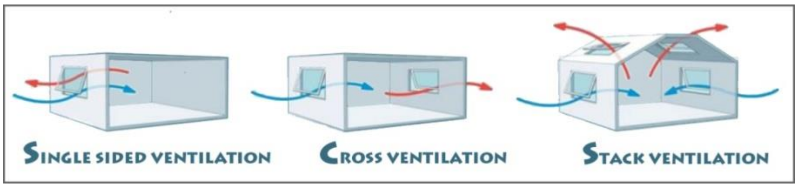


Fig 27: Types of Natural Ventilation (WindowMaster 2019)

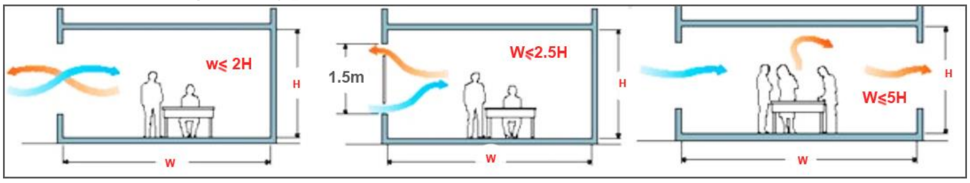


Fig 28: Single-sided opening ventilation (Wmax ≤2*H*), Stack-induced flow through a double opening,(d=1.5m), (Wmax ≤5*H*) Cross ventilation, (Wmax ≤2.5*H*). (Reference: CIBSE Applications Manual AM10)

*2.4.6.1***.** *Single-Sided Ventilation:* (Emmerich et al. 2001)

This method involves having openings only on one external wall and generally towards the wind-direction. Air exchange happens through wind turbulence. It is not used as often as it is ineffective compared to the other two ways (Kevin P 2009)

EX. Commerz bank by Sir Norman Foster (See Appendices)

*2.4.6.2***.** *Cross-Ventilation:* In this method, openings are located such that the ones at the receptive end allow maximum inflow of fresh air and the outlet openings are placed such that air gets circulated in the space efficiently and is pushed out with the inflow of fresh air. In areas with high wind speeds, smaller openings are preferred in the wind-ward directions and larger in the lee-ward or exhaust direction. In case of lower wind speeds, the opposite of the previous is preferred to get better quality air. (Emmerich et al. 2001)

EX.1 Casa ad Appartamenti Giuliani Frigerio, Como, by Giuseppe Terragni (1939–1940)

2. Kanchanjunga Apartment Building by Charles Correa (1970–1983)

*2.4.6.3***.** *Stack Effect:* In this system, there will be ventilation even when there is no wind. (Jalayerian, M 2012) is the inflow of fresh air into the building and outflow at an elevated level as a result of the occurrence of density, pressure and temperature differences within a building. It is often used in buildings with chimney, central atrium or elevated part. (Kevin, P 2009)

2.4.6.4.. *Top-down ventilation/roof-mounted ventilation* the top-down ventilation system, which is using roof turrets that encapsulate the wind from any direction. It has been proved to be one of the most reliable and popular forms of natural ventilation, simply because it uses the natural elements of wind movement to encapsulate relatively clean, fresh air from above roof level and the wind pressure pushes that fresh air supply through the wind-catcher device down into the building below. (Allocca et al. 2003, Dascalaki et al. 1999)

2.4.7.Natural ventilation by opening windows and its characteristics

The most basic natural ventilation system is the provision of openable windows. Windows can cause localized discomfort due to draughts and cold radiation in winter, or solar gain in summer. However, occupants of NV buildings with openable windows are generally willing to accept a wider range of internal temperatures than occupants of air-conditioned buildings with sealed windows, largely because they have more control over their environment..NV openings are of three broad types: (*a*) Windows, rooflights and doors (*b*) dampers or louvers (*c*) background 'trickle' ventilators. (Kevin, P. 2009); (CIBSE 2010)

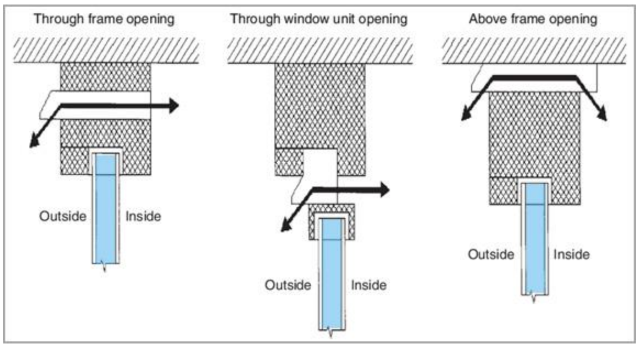
Opening a door or a window is a simple way to improve indoor ventilation and clean air from pollutants where the size of the openings, the climate of the location and the specific season of the year can control the ventilation rate. (Chastain, J.P. 2000)

The average interior air velocity is subordinate to the size and location of the openings, the angle between the wind direction and the inlets and velocity of the exterior free wind. Data shows that opening windows in a typical home can double ventilation rates. What's more, scientists found that opening windows in old-fashioned style hospitals with large windows and high ceilings increased air changes almost 20 times. Scientists in the US also found that opening the door 60 times in an hour also doubled the ventilation rate. In recent years there have been considerable developments in air inlet components for NV application, mainly in the areas of air flow and noise control. (G.Z Brown & Mark DeKay 2014)

In the following, a few of the devices are described.

2.4.7.1.Small openings: These are NV devices that are designed to provide background ventilation for winter and summer. Considerable progress has been made in recent years in developing devices that are capable of providing flow control. (Ulrike & Francine 2015). Trickle ventilators: These are air inlet devices that are used to provide a minimum fresh air rate as background ventilation (e.g. about 5 L/s occupant). Although some are provided with dampers for opening or closing, in normal use these vents are kept constantly open to provide minimum fresh air for maintaining acceptable quality of air throughout the occupancy periods. The UK Building Regulations for instance recommends a trickle ventilator opening area of 400mm2m^2 of floor area for spaces in non-domestic buildings of floor area>10m^2, with a minimum area for a single room of 4000mm2 in domestic and non-domestic buildings. To minimize cold draughts in winter, these should be located at high level, either at the top of window frame or as part of the glazed unit at high level, see Fig 29 . These devices are not capable of dealing with high pollution loads that may occur during peak occupancy and activity periods and they should be used in conjunction with other types of ventilation openings such as louvers or windows.(Ulrike & Francine 2015)

Fig 29. Trickle vents.(Source: Ulrike & Francine 2015).



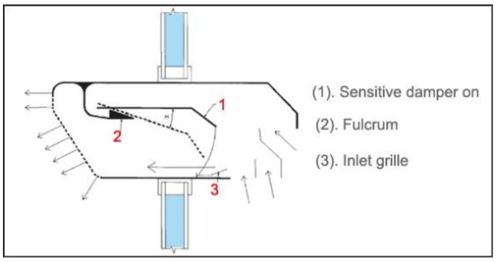


Fig 30: Trickle ventilator positions and Cross-section of a pressure-controlled ventilator: Kevin. P,2009

2.4.7.2..Large openings /Windows: Relatively large windows are often used for airing and, in some countries, for indoor air quality control. They can be tilted, turning and sliding windows or combinations of these. The most advanced windows are windows with an automatic control on the opening to ensure good indoor air-quality levels, at the same time as reasonable conditions of comfort. Comfort conditions and the use of windows are very dependent upon weather conditions, such as outside temp , wind and rain. (Kevin. P, 2009)

There is a wide range of window types and sizes and their ventilation characteristic varies accordingly. The main types of widely used windows are shown in Fig 31. and their characteristics are given below. However, knowledge of the performance of a particular window for natural ventilation is rather limited and is often based on theoretical assumptions of the driving forces and the effective open area and, in practice, therefore, it is only possible to make a rough estimate of the air flow rate through a window opening. Some window types are regarded better than others, but this is mainly based on qualitative measures and, on the whole, the difference between and the limitations in the application of window types cannot easily be .(Ulrike & Francine 2015).

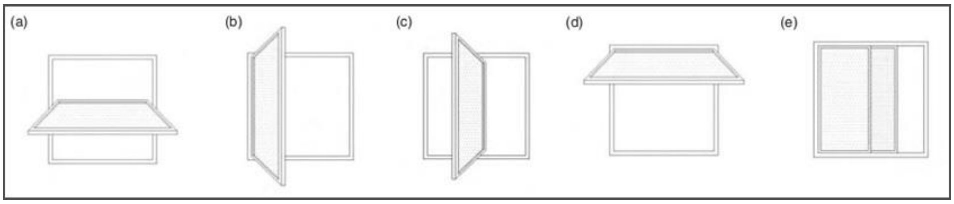


Fig 31: Different types of windows.(a)Horizontal-pivot window; (b)Side-hung window; (c)Vertical-pivot window; (d)Top- or bottom-hung windows (e)Horizontal- and vertical-sliding windows. (Ulrike & Francine 2015).

Horizontal-pivot window This type has a large flow area which approximates the full area of the window and therefore can provide large air flow rates. When used for single-sided ventilation, air enters at the bottom half and leaves at the top if the external temperature is lower than the room temperature. However, when it is used in cross-flow ventilation air enters the top and bottom halves simultaneously, as illustrated in Fig 32

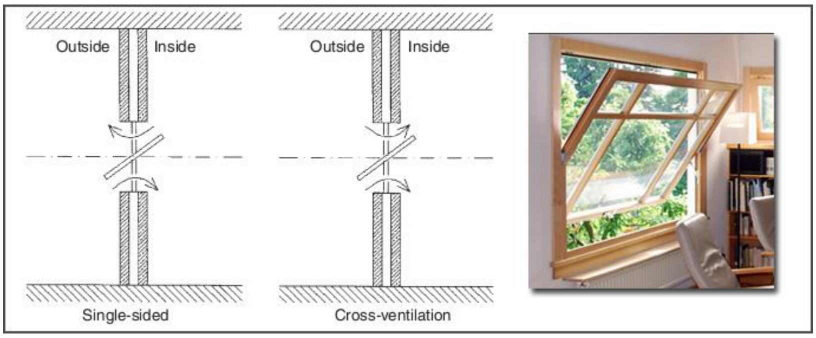


Fig 32: Horizontal centre pivoted window for single-sided / cross ventilation .(Ulrike & Francine2015).

Horizontal pivot windows have more ventilation capacity than center vertical pivot windows. Casement windows and pivot windows have the same advantages and the difference is casement windows are open to strong blast of the wind. With bay windows, pressure differences can be localized. (Iannone, F. 1999)

Side-hung window, Vertical-pivot window Top- or bottom-hung windows, Horizontal-,vertical-sliding, windows Louvers are the most common types of windows. Fig. 33

According to the type of window net free area of an opening, is different and it is obtained by multiplying the gross opening area by the window permeability. In brackets, typical values for different window types are reported. The same algorithm may be also useful to size the opening area, if explicit in function of it. Fig. 33

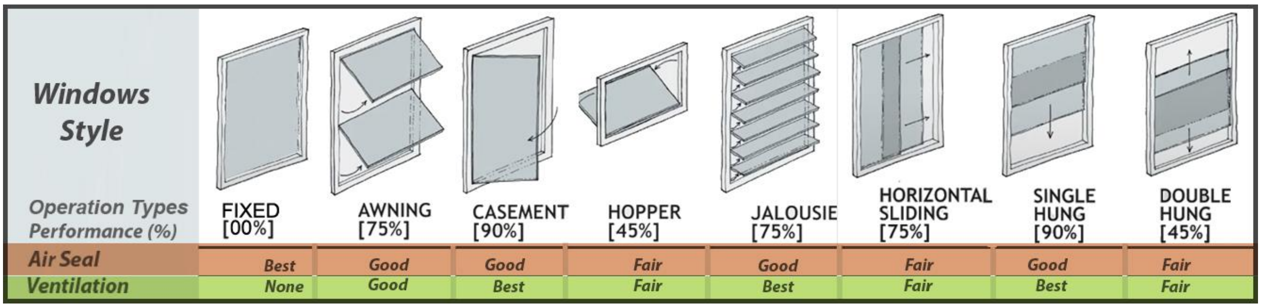


Fig 33**.** Ventilation Percentage of different Windows types. http://www.pok.polimi.it (POK)

Different window designs may be assessed under the following criteria: *Ventilation capacity*: '*Controlability'*: *Comfort*: *Security*: *Sealing*: *Integration with vent actuators*:

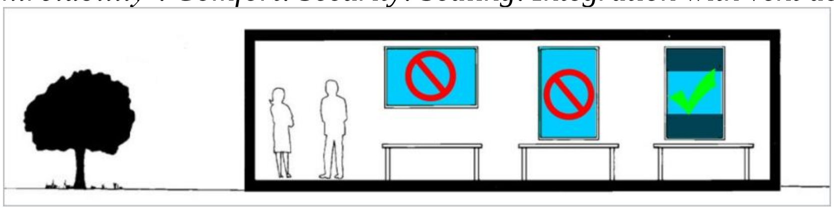


Fig 34. Effect window shape and location in non-domestic buildings (Source: Adapted byAuthor)

Deeper windows can ventilate better, but avoid draughts at working level, consider controllable opening lights/parts Fig.34

Actuator: The actuator is essentially what pushes the window open. Most façade window actuators are chain types and are typically used for three main reasons. Firstly, they deliver automated ventilation and are increasingly chosen to add ‘intelligence’ to the building’s ventilation, helping it breathe more effectively on its own. Secondly, actuators are also used to provide ventilation via out of reach openings, such as roof windows. Thirdly, they may be used to provide smoke ventilation to improve building safety in the event of a fire (WindowMaster 2019) intelligent actuators, allows essential functions like speed control to minimize noise. This technology ensures that openings for night cooling remain within allowed security limits and the pressure safety functions will be the defining factor that reduces a potential severe injury to a minor pinch. (WindowMaster 2019)

Fig. 35.WindowMaster project: Helsingør Kulturværft actuator(WindowMaster 2019)

2.4.7.3. Ventilation ducts and stacks: NV systems using ducts can overcome most of the problems associated with single exposure ventilation or when the types of openings do not provide sufficient fresh air supply to the building, either because the building is very deep in plan and/or a high ventilation rate is required and sometimes improve through-ventilation strategies by balancing airflows rates in different rooms of a building. The performance of the stack ventilation system is most reliable in cold weather and high wind speeds but in milder weather additional openings such as windows are normally needed to supplement the ventilation requirement in the form of single-sided ventilation. Today we find modern multi-duct systems. In these systems, the air enters a cold duct (compared to outdoor conditions) and then is extracted through a warm duct, (compared to indoor conditions).

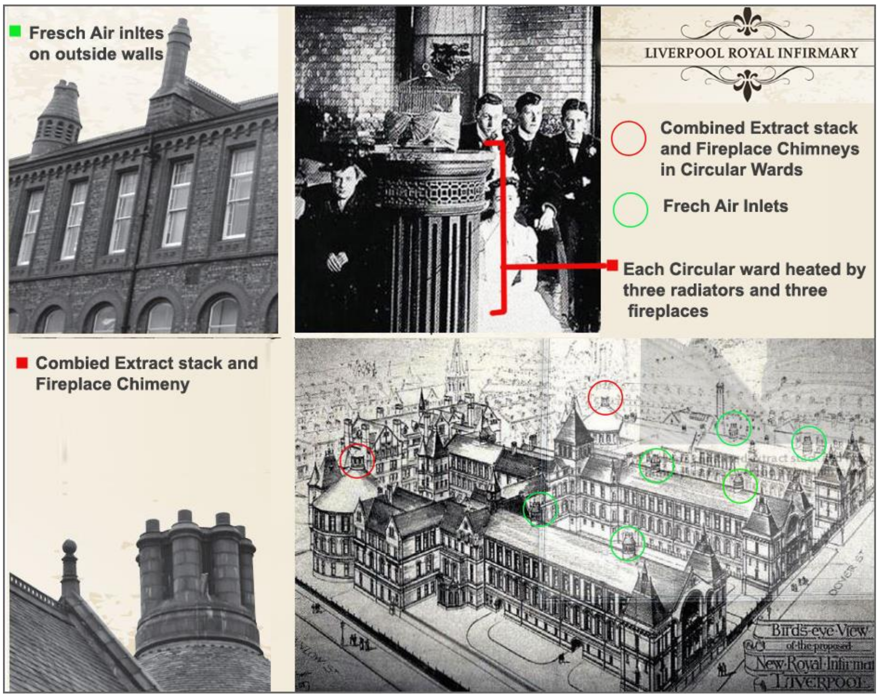


Fig36. EX of ventilation system in a historic infirmary building liverpool -UK (Source: Author)

2.4.8.Technologies and Techniques for Enhancing Natural ventilation

Natural ventilation can be enhanced, by adopting, using some techniques or by providing some devices and smart technologies. First of all, when designing so as to profit as much as possible from the benefits of natural ventilation, both cross and stack, orientation and placement , organization, and design of the rooms play an important role. However, there are some cases in which it is difficult to provide adequate ventilation even if the location is fairly windy. *The First one* is the case in low-rise and high density settlements, where it is difficult to get good wind access, because upwind buildings block breezes. *The second one* occurs when conflict between the best orientation for shade and wind forces sun protection to be favored. also, it may happen that the shape of the plot does not allow the building to be oriented to take advantage of the prevailing wind direction.

To solve these kind of problems ; In some countries, a traditional solution such as *wind catcher*; Fig. 37 a tower capable of capturing winds above the building, bringing in fresh air from outside would be one of several techniques adapted. A prerequisite for using wind catcher is that the site should experience winds with a frailly good consistent speed.

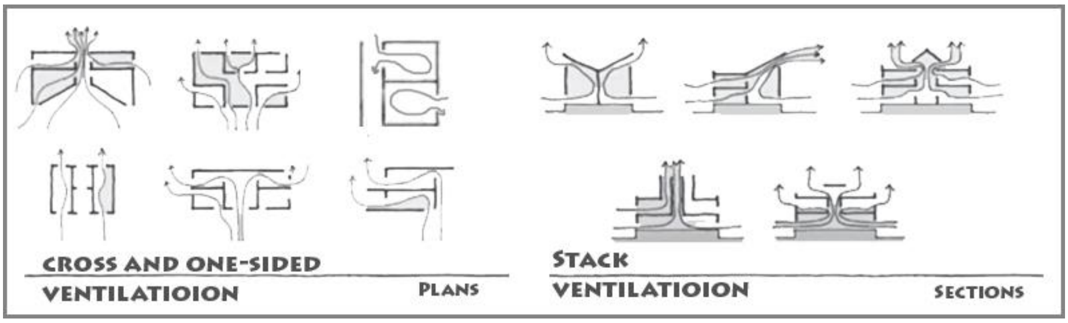


Fig 37: Different cases of air movement in a building. (Source:G.Z Brown & Mark DeKay,2014)

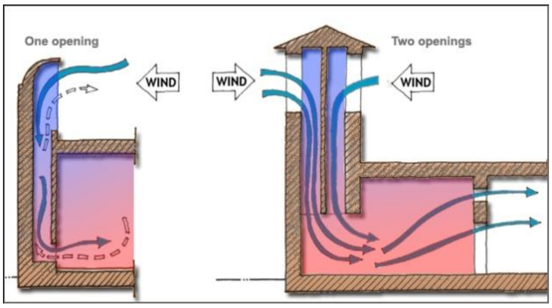


Fig.38: windcatchers/wind tower (source: Adapted by author)

Windcatcher inlets, in order to rise above the layer of turbulence and drag, should be at least *2.4 meters* above the height of surrounding buildings and obstruction. When designing a new building, the size of the wind catcher opening required to achieve a given airflow rate can be determined from a graph, as a percentage of floor area. As we can see in Fig 39, one can enter the design wind speed on the vertical axis of the graph, move horizontally until the curve for the required ventilation airflow rate is intercepted; then drop the horizontal axis to read the size of inlet as a percentage of floor area. (Source:G.Z Brown & Mark De,2014)

The graph is based on an incident wind angle of between 0^{o} (normal) and 40^{o} to the wind catcher opening. For wind catcher designs with openings in multiple directions, the opening in each direction should be sized to meet the airflow rate required. The inlet from a single direction should be no larger than the cross sectional area of the tower, while operable windows used for outlets should be about twice as large as the inlets.

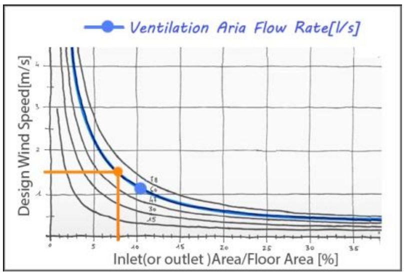


Fig 39:Windcatcher design graph (Source:G.Z Brown & Mark De,2014) (source: Adapted by author)

Ex. Judson University in Elgin, Illinois, near Chicago

2.4.8.1..Methods to Induce natural ventilation: induce ventilation can be very effective in hot and humid climates as well as in hot and dry climates, it can be induced in three ways. *The first way* involves heating air in a restricted area through solar radiation, thus creating a temperature difference and causing air movements, as in ***solar chimneys***. The draught causes hot air to rise and escape outdoors, drawing in cooler air and thereby causing cooling.

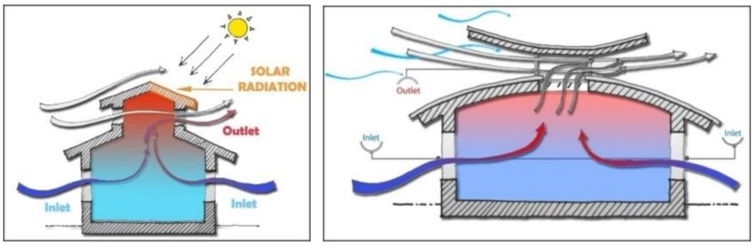


Fig 40: Stack effect / Fig: Effect of VENTURI phenomenon (source: Adapted by author)

The second way exploits wind velocity, either by channeling the airflow inside or by creating a depression with a rotating device moved by wind to extract air from the buildings.

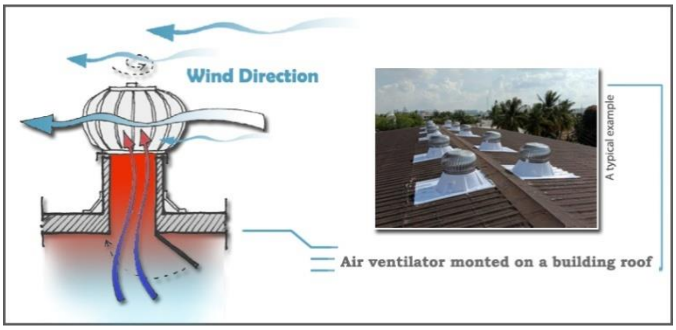


Fig 41: Rooftop Air Ventilator/Wind Turbine(source: Adapted by author)

The third way exploits the VENTURI effect, Fig 41 where air is extracted from the building because of the low pressure created by the wind on top of a *shaft*. In windy areas it could be an effective alternative to ***wind catchers.***

2.4.9.Factors On Which Natural Ventilations Depend

Natural ventilation is dependent on factors like: (G.Z Brown & Mark DeKay,2014)

2.4.9.1..*Wind direction and Orientation of building:* Depends of the wind direction; North-East and South-West are generally considered as the direction of winds. Thus, the placement of openings should be done considering these directions. The building should be oriented to maximize surface exposure (2 facades) to prevailing winds: a building does not necessarily need to be oriented perpendicular to the prevailing wind. It may be oriented to any convenient angle between 0 and 30° degrees without losing any beneficial aspects of the breeze. Fig 42 Natural ventilation flow patterns are based on the creation of pressure and the resistance to pressure provided by the building in order to channel the flow through the intended path. The flow enables the mixing of interior and fresh exterior air on its way, utilizing the forces of the flow itself (wind and buoyancy). These proportional relationships keep the turbulent eddies constantly in motion, and the air will mix as long as there is an environmental force available. .(Ulrike & Francine 2015).

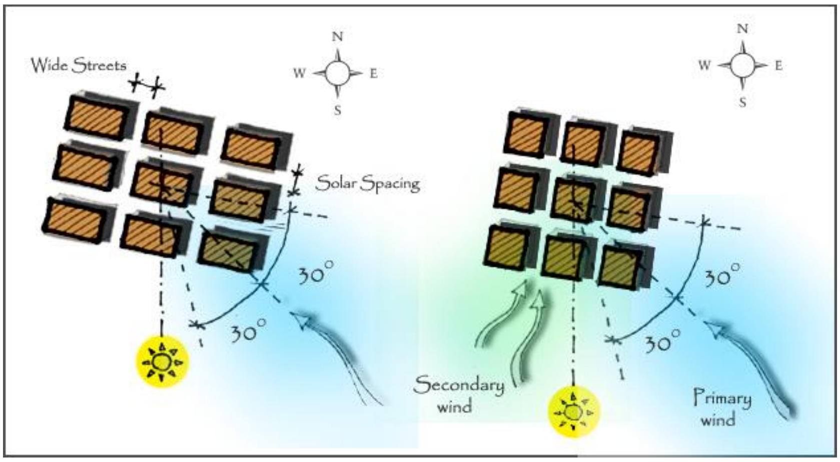


Fig 42: Building orientation to maximize surface exposure to the prevailing wind(Adapted by author)

*2.4.9.2.**Topography/ Influence of terrain(* wind velocity, turbulence, flow pattern):
An uneven topography may hinder the movement of wind due to which the placement, size and types of openings may be altered. Fig 43

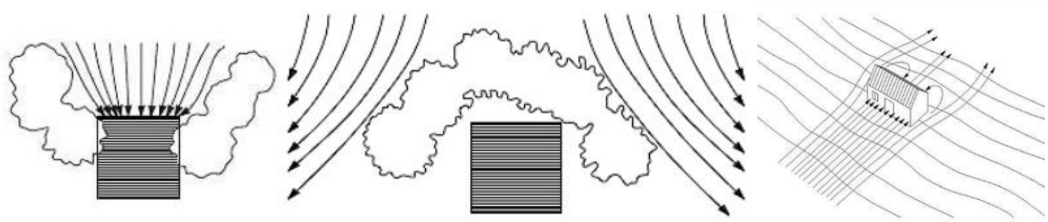


Fig 43: Effect Hedges and terrain on prevailing wind (A'zami, A., 2005)

*2.4.9.3.**Vegetation / Landscape:* Having more vegetation definitely cools the surroundings and absorbs noise. But, apart from these, trees also act as source of fresh hair.
Hedges and shrubs deflect air away from the inlet openings and cause a reduction in the air motion. These should not be planted inside a distance of about 8m from the building because the induced air motion is reduced to a minimum in that case. However, air motion in the leeward part of the buildings can be enhanced by planting low hedges at a distance of 2m form the building. Trees with large foliage mass, with trunks bare of branches up to the top level of the window, deflect the outdoor wind downwards and promote air motion in the leeward portion of buildings. Fig. 53.(Ulrike & Francine 2015).

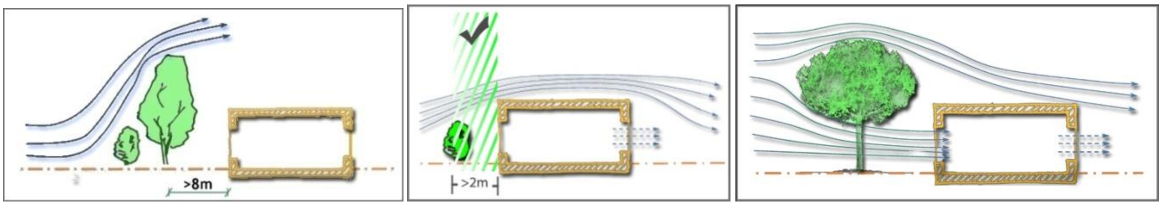


Fig 44: Effect Hedges, shrubs and Trees With Large Foliage Mass (Adapted by author)

*2.4.9.4.Size and types of Openings:*Avoid parallel placing of inlets and outlets and partitions near inlets. Operable windows are more efficient as they could be closed and opened whenever required. Glass panels could be used for shutters to get sunlight even while shutters are closed.

2.4.9.5. Neighboring building exposure and orientation

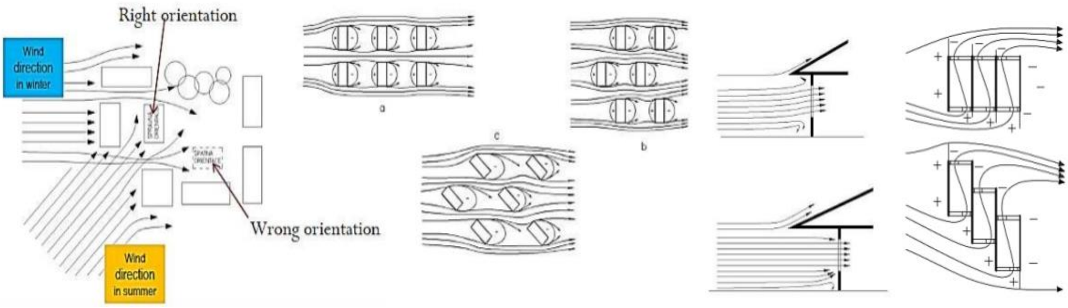


Fig45: Effect Of neighboring buildings and Influence building shape Source: (A'zami, A., 2005)

2.4.9.6..Influence building shape: flow direction through building, ventilation intensity.
Buildings on stilts: Raising the building on stilts is an advantage; it catches more wind.

Fig 46:Examples Buildings on stilts (Adapted by author)

2.4.9.7. Depth of the room and architectural elements: An effective cross-ventilation or one sided design must consider a limitation of the depth of the building to facilitate inward air flow from one facade and outward flow from the other.

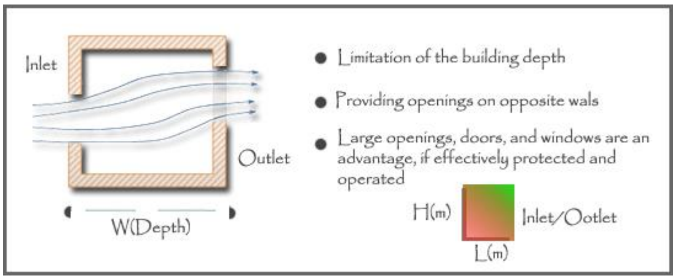


Fig 47: Diagram shows an affective cross-ventilation (Adapted by author)

Since air speed inside a space varies significantly depending on the location of openings, the most effective strategy is to provide staggered openings on opposite walls and room widths should be limited if openings cannot be provided in two walls and Large openings, doors, and windows are an advantage, if they are effectively protected from the penetration of solar radiation. Inlet and outlet openings at a high level would only clear the air at that level, without producing any air movement at the *level of occupancy*.Fig.48. Maximum air movement at a particular plane is achieved by keeping the sill height of the opening at 85% of the critical eye (such as head level).

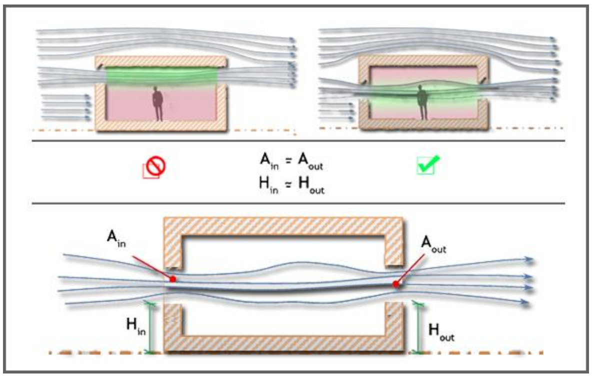


Fig 48: Dependance on inlet and outlet openings levels. (Adapted by author) (Moore,F. 1993)

Greatest flow per unit area of openings is got by using inlet and outlet openings of nearly equal areas at the same level. In rooms of normal size which have identical windows on opposite walls, the average indoor air speed rises rapidly by increasing the width of window by up to 2/3 of the wall width ,Beyond that the increase in indoor air speed is less effective.

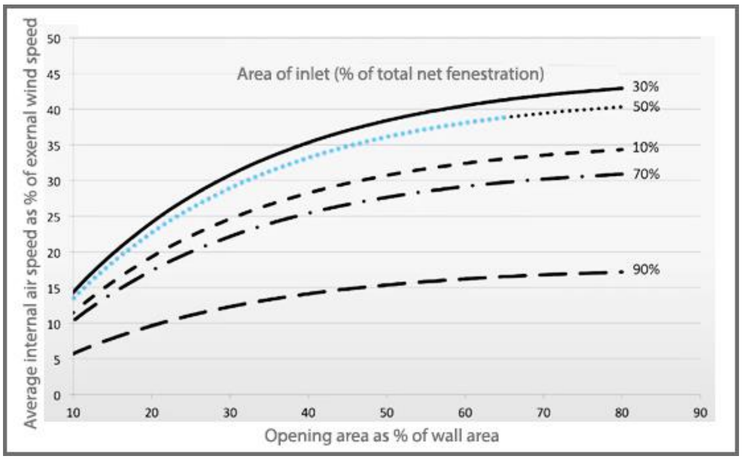


Fig49: Opening width up to 2/3 of the wall width (Moore,F. 1993) http://www.pok.polimi.it (POK)

<u>Architectural elements wing walls, parapets and canopies</u> they also can be used to harness prevailing winds: architectural features like *wing walls* and *parapets* can be used to create positive and negative pressure areas to induce cross ventilation. Geometrical arrangement, including the balconies extended outward or set inward has significant impact on the spreading of pressure along the different sides of the building as well as the choices for providing openings that would greatly affect the efficiency of cross ventilation in the building. (Givoni, 1994).Wing walls are used in either one-sided or two-sided ventilation. When wing walls are used in one-side ventilation, the opening must be at the windward side. When wing walls are used in two-side ventilation the opening must be at the adjacent sides. In this case the walls can or cont be faced to the wind direction; thus, the walls are designed to catch wind from differ directions. (Ahmed A. et al.,2017) Fig.50

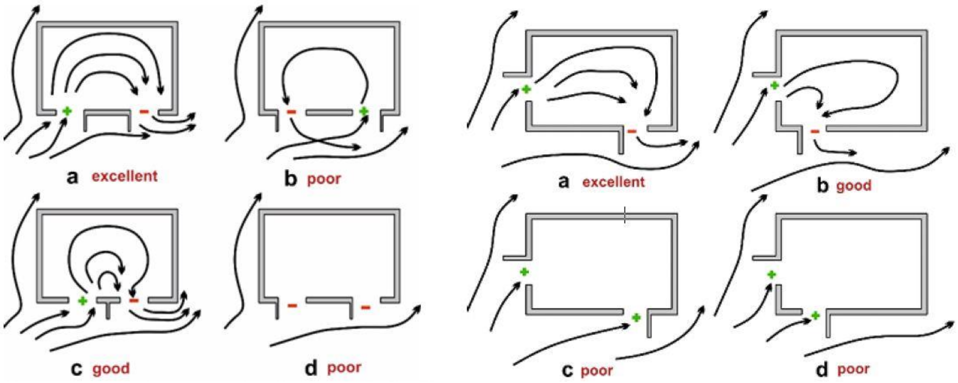


Fig.50 Effect of architectural elements(wing walls and parapets (Ahmed A. et al 2017).

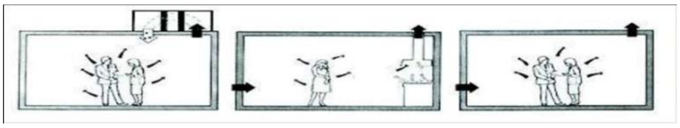


Fig.51. Different outlets and inlets dispositions in NV (Source: Bondil,A. et Hrabosky, J.)

The function of wing walls in one-side ventilation is to create cross-ventilation between the two openings that are at the same side . This is due to the creation of positive pressure over one opening and negative pressure over the other. In two-side ventilation , the function of wing walls is to catch different wind directions. Three parameters can affect wing-wall performance, such as: 1.Wind direction relative to the opening. 2.Relative distance between the opening 3.outside length of the wing walls.

2.4.10.Important fresh air in indoor environment buildings

The fresh air gets in the buildings as described above, and the fresh air gets re-circulated, used and polluted by various sources:

-*By people´s activity (and also animals)* carbon dioxide (CO_2), moisture or odors, etc.

-*By building´s materials/technology and equipment* furniture, floorings (VOCs as volatile organic compounds that are carbon-based compounds that easily evaporate)

-*By outside pollutants from traffic and Earth* CO or radon from the ground, etc.

Thus Renewing the air we breathe is necessary to eliminate the excess of humidity linked to human breathing, to the functioning of the equipment and appliances or other factors such as toxic infiltrations rising from the ground. Excessive humidity causes mold and increases the risk of allergies for occupants and degradation of building materials. In short, the fresh air is essential for our well-being and for our buildings as well. The ventilation of the buildings with use other than dwelling has for objective to answer three major concerns:

- Hygiene of the air we breathe in workplaces and public facilities.
- Safety and Comfort of the people with regard to concentrations of dust / toxic gases.
- Conservation of the building, in particular by avoiding condensations.

2.4.11.The Cleaning of the Pollutants:

Today, indoor air quality, thermal comfort, and energy are more important issues in occupied spaces. Ventilation is essential to remove odor particles and volatile organic compounds (VOCs) as well as humidity (90 percent of human exhalation is humidity), which are the most annoying indoor air quality disturbances to occupants (James & James ,1998). It is also necessary to dilute CO2, which can make occupants drowsy. Foremost, we ventilate to remove excess heat that accumulates inside buildings.(Ulrike & Francine 2015).

There are two basic methods of ventilation to ensure good air quality: *dilution* and *evacuation* of pollutants which originate from

1.Internal: the building itself, furnishing, occupants, equipment, etc.

2.The ground: such as radon, methane, etc.

3. External: Mobile sources such as cars, stationary sources such as power plants and industrial facilities, and factories, Area sources such as agricultural areas, cities, and wood burning fireplaces, Natural sources such as wind-blown dust, wildfires, and volcanoes.

2.4.11.1.Dilution: The most common and recognized method is Dilution, applied in cases where the source of contaminants is not fixed. Where ,In most cases, the sources of pollution, usually the occupants themselves and their activities, are not easily differentiated.

2.4.11.2.1Evacuation: If it is possible to isolate easily the polluting source (including excessive heat and humidity), the contaminated air in the immediate vicinity of the source can be captured and directed to the exhaust system, before it diffuses into the occupied space. This process is commonly used in industry; hoods over cooking appliances, as well as exhaust of combustion products.

2.4.11.3. Filtering: The purpose of an air filter is to free the air from as much of air borne contaminants as in practicable. Filters are required for various dust free industrial processes. The common filters use to clean air are listed below:

Dry Filters Dry filters use materials like cloth, paper or other fabrics to retain dust;When air passes through the curtain of a dry filter, dust particles are trapped.These particles trapped in these curtains can be removed by shaking/vibrating the curtains by motor run vibrator. Dry filters are of two types: (a) cleanable filters (b) throw away filters

Electrostatic Filters Air is allowed to pass through oppositely charged plates connected across 1200v direct current; Air gets ionized into positive and negative which are made to pass through another set of charged plates carrying alternate opposite charges at a potential difference of 500v. Thus due to high electrical field between the collector plate the positive ions are attracted and collected on negatively charged plate or vise versa, the collector plate are washed periodically to clean all the dust.

Centrifugal Filters The electrostatic filters are suited for tiny particles whereas centrifugal filters can retain heavier particles hence used for industrial purpose._Significant features “duel function” of retaining harmful as well as useful dust can be reutilized by the manufacturer. A whirling effect is produced by centrifugal pump blower due to which heavier particles separate. (EPA)

3.14.Air flow and occupant behaviors

Based on what is mentioned above it becomes clear that we have to know the following:

2.4.12.1.Occupant Behavior: When are occupants opening and closing their windows and by how much? Occupants open and close their windows consciously and consistently. The goal of opening the windows is to (1)Create a connection to the outside (pleasant sounds, smells) and (2) to Improve indoor environmental conditions (flush out , air pollutants, VOCs, induce some air movement, replace inside air with fresh outside air).

2.4.12.2. Air Exchange Rate by Natural ventilation : The air exchange rate resulting from occupants opening windows primarily depends on: (CoolVent The NV Simulation Tool by MIT)

(1).Indoor Temperature; (2).Outdoor Temperature;(3).Window Arrangement;(4) Ambient Wind pattern -direction and speed-;(5). Opening, air ducts, and fans sizing.

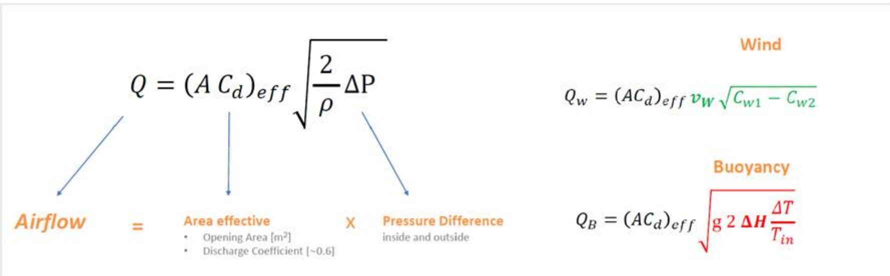


Fig.52. Driving forces for air flow in a buildings, Equations wind and bouncy driven forces

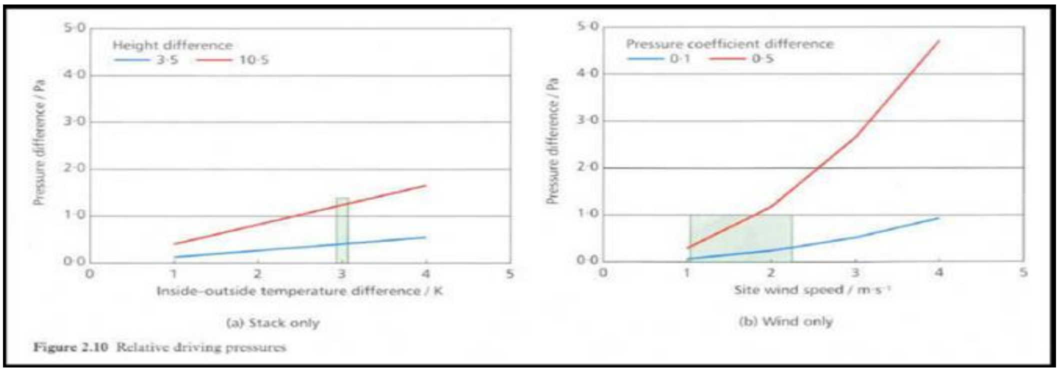


Fig.53.Relative driving pressures (stack and wind) (Source: CIBSE Applications Manual AM10)

2.4.12.3. Wind driven ventilation VS, Stack effect driven ventilation: Wind tends to be an order of magnitude large than buoyancy. Whereas Stack does not rely on wind and therefore can take place on still, hot summer days when it is most needed. stack is a relatively stable air flow (compared to wind) and offers greater flexibility in choosing areas of air intake. It relies on temperature differences (inside/outside). Stack may incur extra costs(ventilation stacks, taller spaces). However Both effects are difficult to predict in urban settings due to microclimatic effects.

2.5. Passive Ventilation Strategies and Materials Used in Natural Ventilation

2.5.1Overview

Diverse methods and materials go into the design of adequate natural systems for buildings. These include summer ventilation control methods, wind towers, and solar chimneys, among many other systems characterized by low energy use, and climate responsive elements.(Ulrike & Francine 2015). The most widely used natural ventilation methods or strategies are discussed below

2.5.2 .Single-Sided Ventilation Strategy

A Single sided ventilation relies on opening(s) on one side only of the ventilated enclosure. It is closely approximated in many cellular buildings with opening windows on one side and closed internal doors on the other side. With single ventilation opening the main driving force is wind, particularly in the case of small openings. Where more than one opening on the same façade is located at different heights, the stack effect can enhance the ventilation rate in addition to the wind. (CIBSE 2010) Although single-side ventilation is a very common and inexpensive strategy the air flow is often uncontrollable, except for an open or a closed position of the ventilator, and is only effective over a distance of about 2.5h from the opening itself, where *(H)* is the ceiling height. Furthermore, some single-sided openings, e.g. windows, are only suitable in moderate climates and are not always suitable for winter ventilation unless the incoming air is heated. .(Ulrike & Francine 2015).

2.5.2. 1 Concept and opening sizing method: The Fig 54,55,56,57,58 illustrate some concepts of this ventilation strategy.

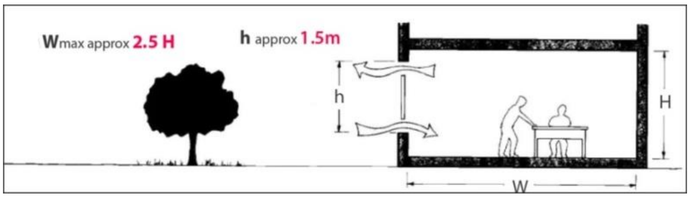


Fig.54, NV temperature difference deriver (one sided ventilation) (Susan Clare Roaf, 2001)

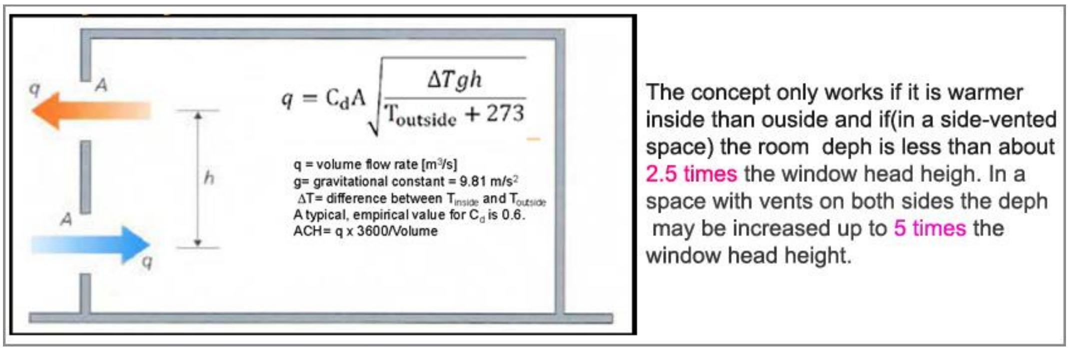


Fig.55 Air flow ; single sided , two vents, buoyancy driven (CIBSE. 2010)

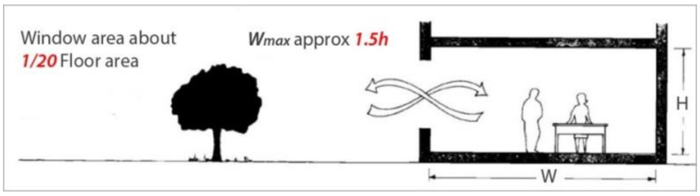


Fig.56 NV Wind turbulence deriver (one sided ventilation) (Susan Clare Roaf, 2001)

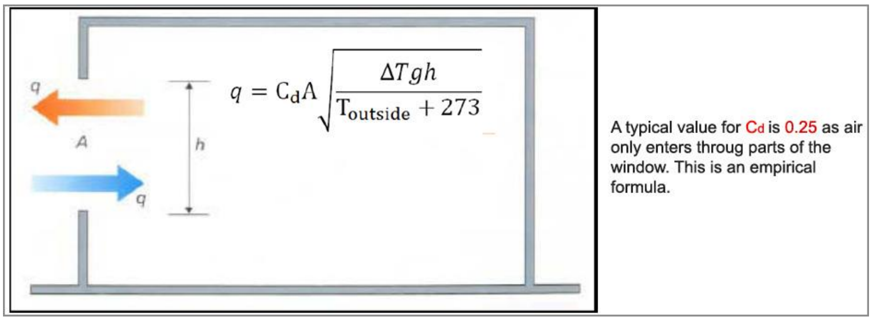


Fig.57. Air flow ; single sided , single vent, buoyancy driven (Source: Tong Y & Derek J.C.C2012)

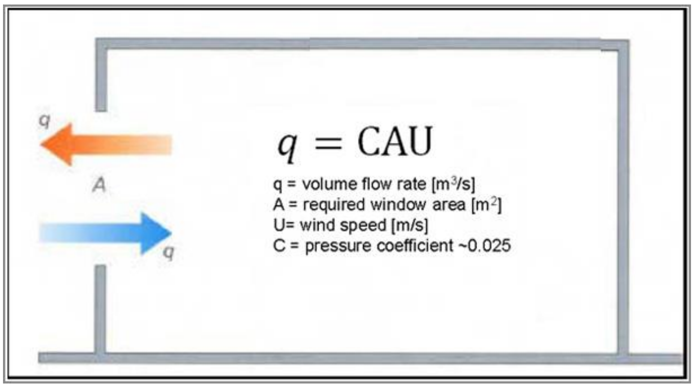


Fig.58. Air flow ; single sided , single vent, wind driven (Source: (Source: Tong Y & Derek J.C.C2012)

2.5.3 Two-sided or Cross-Ventilation Strategy

Two-sided or cross-ventilation occurs when air enters the room or building from one or more openings on one side and room air leaves through one or more openings on another side of the room or building, Fig 59. The flow of air in this case is mainly due to wind pressure, and buoyancy pressure becomes important only if there is a significant difference in height between the inflow and outflow openings. The types of openings that are used for cross-ventilation can be small openings such as trickle ventilators and grilles, or large openings such as windows and doors. Because the air 'sweeps' the room from one side to the opposite side, it has a deep penetration.(Ulrike & Francine 2015).

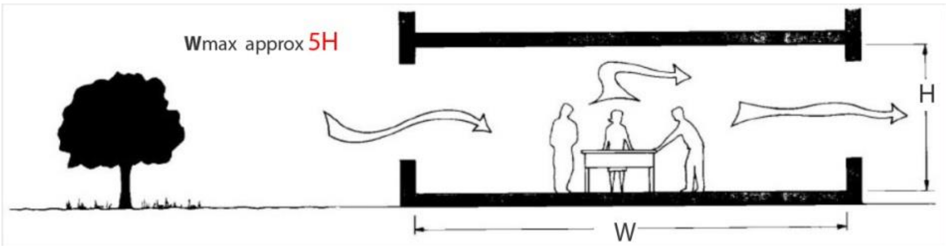


Fig.59. NV in non-domestic buildings(Cross-ventilation) (Susan Clare Roaf, 2001)

Cross-ventilation techniques were highly developed in many traditional architectures and buildings. A visit to a plantation home in the Deep South offers a living textbook for natural ventilation. The large window openings, vents, tall ceilings, large doors, hallways, stairwells, cupolas, and orientation of these buildings were all refined to produce the greatest possible comfort without air-conditioning. (Ulrike & Francine. 2015)

This strategy is therefore more suitable for ventilating deep-plan rooms. The positioning of openings should be such that some are placed on the windward façade of the building and others placed on the leeward façade, so that a good wind pressure difference is maintained across the inflow and outflow openings. Internal partitions and other obstructions can affect or disturb the air flow pattern in the room and the air penetration depth. In Short

- Strategy depends on natural breeze to work, yet Outside air quality may limit the use of natural breezes. Whereas, design enhancements can increase the affect.

-Provide openings on opposite sides of the building. (Susan Clare Roaf, 2001)

2.5.2. 1.Cross section concept and opening sizing method .(Ulrike & Francine. 2015)

About cross ventilation, in general way, the air flow rate(*V uppercase*) passing through opposite openings is given by the *coefficient of effectiveness (k)* times the *net free area of inlet openings(A)*, times the outdoor wind speed (*v lowercase*). K depends upon the direction of the wind relative to the opening, and on the ratio between the areas of the two openings and It is maximum when the wind blows directly onto the opening and it increases with the relative size of the larger opening.

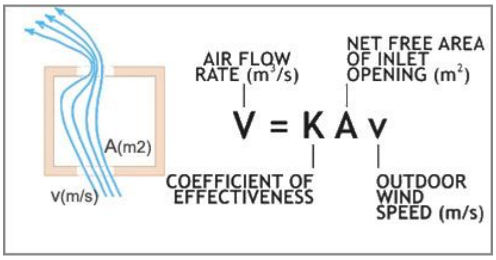


Fig.60: Equation of air flow rate due to cross ventilation (Whole Building Design Guide, 2010)

Wind-driven Ventilation Equation 1 above illustrates how to find the air flow rate for the wind driven ventilation system. For opposite openings of equal area, K= 0.6 for perpendicular wind and K= 0.3 for wind at 45°, when Changes in wind direction up to 30° on either side of the normal to the window wall have a little effect on the value of K. For wind directions outside these limits, the value of K may be considered to change linearly with wind direction.

<u>Here is an example:</u> for example we want to size two opposite opening of equal area in a room, in order to ensure an air flow rate equal to 0.8 m^3/s (**v=0.8 m^3/s**).and assume that outdoor wind velocity is equal to ***v=2.0m/s*** and its incident angle is ***a=45°***(so, ***K =0.3***). Then, the needed opening areas given by air flow rate over K times V, which results, in this case, **A=1.33M^2**

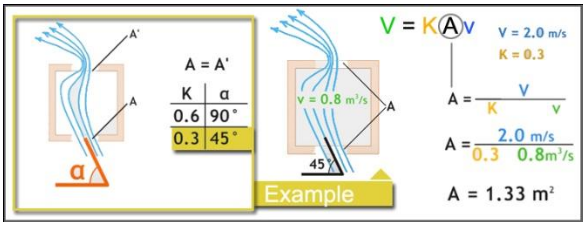


Fig 61.Ex: Air flow and calculate Area (Whole Building Design Guide, 2010. adapted by Author)

If opening areas are different, some graphs, available in the scientific literature, may be useful These graphs provide the air flow rate per square meter through the smaller opening with different wind speed.

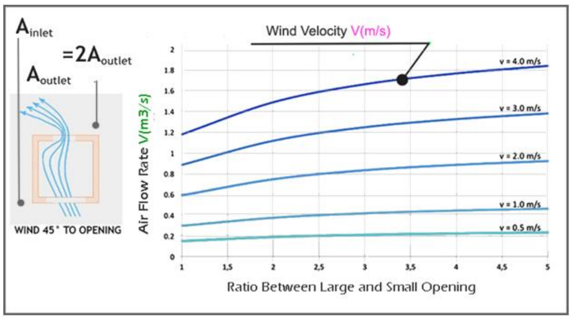


Fig 62.Graph: Ratio Between Large and Small Opening(Whole Building Design Guide, 2010)

With the same data of the previous example, let's assume that the inlet net opening area is twice the outlet net area. We identify on the X-axis the proper ratio between opening areas (That is 2) then we intercept the 2.0 wind velocity curve. finally, we read on the Y-axis the air flow rate given by one square meter opening area, referred to the smaller one (in this case, 0.75m3/s for each square meter). It means that, if we want to ensure a total airflow rate of 0.8m3/s, we must divide it by the orange value(Air flow rate) in order to obtain the smaller opening area. The bigger one (in this case, the inlet opening area), will be given by the smaller net opening area times the ration between the two. Fig.63

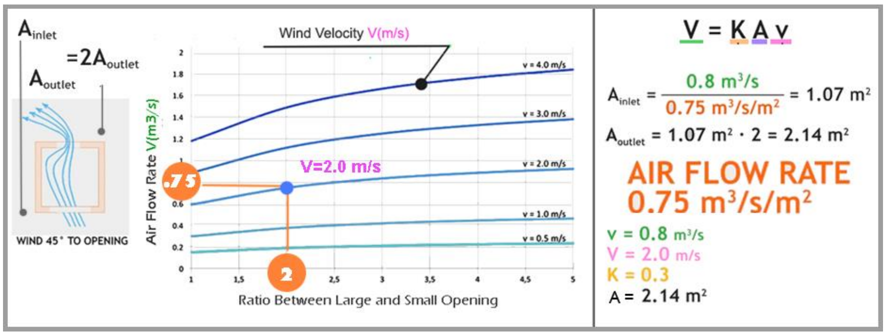


Fig.63.Graph: Ratio Between Large and Small Opening (Example) http://www.pok.polimi.it (POK)

Average internal air speed :A compromise between the absence of information about air velocity and the detailed knowledge of its values in each part of the internal space, is an evaluation of the average wind velocity. Form it, we can derive, as a first approximation, an indication of the effect of the airflow on comfort.

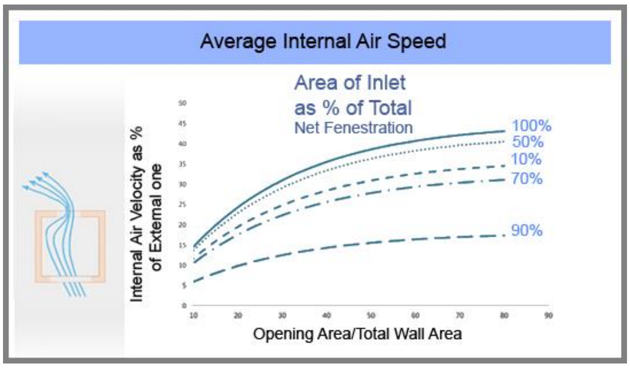


Fig.64. Graph shows the correlation between opening wall area and air velocity(Sciencedirect.com)

The graph shows the relationship between the opening area over the total wall area, the ratio between inlet and outlet opening area, the internal air velocity as a percentage of external wind speed. It refers to a cross ventilated room with two centered opposite openings. For different relative location of openings the obtained value has to be properly corrected by the factors reported in the table, according to the wind direction.

WINDOW LOCATION

ORIENTATION											
0°	0	-10	-10	-15	-15	0	-10	-10	0	-20	-20
45°	0	+40	-15	0	0	0	+40	-15	-60	-10	-60

CHANGE IN %

Table.8: Effect of window location (Source: http://www.pok.polimi.it (POK))

2.5.3.2. Effect of louvers and Veranda :Moreover, louvers used for protection against direct solar gains significantly affect the average indoor air speed and the airstream pattern, so a further coefficient has to be applied to the average indoor air velocity.

Effect of Louvers	Type of louver	% change of average internal air speed (wind direction 0°)
	Horizontal(sunshade)	-20
	L-type	+5
	Multiple Horizontal	-10
	Multiple Vertical	-15

Effect of Veranda	Type of Veranda	Location and % change of average internal air speed (wind direction 0°)	
	Open on 3 Sides	Windward	+15
		Leeward	+15
	Open on 2 Sides	Windward	0
		Leeward	0
	Open Side Parallel to the Room Wall	Windward	-10
		Leeward	0
	Open Side Perpendicular to the Room Wall	Windward	-50
		Leeward	0

Table.9: Effect of lovers and Veranda (Source Susan Clare Roaf, 2001)

Also the presence of a veranda on the windward or leeward side of a room influences the air and the additional correction factor has to be considered. In addition, Fly screens or mosquito nets are in many cases an absolute necessity, but they substantially reduce the air flow. A cotton net can give a reduction of 70% in air velocity. A smooth nylon net is better with a reduction factor of about 40% of the air flow rate and about 35% of the average indoor air speed, as shown in the graph. Here it can be noted that the reduction of the latter increases, but not dramatically, with outdoor wind speed, and it is also affected by the wind's angle of incidence. Besides that, if it is positioned in front of the balconies, such interference could be greatly minimized while allowing it to function without fault (B. Givoni, 1994)

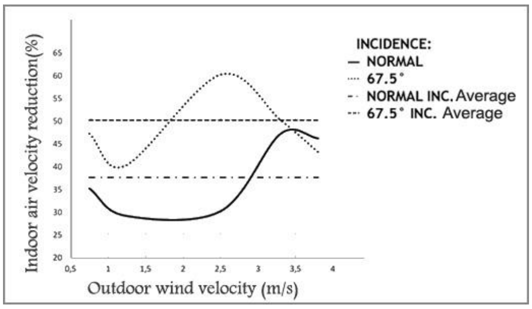


Fig.65. Graph: Effect of Fly-screen (source: theglassgrue.com)

2.5.4.Earth air tunnels (the Canadian well) Strategy. Nina H et al (2015)

Canadian Wells is a ventilation strategy that uses geothermal surface energy for building ventilation at depth of > 2 m below ground, the temperature inside the earth remains nearly constant round the year and is nearly equal to the annual average temperature of the place.

Fig.66. Installation a Canadian well.(Source: Google image)

Its functioning is based on the fact that the subsoil temperature differs from that of the environment. This difference is accentuated at approximately two meters of depth, where it remains stable at between 18º and 24º C. This is an average temperature and it can vary depending on the geographical location and the weather conditions. It is estimated that around 10 or 15 meters deep the temperature is almost stable all year round.

<u>In winter, the ground, at a depth of 2m, is warmer than the outside temperature:</u>
the cold air is therefore preheated as it passes through the ducts. The air is not taken directly from the outside, so there will be a saving in heating energy.

<u>In summer, the ground is colder than the outside temperature:</u> The air entering the building will be naturally tempered by the cooler temperature of the ground.

The Canadian well allows a saving of about 20 to 25% of the consumption related to the heating of new air and 5 to 10% of the total heating consumption. It allows, with the help of other accessories, to naturally cool the incoming air and in many cases cooling the building without air-conditioning in summer. In order to optimize the heat exchange, the Canadian well must respect a low speed air flow. This characteristic makes it compatible with the systems of natural or hybrid ventilation systems.

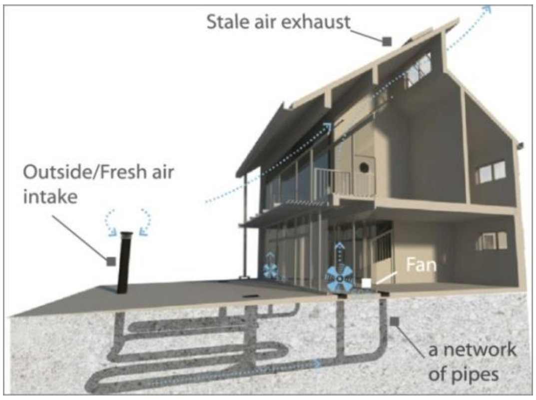


Fig.67. Diagram shows the functioning of Canadian well (Source: Nina Hormazabal-Poblete)

2.5.4.1.The components of the Canadian well: This geometrical system consists of an fresh air inlet, equipped with filters to avoid the entry of rodents and insects into the pipe with a length of 30 to 50 meters and is buried at an average depth of 1.50 m. The pipe must be smooth and sloping for the flow of condensation water which must be recovered by a manhole, and a ventilator which will allow to blow the outside air into the interior building.The system has four main component elements:

<u>An external collection point of the air.</u> The chimney is located by choosing an area where the air keeps moving and must have a grid that prevents access to the system by insects or animals that can contaminate the air.

<u>Filters,</u> necessary to purify the air and prevent the entry of dust and dirt into the ducts.

A network of pipes connected to the house, placed in the subsoil at a depth between1.5 m and 5 meters and covering a certain number of meters underground. This network of pipes works under the principle of thermal inertia to adapt the air temperature that during the summer is higher than the temperature underground. Therefore, when the air passes through the pipes it releases heat to the ground and cools down, reaching the home with several degrees less and creating a comfortable environment.

A system for air circulation. The system needs an element that drives the air and circulates it through buried pipes. Depending on the design of the work, it is possible to opt for active (mechanical/fans) or passive elements (solar chimney).

A drain point. The condensed water in the pipes, due to the inclination is directed to the drain point where it is removed from the system. (B. Givoni, 1994)

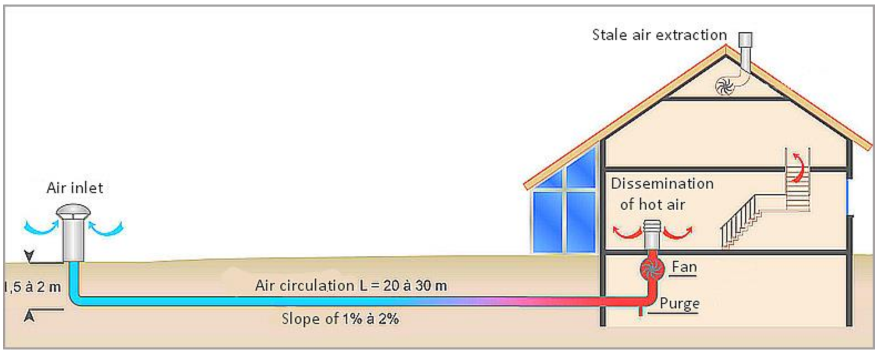


Fig.68. Diagram of functioning of the system of Canadian well. (avant-gardening.com/puit-canadien)

Fig.69. Different forms of fresh air inlets.(Source: Google image; www.maisoncommunication.fr)

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2.5.4.2.Advantages and disadvantages of air-ground heat exchangers :

Advantages:

- The contribution of tempered air in winter and fresh air in summer
- They generate a healthy habitat by ensuring a good level of air renewal and maintaining a healthy degree of moisture inside the home
- Require a low economic investment for their installation, especially if the works are carried out in the construction of the house..
- They ensure a low-cost maintenance needed for the periodic cleaning of the pipe, the change of filters, the cleaning of the condensation tank and for the air ventilation system.
- Represent an ecological system that takes advantage of a natural resource, reducing the use of energy and fuel needed for artificial air conditioning.

Disadvantages:

- In some cases come with a high earthwork costs and delicate maintenance.
- Spread unwanted visitors micro-organisms or radons in the building.
- Limited in mid-season.

Despite the simplicity of its working principle and components, the design and installation of a well-functioning such a system requires the intervention of qualified professionals and masons. Depending on the results of a study on the specific thermal conductivity of the soil, the design defines the parameters of the length, diameter and number of pipes, the depth of pipe burial, the appropriate place to install the air collection point outside, the mechanics of the ventilation system

2.5.4.3. Exampes Analysis see Annex(1.3.4)

2.5.5.Stack Ventilation Strategy

Buildings which require ventilation rates greater than those achievable using either single-sided or cross-ventilation may be ventilated using stacks. In this case, buoyancy is the main driving force and, therefore, the height of the stack becomes significant.The stack pressure is determined by the difference between the internal and external temperature and the height of stack. The Concept is based on thermal convection and therefore does not require a natural breeze. (CIBSE 2010) (David et al. 2011)

- It works best in spaces with high ceilings that provide high louvers for heat escape and low louvers for incoming cool air.

Depending on the position of air inlet and outlet in the building, the wind pressure could assist the stack pressure, reduce its influence or indeed reverse the effect, i.e by forcing the air through the outlet. Therefore, when stacks are incorporated in the building, careful design considerations are needed to avoid these adverse effects occurring. This usually requires either a wind tunnel investigation of a scaled model of the building and the stack, or computational fluid dynamics (CFD) analysis of the flow around and within the building. In buildings which have atria/atrium , the stack is most conveniently incorporated with the atrium for two main reasons. (Bright Hub, 2010)

- First, the solar gain in the atrium causes an elevation of the air temperature and hence there will be more effective stack flow.
- Second, the atrium will act as a buffer zone between the building and the external environment which can reduce heat losses from the building in winter.

The most common used stack natural ventilation methods or strategies are as fellow: (1).Simple stack (2).Large enclosures/Atria(3).Windcatchers/ Windtowers (4).Solar-induced ventilation/Solar chimneys.

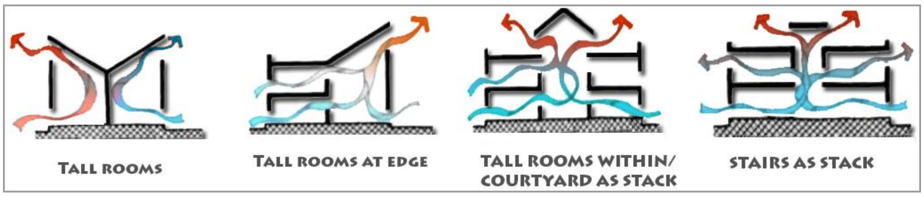


Fig.70. Different stack operations in buildings. (Source:G.Z Brown & Mark DeKay,2014)

2.5.5.1.Stack effect concept and opening sizing method

Heated by internal loads, air entering a building that is not air-conditioned tends to rise, this because it warms up and its density, and therefore its weight, is lower than that of the outside air, and where there is an opening at the top, the warm air escapes through it, and is replaced by the outer, colder and heavier air, which enters from the bottom.

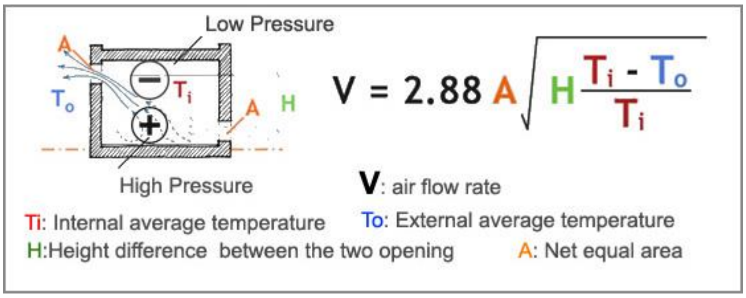


Fig.71: Stack effect equation (Source: CIBSE. 2010 adapted by author)

Air flow rate equation In this way, the stack effect occurs In the absence of wind, if internal resistance to flow is not significant, the air flow rate v, crossing two equal size opening at different height through the stack effect, depends on the difference between the internal average temperature Ti and the external To , on the height difference H between the two opening and on their net equal area A multiplied by a constant factor equal to *2.88.*

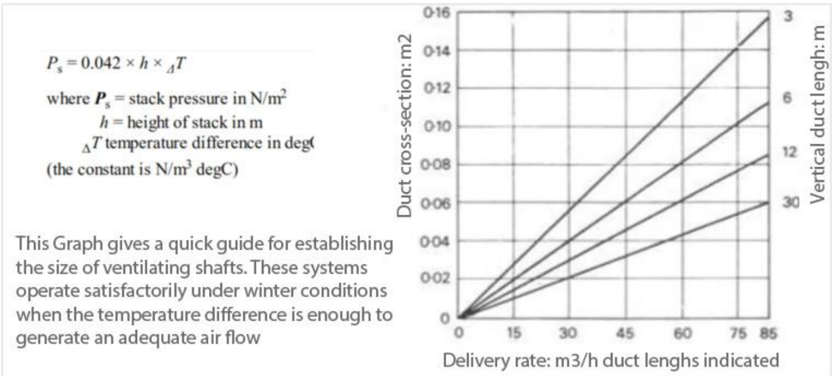


Fig.72: Graph gives the duct cross-section vs vertical duct length and Air rate(Source: CIBSE. 2010)

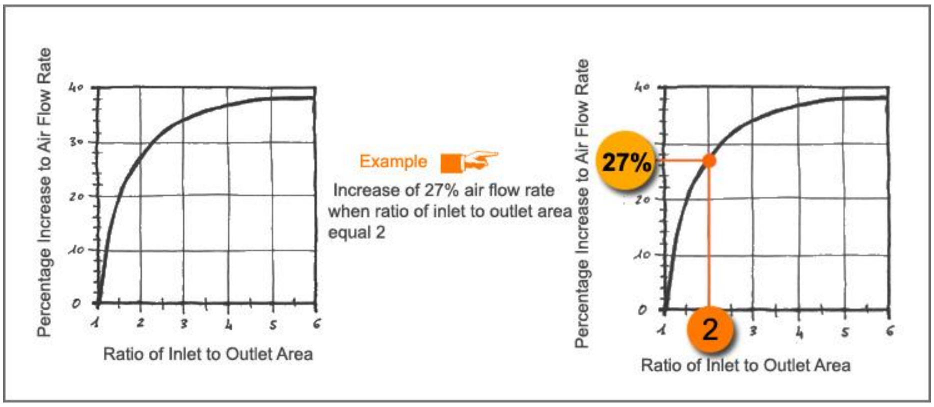


Fig.73: Increase on Stack flow rate due to differential openings(Source: CIBSE. 2010)

If the inlet and outlet areas are not equal, the air flow is first determined using the smallest of the two areas and then, according to the ratio between them, the percentage of the flow increase can be provided by a graph. Where appropriate, the same correction factors for louvers and fly screen, as for cross ventilation , should be applied. Since the air flow increases with the sack height and the temperature difference. The height difference H between the two openings should be increased as much as possible, as should their size. Because of the explained law which drives the stack effect, the related flow are may be enhanced by increasing the temperature difference between inside and outside.

2.5.5.2.Simple stack ventilation.(Ulrike & Francine 2015).

In a simple stack or chimney the driving force is wind as well as buoyancy. To effectively utilize the wind pressure, a correct location of the stack outlet on the building at high level is essential. This requires knowledge of the distribution of wind pressure coefficients around the building and in the case of a roof stack the use of equation of stack as a guide.

The wind and buoyancy pressures acting on a stack will balance the pressure losses in the stack to produce a given air flow rate through it. In sizing stacks, therefore, the friction losses, fitting losses and entry and exit losses must be equated to the total pressure difference due to wind and buoyancy acting between the inlet and outlet of the stack.

Air flow rate due to the stack effect is proportional to the vertical distance between the inlet and outlet to the stack and the temperature difference between the air inside and outside the building. The performance of the stack ventilation system is therefore most reliable in cold climates because it is essentially a temperature-driven system. In milder climates open windows are normally needed to supplement the ventilation requirement in the form of either a single-sided ventilation opening or cross-ventilation arrangement.

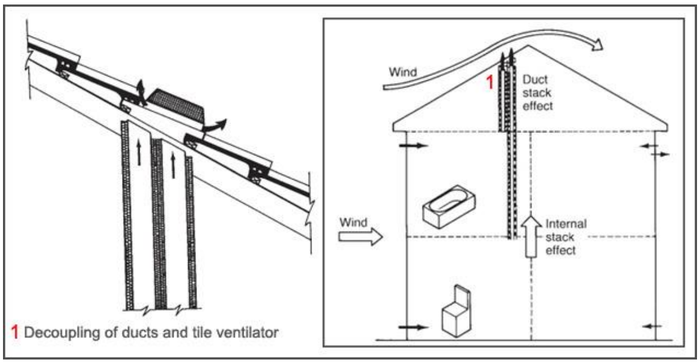


Fig.74. Stack Ventilation in a house.(Ulrike & Francine 2015).

2.5.5.3.Large enclosures Ventilation(atria, atrium, lightwell...)

Large enclosures such as atria experience large temperature stratification and this phenomenon can be utilized to ventilate the enclosure naturally. As a special case, glazed atria are becoming increasingly popular structures for creating a microclimate approaching that found indoors, particularly in high northern latitudes. Because of the large glass area in such structures the thermal environment inside is greatly influenced by external weather conditions. A prominent feature of atria is the reliance on natural lighting for much of the day, solar gain through the glazing and radiant heat transfer with surrounding buildings. At high northern latitudes in winter a certain amount of auxiliary heating will be required to maintain acceptable indoor temperatures (e.g.15◦C) for users of the atrium and also to reduce the risk of water vapor condensation on the internal glass surfaces. In the summer, solar gain through the glazing normally elevates the internal air temperature and causes a large vertical temperature gradient and sometimes overheating problems at upper levels such as shops and offices. Therefore, mechanical ventilation created by extract fans or buoyancy-driven ventilation through roof hatches is needed to remove the excess heat in the warm seasons.

EX. Judson University in Elgin, Illinois, near Chicago (See Appendices)

The Atriums/ Atria ; Atrium is derived from the Latin word "āter" which means "Dark" and refers to a central space open to the sky and surrounded by rooms that used to be covered with dark black smoked walls in traditional houses of Rome. The idea of atrium was partially inspired by courtyards, an old tactic for climate control However, in the modern era, its design has changed in a way that it is usually covered with glass walls and roof creating a common space interconnecting the adjacent galleries and stories within an atrium building._Atria and courtyards are commonly embedded in some buildings for natural ventilation and cooling purposes. Both atria and courtyards form centerpieces in buildings and connect them to the environment by providing natural ventilation and sunlight through exchange of the internal air with the external one . Comparative analyses of the central atria and courtyard reveal that atrium, with the same geometric dimensions against varying climatic and glazing conditions, is more energy efficient with increasing building height , while applying an open courtyard to low-rise dwellings during summer and an atrium for the rest of the year, leads to an optimal balance between energy consumption and summer comfort in tough climates(Li, L. & Mak, C.M. 2005).

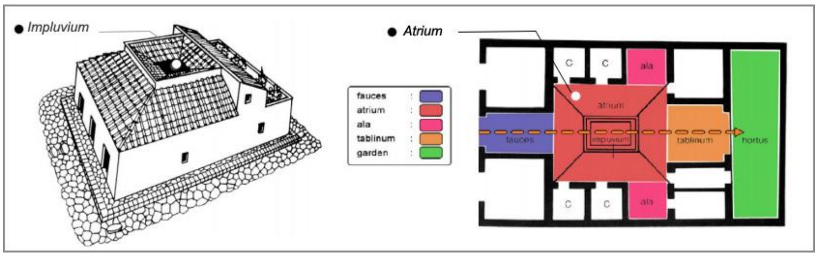


Fig.75 Ex.The Roman Arium: *In the Roman and Greek architecture, the* ***sunken*** *place of atria has called* ***impluvium*** *It was the central part of the buildings in order domesticating natural light an air into building*.(Source: Athmani.N, Zebiri.N, 2016)

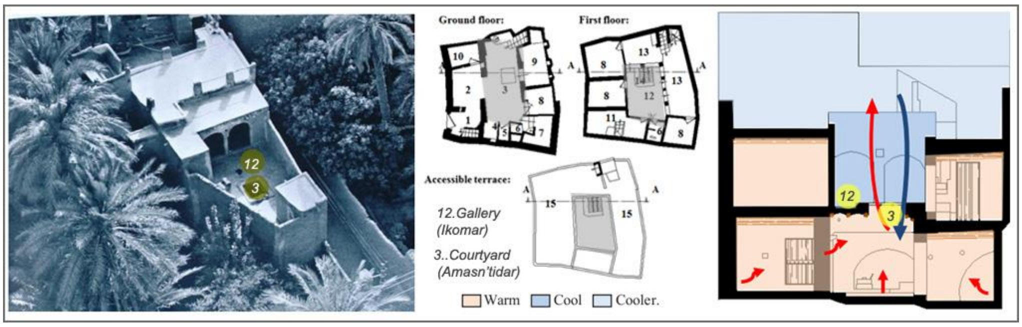


Fig.76.Ex/Typical Mzabite house at Béni-Isguen palm grove. Ghardaia .Algeria (adapted by author)

The large glazed spaces date back to the 19th century, a period during which the glass and iron industries experienced important developments. The industrial evolution allowed the appearance of metal structures with increasingly large spans. In combination with modular glazing, cast iron columns and wrought iron rails became the standard technique for rapid prefabrication and gave rise to countless buildings. It is the epic of the glass spaces like the botanical greenhouses, railway terminals, covered passages and public spaces .

After modernity of architecture, they have some large windows and/or a glazed roof. In resent centuries of development, benefits of atrium can be identified in environmental, economic and architectural aspects. As it mentioned, atrium is being used in the large-scale building such as; complexes, retail shopping malls and large office. (B. Givoni, 1994)

Fig.77 The Crystal Place at Sydneham (1854)/ The great exhibition at Crytal Place. 1851
The evolution of a traditional form and the appearance of large spaces glazed spaces

Fig.78. Modern atria (b)The triangular atrium JP tower KITTE building interior.Tokyo
(a) Atrium in adminstration and finance business building. Belgrade.

__Most common Generic forms of atria__ *:*The design of an atria is based generally on climatic conditions, architectural experiments, expected level of thermal comfort, and functions of building. The placement of atrium in building is the main factor which determines the potential environmental advantages of atria in the building. We can find four common different shapes of atrium, as main category of atria forms based on the atrium location in the building as shown in Fig 98 Each form of atria has a particular environmental advantage which is chosen according to its ambient condition, expected ventilation and daylight performance. (M. Ouria, et al. 2017)

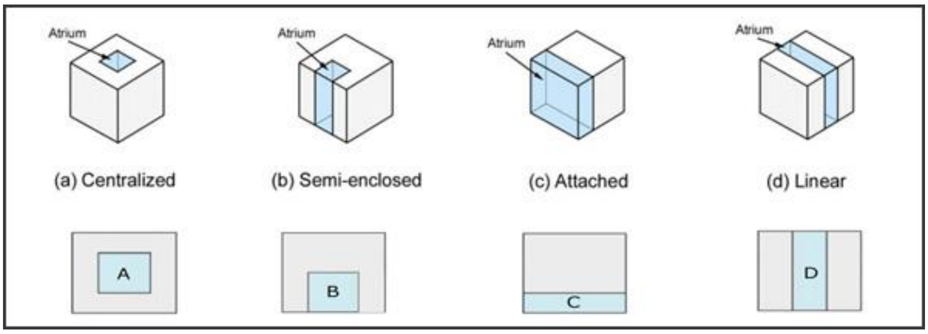


Fig. 79. Four common types of atria (Source: N.Baker 1988)

Another more exhaustive classification has been established from a statistical study of about two hundred atriums built in Japan, taking into account not only the positioning of the positioning of the glazed volume but also its proportions.

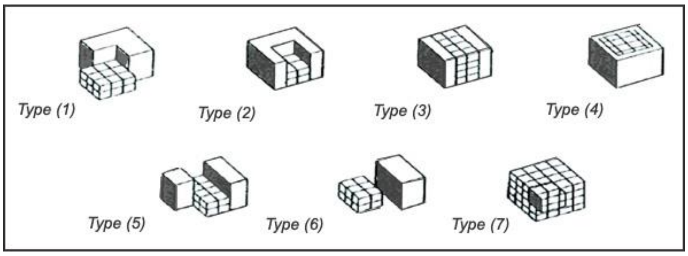


Fig.80. Atria Classification established by Yoshino 1995 (Source: Belmaaziz, 2003)

Another typology established by Saxon (Saxon. 1983) on two thousand built atriums built; the latter draws up a range of spatial forms of atriums which he classifies according to eleven categories:

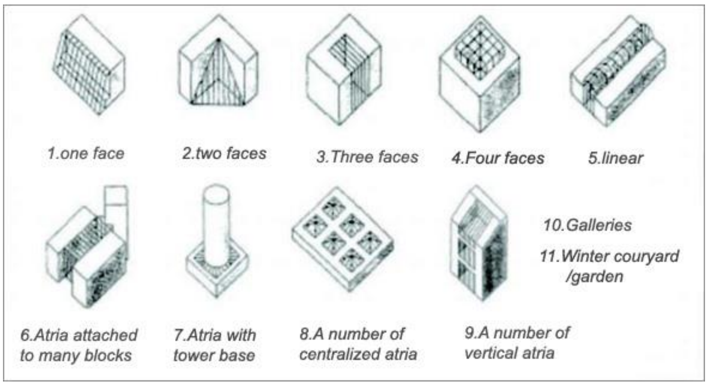


Fig.81. Atria Typologies established by (Yoshino. 1998)

The placement of the atria is the main factor determining the advantages that an atria could potentially have in a building (Moosavi et al., 2014). Out of nine classified generic types of atria (Saxon,…), five types have been recognized as the simpler forms suitable for buildings whether it be small or complex (Fig 81):

- Single sided (ex: Law Courts, Vancouver)
- Two sided atrium (ex: Ford Foundation, New York)
- Three sided atrium (ex: Hercules plaza, Wilmington)
- Four sided or central atrium (ex: IMF headquarters)
- Linear atrium (ex: Hennepin County)

Central atria, similar to central courtyard in plan, is the most common form of atria and used normally in deep plan office buildings to allow natural light into the centre. Linear atria also allows air and light deep into the plans of a deep plan building. Moreover, single sided atria have been used usually in temperate climate as a glazed façade in order to have more solar heat gains in winter time as well as great views during the rest of the year, while linear and central atria seem to be used mostly in hot and humid climate.

2.5.5.4.Double skin façade Ventilation Strategy

These systems are similar to buffer spaces allowing to pre-condition the ventilation air.

A double-skin facade is generally made up of a glazed screen, a space forming the cavity of the facade: The height of the double skin is at least one floor, but more commonly 3 floors or more.The adjustable opening placed on top and the bottom of the of cavity.

The operation is based on the principle of the thermal chimney effect. A column of warm air (low density) is surrounded by colder air (higher density) which causes a buoyancy effect that sets the air in motion. (Wong, P.C el al. 2006) – (CIBSE. 2010)

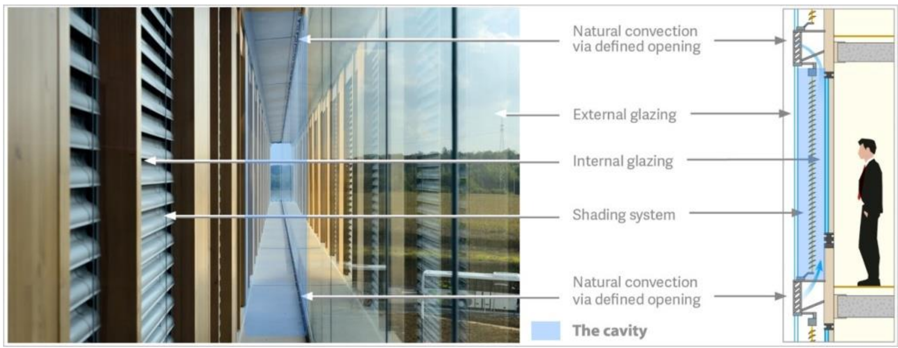


Fig 82.The Double skin facade system (DSF) (Source: Google image adapted by author)

<u>Type of double-skin façade according to the type of airflow:</u>

The design of a facade can adopt several modes of ventilation (see diagram "types of ventilation of the cavity"):

-Outside air curtain (1): Air is introduced into the cavity from the outside and exhausted directly to the outside. This forms of air curtain inside the cavity enveloping the façade placed on the outside.

- Interior air curtain (2): The air comes from inside the room and is taken back and reinjected into the room. This forms an air curtain enveloping the interior façade.

-Fresh air supply (3): The ventilation of the façade is carried out with outside air. This air is ducted into the room or into the ventilation system. The ventilation of the façade allows to supply the building with fresh air.

-Exhaust air (4): The air from inside the room is exhausted to the outside. The ventilation of the facade allows to evacuate the air from the building.

-Buffer space (5): In this case, each of the skins of the facade is tight. The cavity forms a buffer space between the interior and exterior environments, no ventilation being possible.

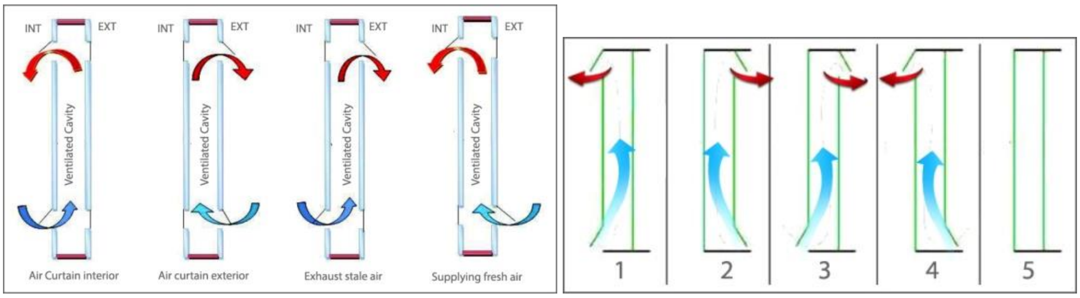


Fig 83. Different type of double-skin façade according to the type of airflow: (Source:Redrawn from Haase, Marques da Silva, & Amato, 2009)

<u>Advantages and Disadvantages of Double Skin Facades</u> (Francesco G, et al. 2019)

<u>Advantages</u> (1)Reduce cooling and heating demand all year around;(2)Clear views and natural light; reducing using artificial lighting during daytime ;(3)Improve thermal insulation and acoustic of the building (4)Allow natural ventilation and air renewal, creating a healthier environment.

Disadvantages (1)Initial cost of construction; and its high maintenance demand;(2)Space consumption; (3)It may fail to function properly if the context changes significantly (shading by other buildings, for example).

In brief (DSF) can provide advantages in terms of improved energy management, sound insulation, thermal insulation, as well as the possibility of enjoying fresh air from the cavity through opened windows and therefore enhanced comfort for building occupants. Besides, additional shading systems can be placed between the outer and inner glazing, providing dynamic selectivity (i.e. the ratio between max daylighting and max solar protection).

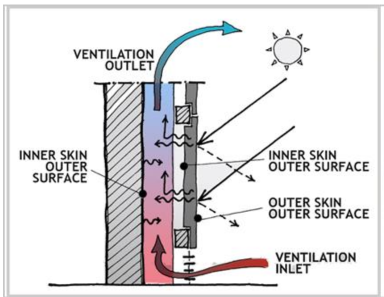
Example (See Appendices)

4.5.6. Solar-induced ventilation strategies

Natural ventilation systems are usually designed to utilize both buoyancy and wind pressure under the expected environmental conditions. In situations where the wind assists the buoyancy pressure, the air flow rate that can be supplied to a building is the highest possible for a given ventilation strategy and environmental conditions. However, in cases where the wind effect is not well captured or where the buoyancy pressure is not sufficient to provide the required ventilation rates then solar-induced ventilation may be a viable alternative. This strategy relies upon the heating of part of the building fabric by solar irradiation resulting into a greater temperature difference, hence larger air flow rates, than in conventional buoyancy-driven strategies in which the air flow is due to temperature difference between inside and outside. There are usually three architectural elements which can be used for this purpose: (1)Trombe wall(2)Solar chimney and (3) Solar roof.

The first type incorporates glazed elements in the wall to absorb solar irradiation into the wall structure, whereas the solar chimney and solar roof usually rely on the wall of the chimney and roof tiles to absorb and store solar energy respectively. These devices are governed by the same physical principles and are based on the same fluid flow and heat transfer equations as other natural ventilation systems, although they have certain unique characteristics. These devices have common characteristics with each other, which are described here first before considering each device separately. (Wood & Salib 2013)

2.5.6.1.Trombe wall ventilation Strategy: A Trombe wall collector consists of a wall of moderate thickness (thermal mass) with lower and upper openings covered externally by a pane of glass. A gap of 50–100mm between the glass and the wall allows the heated air to rise. Trombe wall collectors have traditionally been used for space heating by allowing air from the room to enter at the bottom of the wall which is heated by the collector and then returned back to the room at high level, see Fig 105 (Ulrike & Francine.2015).



CLIMATIC ZONE	TYPE
HOT-ARID CLIMATES	HEAVY WEIGHT WALLS (E.G. 30 + CM CLAY TILES) IN DAYTIME AREAS, MEDIUM WEIGHT/INSULATED ROOF.
UPLAND CLIMATE	MEDIUM WEIGHT WALLS (E.G. 25-30 CM CLAY TILES), MEDIUM TO LIGHT WEIGHT/INSULATED ROOF.
HOT-HUMID CLIMATES	LIGHT WEIGHT WALLS (E.G. 10 CM CLAY TILES) AND VENTILATED ROOF.

Table: Rules of thumb for walls and roof design

Fig.81.Ventilated and reflective outer skin (Source : www.cobse.fr. Adapted by author)

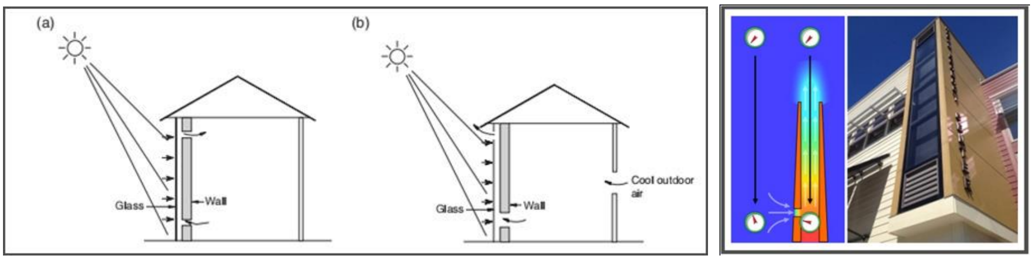


Fig.85 .Trombe wall ventilator.(a) Collector for winter heating and (b) for summer ventilator left ;Ex. of a Cutting-age desing of Solar chimney (two-stroy block) right .(Ulrike & Francine 2015).

The arrangement shown in Fig 82(a) is for the winter situation where the Trombe wall is used to heat room air. However, by putting a high level external opening on the glazing and closing the top opening to the room, this device can be used for cooling the room by drawing outdoor air from another opening into the room and the warm room air is extracted out through the Trombe wall, Figure 82(b). To be effective, the wall needs to be placed in a south or south-west facing position in the northern hemisphere. .(Ulrike & Francine 2015).

2.5.6.2.Solar (or thermal) chimneys Ventilation Strategy: A solar chimney is one of the ways of improving NV in the building. Solar chimneys in buildings help to reduce energy usage, CO2, and pollution in general. The solar chimney has been used for centuries in different places, especially in the Middle East and by the Romans. A solar chimney is a vertical shaft utilizing solar energy to help the natural stack ventilation through a building (Bansal et al. 1993).

The solar chimney can have one or more transparent walls that will allow the solar radiation to accumulate and heat the air inside the chimney. A density gradient between the interior of the building and the chimney, caused by the difference in air temperature and consequently an upward movement of air. In essence, it is a vertical shaft, which usually forms a transparent part through which light / heat flows, and an absorber, which is heated. The chimney heats up , the temperature inside the chimney is then higher than in the surroundings, which causes the hot air to rise through the chimney and extract air from the building.

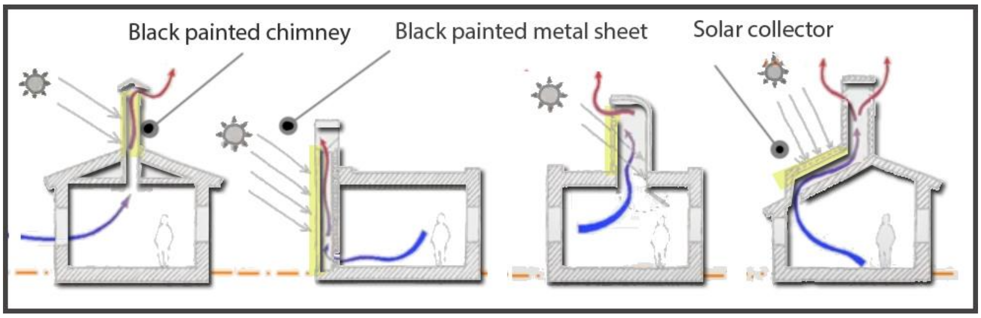


Fig.86. Solar Chimney principle with different disposition and typology. .(Ulrike & Francine 2015).

Sunlight is the fuel that keeps all that air moving. As cool air enters the stack through the lower louver –vent-it is heated by sunlight passing through the stack's south-facing window. The stack's inner lining is painted black to absorb as much of the Sun's energy as possible. This movement of air across a heated surface generates what we call a passive heat exchange. So named because, other than sunlight, there is no energy being actively introduced to heat the air inside.

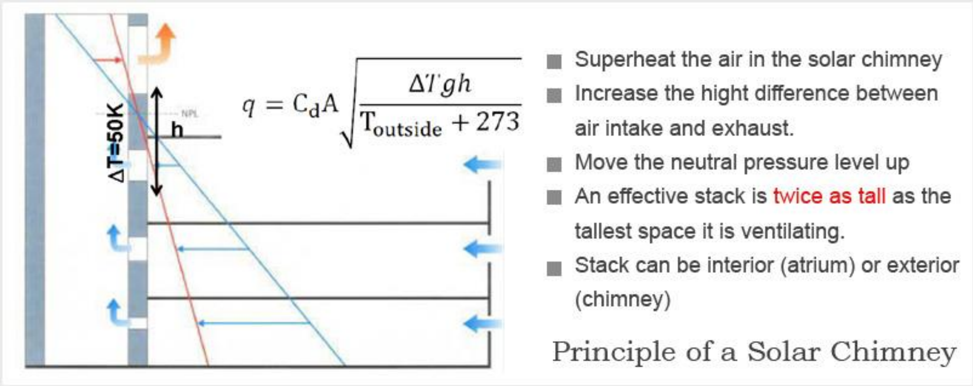


Fig.87. Principle of a Solar Chimney (CIBSE (2010)

Types of solar chimney : There are two types of solar chimney:

1.Vertical solar chimney: This type of chimney is the most responsive type, it has an air inlet at the bottom and an outlet above, depending on the positioning of the opening; Three types of solar chimney are possible to integrate in a building for natural ventilation. The advantage of the vertical chimney is the ease of integrating it on the building facades but this chimney is limited in some days in winter when the altitude of the sun is low as well as summer days when the sun altitude is much higher. It can be cylindrical, which imposes a difficulty of construction, so it is preferable to use a blackened metal chimney.

2.Slanted solar chimney: This type of chimney is integrated in an inclined manner at an appropriate angle to capture as much solar radiation as possible. Unlike the vertical chimney, the sloped chimney can provide sufficient ventilation on summer days when the sun's altitude is much higher by 30° to 45° inclination. (Ahmed A. et al. 2017).

Fig 88. Ex of Solar Chimney incorporated on a staircase (Source: Google image adapted by author)

Examples : 1.Tanga School in Falkenberg (Sweden): see Annex (1.3.4)

2.5.6.3.Solar roof ventilation Strategy: In climates where the solar altitude is large, a Trombe wall or a solar chimney may not be very effective collectors of solar energy and, therefore, the ventilation rate that can be achieved with these devices may be limited. In this situation, a sloping roof collector can be more effective in collecting solar energy but because of the sloping surface the height of the collector will be small. A solar roof ventilator is shown in Fig 89 (a).

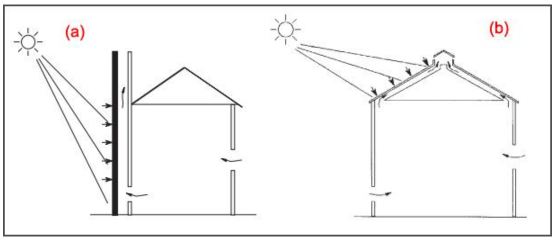


Fig.89. (a) Solar chimney;(b) Solar roof ventilator.(Ulrike & Francine 2015).

The advantage of a roof collector is that a large surface area is available for collecting the solar energy and hence higher air exit temperatures can be achieved than those for a Trombe wall or a solar chimney. As a result, a roof ventilator could achieve ventilation rates close to a solar chimney or even higher depending on its design and the climate.

*2.5.6.4.Exampes:*EX.. The Charles de Gaulle School (See Appendices)

2.5.7. Wind towers /Wind-catchers ventilation Strategy

Windscoops have been employed in buildings in the Middle East for more than three thousand years. (Allard, F. 1998) They were traditionally constructed from wood-reinforced masonry with openings at height above the building level ranging from 2m to 20m even up to 30m . In the modern design of windcatchers, the two ventilation principles of wind-scoop and passive stack are combined in one design around a stack that is divided into two halves or four quadrants/ segments with the division running the full length of the stack. Due to manufacturing requirements, the area of each segment is in some cases the same (e.g. a square-section windcatcher) but in other cases (e.g. circular-section windcatcher) not all segments have the same section.

This device is a cover rising high above the building with an opening facing the prevailing wind. It traps the wind inside the top of the tower above the building where it is cooler and stronger, and conveys it through channels (ducts) down into the building. The wind tower can replace ordinary windows and provides ventilation and air movement(HASSEN F, 1988)

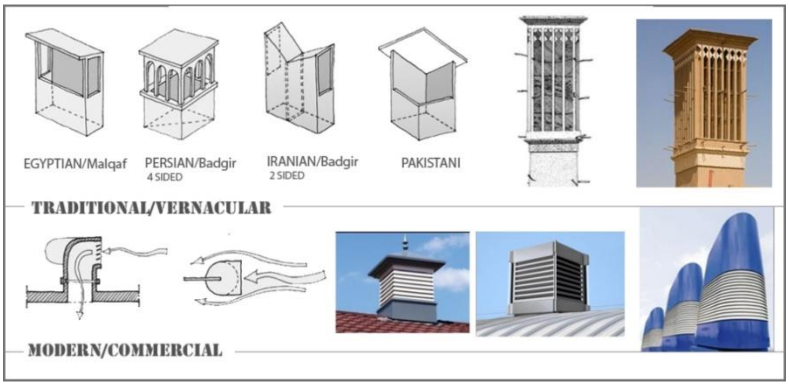


Fig.90. Traditional and modern Wind Tower/ WindCatcher (Source: Google image adapted by author)

2.5.7.1..*Wind Tower Operation:* The wind towers are designed to "capture" the wind and increase its pressure depending on the model, the air can be blown in and out through two ducts located in the same tower. The air, coming from a wind tower, is cooler, less dusty, less polluted but less humid, because it is captured at the roof level. The new air introduced, drives out the hotter and stale air. Modern wind towers are usually equipped with self-orienting scoops in the prevailing winds, to create a *venturi effect*. When the prevailing wind is centered on a narrow sector, the scoop consists of a large vertical section that will narrows slightly to the vertical section of the inner duct. (Romina M .2009).

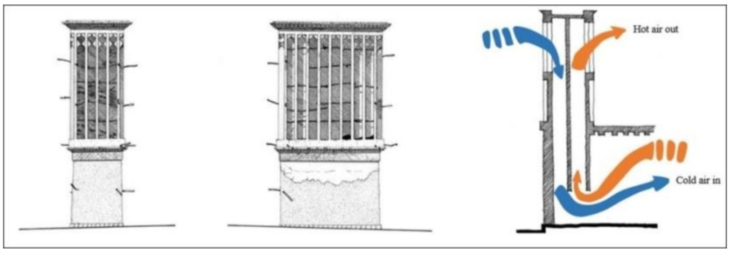


Fig.91. Diagram shows the air flow in a wind tower (Source: Google image adapted by author)

The design of the wind tower or windcatcher not the only consideration. The air outlet is also very important when the wind blows from one direction, it exerts a positive pressure on the building facade facing it, but it also creates a negative pressure on the on the roof and on the opposite side of the building. If the exhaust openings are placed in these areas, the air is drawn in and out of the building. Regarding the operation of wind towers, two categories are known:

<u>Wind Towers Facing the prevailing winds</u>

- In areas where the prevailing winds are unidirectional;
- In areas where the winds come from all directions, when they are available;

<u>Unidirectional wind tower</u> In this case the head of the tower will have a single opening facing this direction, consists of a single passage or duct, usually built into the thickness of the outer wall, rising wall, rising high above the roofs.

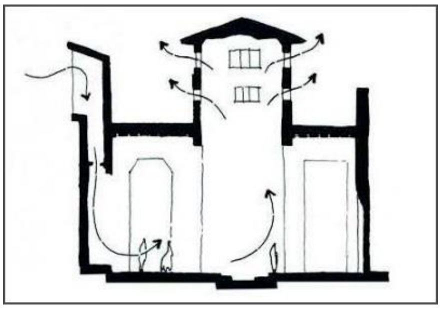


Fig.92: Section of a typical windcatcher and an example in Aghazadeh Mansion. Abrkouh. Iran

2.5.7.2.Classification of Wind Towers: Towers can be classified according to several criteria, we can classify them according to their *function*, their *shape* (plane) and the *number of openings*.(A'zami, A. 2005)

<u>Classification based on function:</u>

The head or the top of tower can have openings or air passages on one, two or four sides that face the predominant direction to accommodate the wind in appropriate directions.

Wind towers are often described by the number of directions they face, such as unidirectional (yek-tarafe), bidirectional (dotarafe), quadri directional (carboniser-tarafe), and octodirectional (parasites-tarafe).

- Unidirectional (yek-tarafe) The tower has only one opening
- Bidirectional (dotarafe)The tower is a simple or base example divided into two vertical compartments; it has only two openings, it is often named by the direction.
- Quadri directional (carboniser-tarafe) These are the most popular wind towers and are divided into four main compartments.They are most often used or positioned on water tanks.

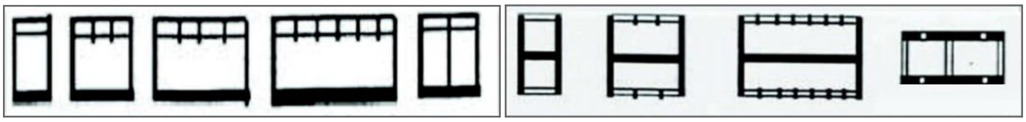


Fig.93. Typical plan of a Unidirectional and Bidirectional Wind Tower (Source: Ghaemmaghami.P.S; Mahmoudi.M Mai 2005).

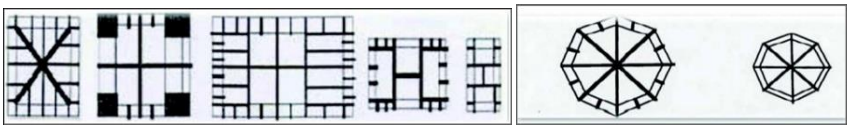


Fig.94. Typical plan of Quadri and Oto-Directional Wind Tower (parasites-tarafe). (Source: Ghaemmaghami.P.S; Mahmoudi.M Mai 2005).

➢ <u>Classification based on plan shape:</u> (A’zami, A., 2005).

Several plan shapes have been reported: the square is the shape used in rectangular shapes; are composed of uni, bi and quadru-directional wind towers and octo towers are those with an octagonal plane and can therefore receive wind from any direction.Compartments are elements inside the ducts of wind towers which divide the latter into several ducts, these compartments form a flat grid of openings ending in a heavy masonry roof on the tower.

<u>These can be classified into two groups:</u>

-The main compartments spread out in the center of the tower, forming a separate compartment behind the openings. Their base is often between 1.5 and 2.5 m above the first floor level. The patterns of partitions vary from tower to tower, but most known shapes are I-, H-, and X-shaped.

-The secondary compartments remain as wide as the outer wall, about 20 to 25 centimeters. An air duct can be subdivided into additional partitions with a structural or having a structural or thermal role. These can separate the tower into two or four ducts respectively.

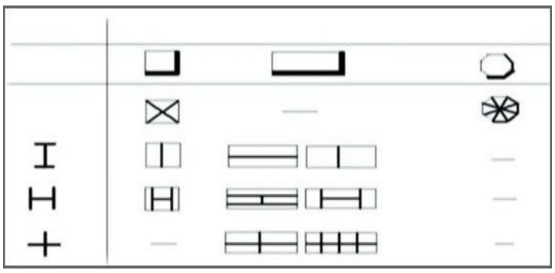


Fig.95. Classification of Wind Tower based on shape plan. (A’zami, A., 2005).

The earth plaster covering the facade of the wind towers has a light color, to reflect the solar rays. Wind towers in humid and hot climates are covered with plaster (of gâche and sarooj) because this type of plaster has a great resistance. Ex in Fig. 96.1.2

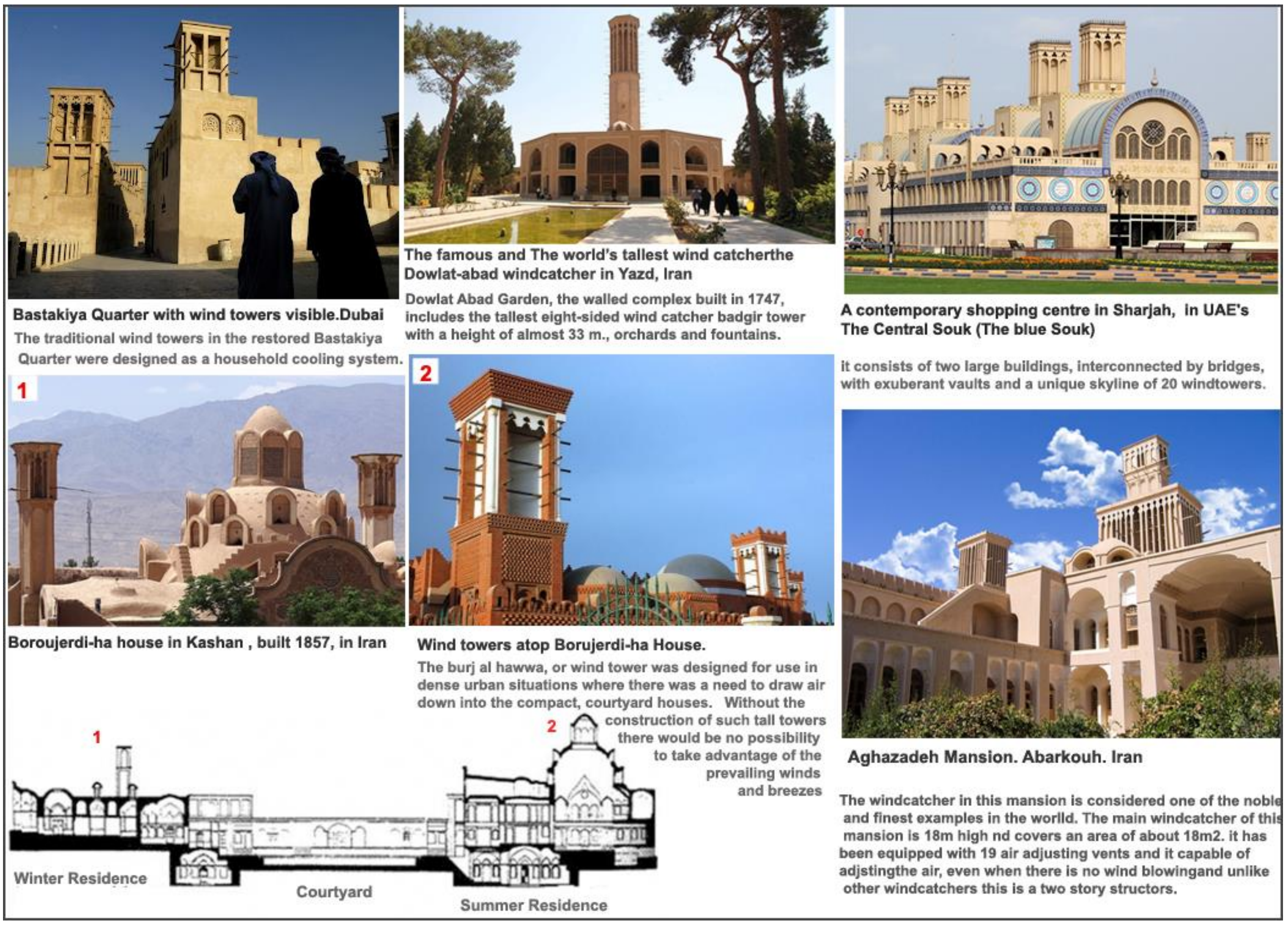


Fig.96. Different types of traditional architecture of Wind Tower. (Source: author)

2.5.7.4. Modern installations of windcatchers: Windcatcher systems are increasingly being installed in buildings to enhance natural ventilation where conventional systems do not provide sufficient air flow. In most of these modern installations the windcatchers terminate at ceiling level with four quadrants acting as air supply/extract ducts, see Fig 97

Fig.97. Modern passive stack ventilation terminals; Suncatcher and windcatcher. (a) External view of slots and of sun pipes for a suncatcher and (b) The four air flow segments of a windcatcher. (Source: Google image adapted by author)

Circular and a square section windcatchers are available either for ventilation purposes only or are integrated with natural lighting devices. In this case the term'suncatcher' is sometimes used to distinguish this variety from standard windcatchers, Fig.119(a). In this case, the central part of the device is constructed from polished metal tube with a transparent dome cover to provide natural light to the room. At ceiling level a light prism cover is used to diffuse natural light before entering the building (A’zami, A., 2005).

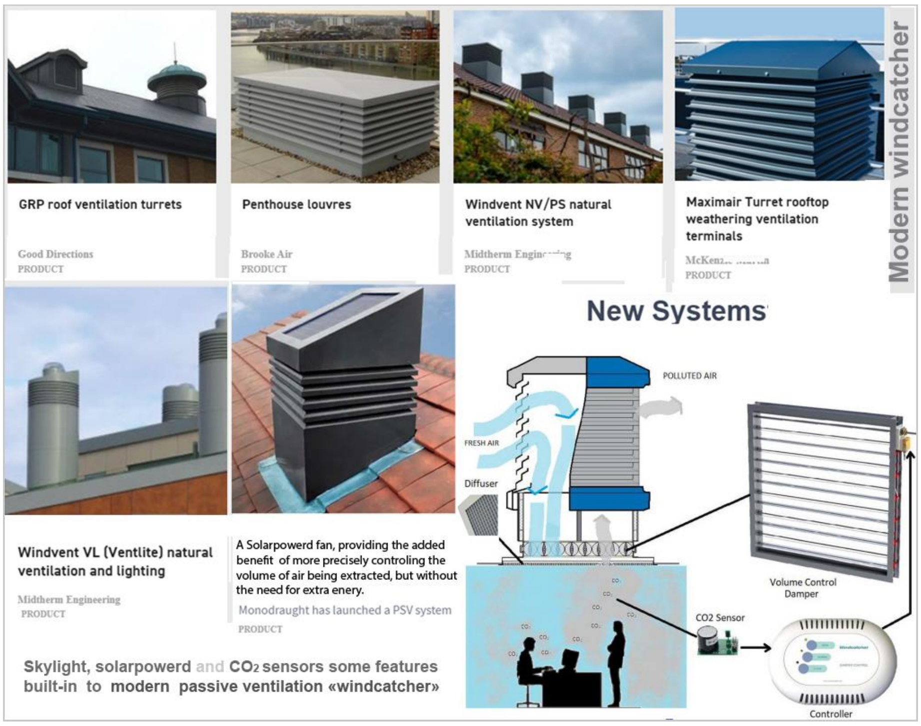


Fig.98. Different commercialized windctchers with new technologies .(Source: G. I.adapted by author)

2.5.7.5..Examples: The BRE environmental building, 2.3.Shools monodraught systems.

2.6. Passive retrofitting Guidance and efficient protocol s for ventilation

"Target existing educational buildings by using passive ventilation strategies to improve IAQ and IEQ as a whole."

2.6.1.Overview

A *retrofit design support tool*; play the role of guidance during this phase of passive ventilation retrofitting Fig 99,100 Table 10 where the most important choices will be made with a direct effect on the IAQ and thermal behavior (occupant health, well-being and performance), energy performance of the building (energy consumption, utility bills and clean energy) and impact on the environment (pollution ,co2, and natural resources). Fig 102 Taking into account all these assumption, a practical guide of recommendations is needed to help achieving a healthy and comfortable indoor environment with low energy and low polluted building designs. This latter is will based on the relationship between the climate parameters and the general aspects of the building; concretization of each strategy can be achieved through the application of different architectural elements simultaneously; the interaction between this elements makes the mission more difficult to achieve natural ventilation because of the multiple options, sometimes contradictory choices. Fig 101

Therefore, the various plans that define the strategy must be designed as a coherent and consistent whole, in order to solve the main need and compromise with other important elements with different needs, thus reducing the contradiction between the distinct conceptual strategies Fig.103. The last Figure 104 shows the relationship between the suggested conceptual strategies (recommendation and result of the climatic and bioclimatic analysis) (Emmerich, 2011. Axley 2001) and the architectural elements manipulated by the architect to achieve the most adaptive , adequate and efficient passive ventilation possible.

2.6.2.Variable and Invariable Influential factors of passive ventilation strategies

3.2.1.1.Environmental conditions (1) Geographical location of the site (altitude, latitude, longitude, topography);(2)The orientation of the site and the interferences of the site (other constructions, vegetation);(3) Climatic conditions;(4) Direction and speed of prevailing winds;(5) The direction of the construction (orientation of the facades);(6) External shadows related to the envelope.

3.2.1.2.General aspects of the building: (1) The external volume and morphology.;(2)The orientation of the facades. ;(3)The external opaque and glazed surfaces exposed to solar radiation.;(4)The external surfaces open to ventilation.;(5) The level of masking on the facades due to integrated devices (architectural architectural devices).;(6)Basic building materials fabric;(7)Urban, rural, suburban structure;(8)Old, new building

3.2.1.3.Others:(1)Occupancy ratio;(2)Activity type;(3)Time of occupancy;(4)Resident behaviors…etc (Shittu Abimbola K. 2010, Priolo ,1998)

2.6.3.The tiered approach for the integrated design process and energy process strategy

1.By adapting (Norbert L.2001)" *Sustainable/Bioclimatic Design Methods* " approach, which is an approach pays special attention to the design of heating, cooling, and lighting systems to produce comfortable, energy-efficient, economical, and sustainable buildings. His philosophy is that the building itself needs to do most of the heavy lifting before active and even passive systems are employed Fig.99

All of the suggested strategies that may be achieved by natural means, that is, by adapting architectural design to utilize the climate elements for better indoor environment. Other problems, which fall outside the natural possibilities either basic or enhanced ones (solar chimney, wind tower ...etc) , then we will have to be remedied by mechanical means, such as ceiling fan (hybrid system), or air conditionings (heating, cooling and dehumidification) but with clean potential energy.

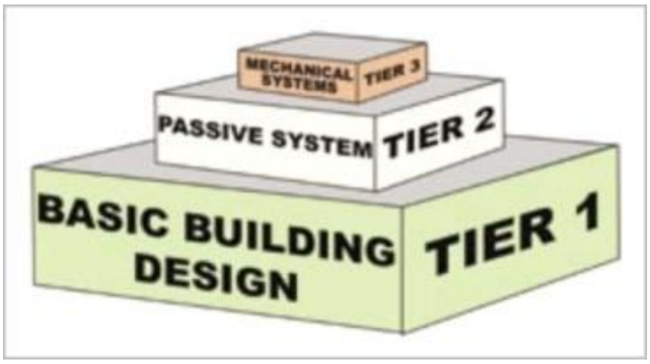


Fig.99 " The three-tiered design approach” to sustainable design involves considering basic building design before passive and active systems/(Norbert Lechner’s 2001).

	Heating	Cooling	Ventilation	Lighting	Acoustic
Tier 1	Conservation	Heat Avoidance	Fresh air	Daylight	Isolation
Basic Building Design	. Surface-to-Volume ratio	.Shading .Exterior colors	.Building Orientation.. .Fenestration	.Windows .Glazing type	.Construction materials -Baffles
Tier 2	Passive Solar	Passive cooling	Passive vent	Daylighting	Blocking
Natural Passive Energies	. Direct gain . Trombe wall	.Evaporative Cooling	.Cross-vent . Stack vent -	.Skylights .Clerestories	. Tampon .Natural barriers
Tier 3	Heating	Cooling	Ventilating	Eclectic light	Block systems
Mechanical Electrical	. Furnace .Ducts	. Refrigeration machine	.Ceiling fans HVAC Systems	. lamps . Fixture	....

Table 10 The three-tiered approach to the design of heating, ventilation, cooling, acoustic and lighting systems (Lechner 2001. adopted by author)

Fig.100. Global Retrofitting Strategy " The three-tiered design approach" (Source : adapted by author)
" Microclimate-responsive elements design Vs energy efficient strategies."

“The first tier is the architectural design basic architectural elements mostly of the building fabric itself. Windows (location, size, shape.), wings (shape, size, location...) with responsible for succeed or fail of "Basic passive strategies" such as simple stack or two-sided natural ventilation; poor decisions at this point can easily double or triple the size of the mechanical equipment and energy eventually needed. *The second tier* involves the use of enhanced passive strategies, through such methods The proper decisions at this point can greatly reduce the unresolved problems from the first tier. Tiers one and two are both accomplished through architectural design mostly of the building. *Tier four* consists involves the use of Hybrid strategies to handle the problem, it's the use of both natural and mechanical systems to solve the unsolved problem by the second tier (advanced or enhanced passive strategies). While the *Tier four* consists of mechanical equipment using mostly renewable energy sources to handle the loads that remain after tiers one, two and three have reduced the loads as much as possible”

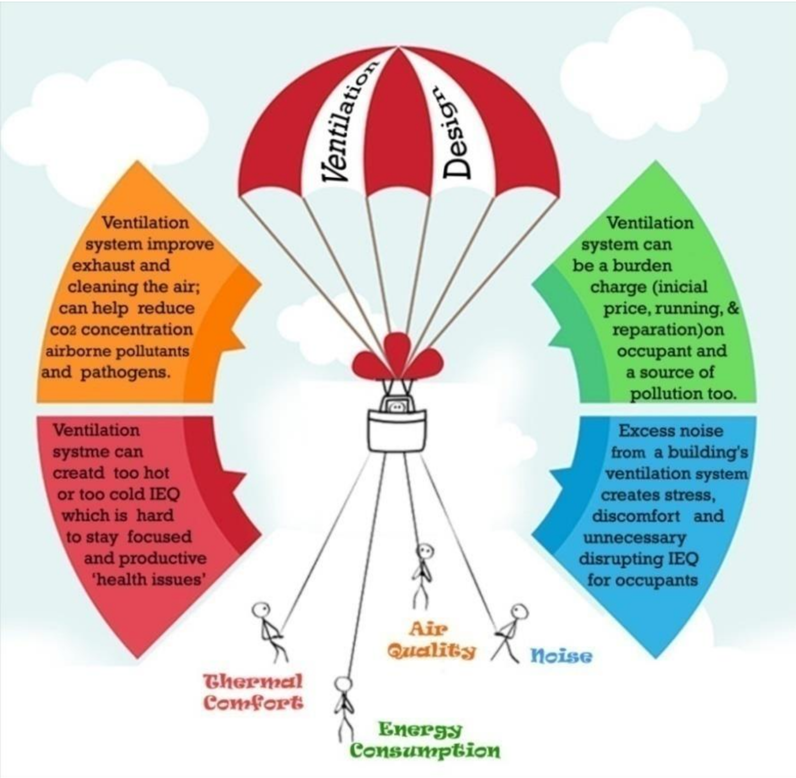


Fig.101 Ventilation Design (strategy) and interaction with other factors.(source: author)

2.In addition to the adopted three-tiered approach with the energy strategy adopted Fig.100 we attempt to integrate architectural elements or passive systems into the building which is the approach of "Integrated energy design": Energy sufficiency , Energy efficiency, renewable energy Fig.100 , with this process strategy we can acquire a new building with sustainable features; which is known ."Climate Responsive design".(Ulrike & Francine 2015)

3.The other aspect of the passive retrofitting guide proposal emphasis or focused on four axes respectively: Fig.102

- Occupant/Resident: health, performance and well-being is the utmost actor in the retrofitting operation.

- Environment: Minor usage of resources and no air pollution emissions or others kind of pollution (noise, solid waste...etc) during or after retrofitting operation. Environmentally friendly retrofitting intervention.
- Economy: low reroofing budget; initial budget (system or construction materials cost), running (energy consumption) or/and reparation operation.
  " Using mechanical systems in some cases is inevitable, thus using clean energy is recommended when all passive systems fail to meet occupant basic needs."
- Building: "Aesthetic and functional aspect of the building", the retrofitting operation to some extend needs to respect and follow a particular local cods and aesthetic aspect "Zero or minor modification in those elements "

Fig.102. Diagram shows the four main blocks targets of retrofitting strategy. (Source: author)

4.With the use of the climatic, bioclimatic analysis results and clean energy potentials available outcome studies' to deliver an "adequate retrofitting design" by using the right strategy for each specific problem or case.

5.Fig 103 shows the relationship between the design strategies result of the bioclimatic analysis and the architectural elements manipulated by the architect to solve a specific problem. We also see that the realization of each strategy can be achieved by several architectural elements at the same time. Or two elements from two different strategies to meet some comfort level.
In fact, to some extend some situation makes the architect's mission more difficult because of the multiple choices which are sometimes in contradiction. For this reason using a loop Strategy, the architect may take another alternative strategy path. because each element can solve one or several conceptual problem in the same time, in a synergic and complementary way. For difficult situations, we will need simulation and modeling for accurate evaluation which we would see that in the next section.

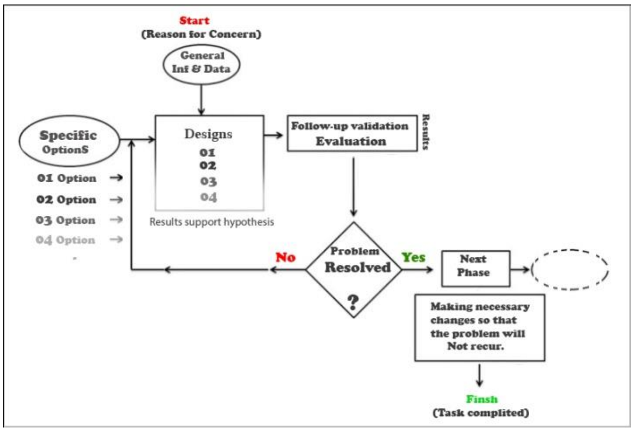


Fig.103 Design loop strategy (Haapasalo, Harri 2000 redrawn by author)

Fig.104 Research methodology for selecting the adequate passive ventilation strategies and the Relation between architectural elements and Ventilation Design

"Retrofit-Design Support Tool Proposal for Passive Ventilation"(adapted by author)

" Proposal Guide for Passive Retrofitting Strategies for comfort and ventilation."

2.6.General conclusion:

Nowadays the drive to achieve energy efficient buildings ever more airtight constructions are becoming prevalent yet critical, because arise of some problems associated with this latter such as using an air pollutant and high energy consuming conditioning/ventilation systems which cause SBS, thus the need for a healthy and efficient new system is decisive. A system that can extract air from the right places and introduces the right amount of fresh air, can minimize air pollutions emission can lower the energy consumption and the most importantly can provide a healthy fresh air. Therefore, get a ventilation design wrong and we have either a damp, stuffy building or one that is cold and draughty which can cause discomfort to occupants and even a sever disease (virus contamination), this is why Air-Flow matters and passive ventilation systems that offer high-quality indoor environment that come with low budget, low energy consumption and no CO2 emission matter most.

From above , it is concluded that the first task of designing these successful passive ventilation systems is to perform a climatic and bioclimatic analysis which require a knowledge of many environmental factors; prevailing wind speed and directions solar orientation and radiation intensity, as well as weather data, to name few. Thus, Well-harnessed of natural elements and resources is the first step to achieve a good indoor environment. It's also conclude that with an adequate passive ventilation systems potentially provides energy savings along with improved occupant satisfaction and can also help to cool a building "vernacular architecture" and these passive system demonstrate that can work effectively in most non-domestic buildings and all climates especially in Mediterranean climate. Moreover, many studies have shown that people who spend time in buildings equipped with natural ventilation have fewer building related symptoms, such as headaches, eye irritation, etc and from an educational perspective improving the indoor air quality using natural ventilation strategy in educational buildings bringing down the level of CO2,increasing daylight and benefiting from the beiofila with operable windows will improve the indoor climate and thereby the students' ability to learn will have profound effects on productivity and academic achievement in classroom. However, to achieve a constant good NV performance which is not always can be guaranteed because of the unpredictable nature of wind or other factors (noise, air pollution, privacy…), thus smart technologies sometimes is needed (sensors, automatic actuators…)

In Algeria as of many developing countries, absence or an inadequate ventilation plan design (natural or mechanical) making the IAQ more critical in context of occupant's health and performance , energy use and air pollution .These so-call adventitious ventilated building need to be properly retrofitted with an ideal passive ventilation system, above all Algeria climate considered suitability to this type of ventilation system , especially amid of rising temperatures and energy costs, it also can save money, preserve our natural resources with no GHG emission only by using natural elements and available clean energy such as solar and wind energy. In addition, as solar energy is a good potential as clean energy in Algeria can generate elasticity for these passive ventilation systems, thus it's more important to consider passive ventilation and cooling design strategies than ever. By using interdisciplinary approach on considering all above factors is key solution . to offer healthy and efficient IEQ

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Case of Study

This section is organized into two chapters. Each chapter deals with specific issue; issues addressing the following:

3.1. Site investigation
3.2. Simulation and Modeling

3.1. Site investigation

3.1.1.Climatic analysis

The climatic conditions of a place can be seen as constraints from which one wishes to protect oneself and as a potential advantages that one wishes to exploit. The bioclimatic or passive architecture (Passive ventilation)has for object of a harmonious synthesis between the vocation of the building, the comfort of the occupants and the taking into account of all these climatic conditions. It is for these reasons that it is necessary to evaluate and study the climate of the site of the project before any architectural design intervention.

3.1.1.1Climatic characteristics of the case study area in Blida region: In order to better characterize the climate of the city of Blida (project site case study), we've analyzed various parameters which constitute its climate, by interpreting these meteorological data which are spread over a period of more or less than ten years period and current (ONM)data. After reviewing several climatic data sources (climate data., Meteoblue , Weather atlas, Weather Spark; Climate Consultant and app.formit.autodesk.com tools. *(Appendix)*, it's concluded that the data which are reviewed are more or less consistent with the National Metrology of Algeria (ONM) data and our field inspection time period, except the wind climatic data is still needed more study have to be done due to the complexity and the irregularity of wind pattern in this region. Blida situated in the northern hemisphere. At a latitude of 36 ^{o}30 in the North, a longitude of 2^{o} 52 in the East and an altitude of 188 m .Where the climate is warm and temperate. Winter temperatures vary *between 3°C and 15°C* . In summer they *rise to 25°C in May* to reach an average of *36°C* in July**,** During coldest winter and snowfall, the temperature can drop below *-1°C* and can reach *46 °C* in hottest summer. Which is partially consistent with, different historic monthly temperature recorded in Blida

The region is thus characterized by two seasons:

- A cold season from November-April; whereas *January* is the coldest month.
- A hot season from May-October; whereas *July* is the hottest month in Blida region.

Historic climatic data also show that temperatures vary significantly between night and day; with a mean average temperature differences *6°C*. Several months are recorded drop of nighttime temperature up to "1/4".*January* as the coldest month recorded temperature differences between daytime and nighttime *8°C to 12°C* while in *July* as the hottest month, nighttime temperature dropped to a half "*15°C* " (from 34.6 to 19.5).

The month with the highest relative humidity is *January* (70-.75 %). The month with the lowest relative humidity is *July* around (50-55 %) which is one of the uncomfortable this period of uncomfortable last 3 to 4 months (begins in late-June to early-October). In this period uncomfortable or muggier percentage is at least 10%; it reaches its max in *July* and *August* above 30%. which creates unhealthy, harsh and inconvenient IEQ.

3.1.1.2.Climatic characteristics of the case study area in Ain defla region: Ain Defla situated in the northern hemisphere. Where the climate is semi-arid Mediterranean climate where summers are hot and dry and winters are mild and rainy. Winter temperatures vary between *4°C* and *17°C* . In summer they rise to *26°C* in *June* to reach an average of *39°C* in July, During coldest winter, the temperature can drop below *-1°C* and can reach *46 °C* in hottest summer. Which is partially consistent with, different historic monthly temperature recorded in Ain Defla. Besides, it shows that the monthly average temperatures range from *M = 46.20°C* in the hottest month July to *M=1°C* in the coldest month (January /February). The region is thus characterized by two seasons:

- A cold season from November - April; whereas *January* is the coldest month.
- A hot season from May-October; whereas *July* is the hottest month in Ain Defla.

Historic climatic data also show that temperatures vary significantly between night and day; with a mean average temperature differences *10°C*. Several months are recorded drop of nighttime temperature above "1/3". January as the coldest month recorded temperature differences between daytime and nighttime *8 -10°C* while in *July* as the hottest month, nighttime temperature dropped to a 1/3 "11°C " (from 37.6 to 26.1).
The month with the highest relative humidity is *January* (60-.70 %). The month with the lowest relative humidity is *July* around (25-50 %) which is one of the uncomfortable or months of the year; this period of uncomfortable last 3- 4 months (begins in late-May to early-October). In this period uncomfortable percentage least 10%; it reaches its max in July and August around 15%. which creates unhealthy, harsh and inconvenient IEQ.

3.1.1.3.Conclusion of the climatic analysis (Blida and Ain Defla):
From the climatic analysis performed, it is crucial to take the climate data into consideration in the design process. This means that the variety of climates on the globe necessarily implies an architectural diversity. The latter must primarily meet the specific comfort and thermal needs of each climatic zone, and each project character , it can also serve as a benchmark to determine specific architectural characteristics. The climate of the both cities can be identified according to qualitative aspects and quantitative data such as the duration of insolation, the speed and direction of wind (wind rose) ...etc. These latter data will help us to better understand our project sites to apply an adequate passive ventilation strategy for retrofitting the projects in questions. (See Appendix for more details graphs, tables..etc)

3.1.2.Bioclimatic analysis
A project's bioclimatic analysis depends on the locations physical, climatic and environmental characteristics, as well as the users' requirements and the activities within different spaces.
Then the purpose of Bioclimatic Architecture is to design spaces worthy, comfortable and healthy for the users' body, mind and spirit, considers the usage of the natural resources of the environment. Among the bioclimatic tools most frequently used in the preliminary design analysis are: (1)the bioclimatic diagram by Olgyay , adapted by Szokolay , (2)the psychometric diagram by Givoni ,(3) the Effective Corrected Temperature nomogram ,(4)the stereographic diagram by Szokolay's,(5) the comfort triangles by Evans and,(4)Mahoney indexes.
bcChart Bioclimatic tool is one of the more important tool that developed in a conventional spreadsheet. (See results in Appendix) Then, it can be assumed that the way to carry it through follows the procedure which, according to the same study, can suffer slight variations.

3.1.2.1.Conclusion of Bioclimatic analysis (Blida and Ain Defla): Application of different methodologies for bioclimatic analysis are extremely important for our project sites ;

besides such approach gives more precise results of locations' bioclimatic potentials. Bioclimatic analysis Not only help us to conform that these projects are not passive buildings, or considered any bioclimatic elements and site specifications, or subjected to any natural ventilation cods or norms (building orientation, widows size..etc) , which make these building adventitious ventilated buildings. Plus it help us to consider the most efficient natural elements in conceptual design .Thus, the appropriate and most efficient bioclimatic strategies can be more accurately identified. Solar energy was presented as an important element in both locations, therefore BcChart tool would be an ideal choice offering more efficient and accurate bioclimatic strategies.(Solar energy)On the other side, air movement is harder to control and predict in both sites ,due to various influential parameters, such as degree of urbanization, building aerodynamics, stack effect, etc; which means always count on stack than wind, for such complex evaluations more sophisticated perform whole CFD simulation building tools would be far better alternatives (the following section). Also these Bioclimatic strategies are not directly exploitable in architectural designs because the solutions (strategies) generated by the previous bioclimatic analysis are often presented without explanation ; indicating only 'what to do' ,rather than 'how to do it' ,thus a *Retrofit-Design Support Tool Proposal for Passive Ventilation or* a practical guide Fig.104 is needed to help achieving an adequate and passive ventilation strategy which lead to a healthy and comfortable indoor environment with low energy and low polluted building designs.

3.2. Simulation and Modeling

3.2.1. Background: The ventilation strategies in school buildings in many countries still appears to be relevant to contemporary issues. Dealing with this subject is challenging especially during the school buildings design, retrofitting process on one hand and efficient ventilation system or mechanism which features in balancing in energy use, promote health and persevering environment on the other hand.

Building retrofitting plays a critical role in achieving sustainable development and is an efficient way to improve the indoor air quality (IAQ) of existing spaces. The IAQ in classrooms has a significant impact on the *health* and *academic achievement* of students. (Hyeun J.M et. al 2016) However, improving the IAQ of existing classrooms is challenging if minimum architectural modifications are allowed. Different natural ventilation *retrofitting techniques* were proposed to improve the IAQ in existing classrooms at Blida University of Science and engineering, which is located in a hot arid region and a primary classroom (prevalent design in Algeria) located in Ain defla.

There are multiple factors to take into account when deciding how a educational building should be ventilated, such as the building's position, wind exposure, entrance locations, and more. The goal is to ensure that a sufficient amount of fresh air will move through the building to ensure comfort for occupants.In many cases, using natural ventilation is a tempting option, but it is difficult to solely rely on this solution without proof of performance. This is where CFD simulation can help, enabling us to validate the use of natural convection in a building and reduce the costs of artificial air exchange systems. With our CFD simulation can help in making informed decisions about using natural ventilation as a part of a building's air exchange system. We will learn:-How we can ensure air comfort with passive strategies within the building and How air exchange ratios can be calculate form the use of NV.

3.2.2 Case Study Part One (Air distribution, air contaminants and comfort)

Overview of "A classroom in an elementary school in Ain defla "*:* In this research, the evaluation of a computer simulation results of the IAQ and natural ventilation strategies for a typical elementary classroom located in Ain defla are presented. The urban elementary school situated in the a well dense and polluted area, it was built before 1980 and located at (36°15)N and 1°58E, altitude 270m. Fig.105

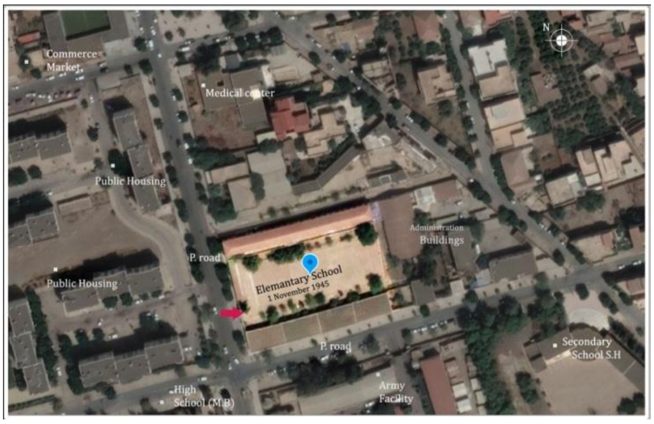

Fig.105 Aerial photograph shows the situation of the elementary school


Fig.106. Views of different parts of the school; main entrance(a); Southern facade view (b); Northern wall of classrooms bar (c).

3.2.4. Material and methods

*3.2.4.1..Overview:*To achieve a comfortable, safe and healthy indoor classroom environment by natural or hybrid ventilation means with a tight budget and little impact on environment, we follow *Retrofit-Design Support Tool* in Fig 104 in this model we concentrate on the air movement and the air pollution behavior produced from indoor and outdoor.

We will use (FLUENT- CFD) as a tool of simulation to review and evaluate different cases or strategies of ventilation. Several natural and hybrid mechanism will be evaluated in order to come up with an exemplary model that we may follow as architect to shift our retrofit our deciduous or/and stock adventitious school buildings (sick buildings) to a healthy and comfortable indoor setting for our students, our professors and our future.

In addition to those factors presented in blocks of targets of retrofitting strategy we emphasize on other specific factors:

- The location of the school and its orientation (Urban site), source of pollution.
- Zone of occupancy in a classroom is about (80-120cm) for school children.
- The shape, form of the building and its architectural elements (windows,...)
- The presence of a considerable noise and sunrays, from the southern facade.
- The outcome of the climatic and bioclimatic studies.

*3.2. 4.2.Description of the model:*The model "classroom" is located in one story educational building (ground floor) where the classrooms shaped a bar form; all the classrooms are identical. The characteristics of the simulated classroom that was used in this study are the following: the typical simulated classroom is located on the ground level; the northern wall is overlooked on the center of the school (playground, and school yard), the other wall is faced a main street on the south side of the school. It is located in a urban region (noise, air pollution from cars...etc) in fact all its window oriented toward the south (main road) are closed and fixed. The classroom dimensions were 8.40/ 6.00 /3.00 m (length/width/height), with a volume of 151 m3, with no false ceiling cavity and two-sided windows as shown in Fig.106.107,108. The dimensions and locations are illustrated in Fig.108 and 6.

Fig.107 Classroom Northern facade (left); Southern facade (right) the exterior wall of the school

Fig.108. Interior of a typical classroom(the model to simulate)

3.2. 4.3. The weather data Climatic and bioclimatic results analysis were used to determine outdoor climate of our case study temperature , wind speed, and direction ...etc

Month	Average Monthly outside DB temperature, Blida(2020)											
	Jan	Feb	Mar	Apr	May	Jun	**Jul**	Aug	Sep	Oct	Nov	Dec
***DryBulb** Average*	**6.3**	**8.2**	**13.0**	**16.5**	**22**	**27.1**	**30.6**	**30.1**	**26.4**	**23.3**	**13.6**	**8.3**

Table 11. Dry Bulb temp mean average degrees Cº(2020)

Wind direction and its velocity variable in presented in (Fig.114.).The winds come most often from the_west_(51% of the time), east (44%of the time), where minor winds often come from the north (4% of the time) and northwest (1% of the time).

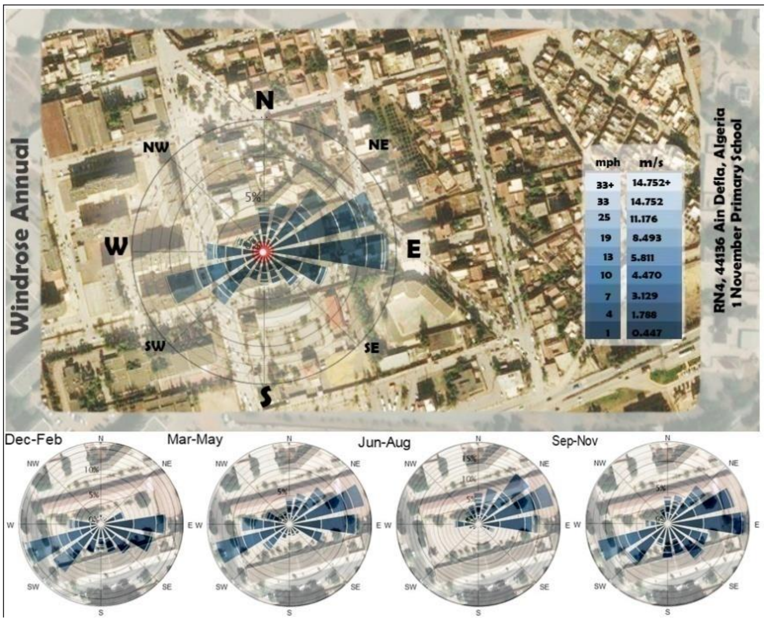

Fig.109.Wind rose (App.formit.autodesk tool) of Primary School "1er November 1954"-Ain Defla.

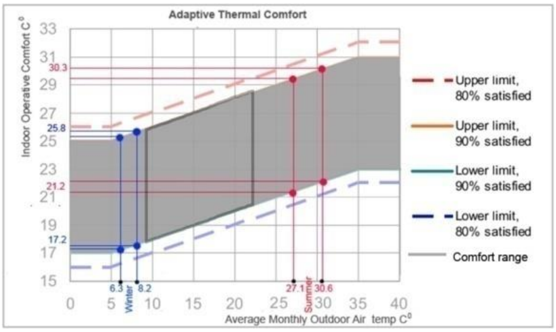

Fig.110.Ranges of adaptive comfort, in Ain defla region, according to the average monthly outdoor temperature (Sourece: ASHRAE Standard 55: 2004.adapted by the author.)

Fig.111. Elevation Plans and cross-section of a typical classroom showing the location, dimension, types and form of fenestration openings.

3.2.5. Building modeling In order to analyze possibilities of IAQ improvement in school a typical classroom was selected to perform a passive retrofitting techniques; the primary conditions of the classroom equal to field measurement conditions were modeled in CFD. The outcome of the field measurement and approved ones of a classroom were used as boundary conditions to create the base CFD models BC. Fig 111

We use CFD .ANSYS. to evaluate and solve a set of partial differential equations to predict air flow velocities, behavior, temperatures, contaminant dispersion, etc. In this analysis we choose The k– ε turbulence model with the first order upwind scheme for momentum, turbulence kinetic energy and turbulence dissipation rate.

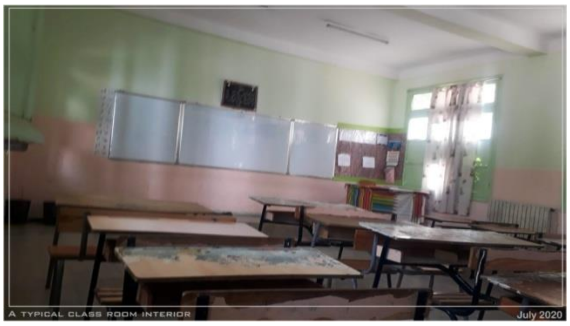

Fig.112. Classroom views interior and exterior /July 2020

CFD model was created according to field measurement Fig. 111,113; the Occupancy and furniture were simplified to base shapes to simplify simulation. Different number of grid cells were obtained in the molding results , 1.6 million grid cells were selected as adequate one to achieve precision and to obtain converged solution. however, in some places such as close to the air supply, outlets or other specific locations. density were increased to reached 3 million grid or more.

3.2.5.1.. Proposed natural ventilation retrofitting techniques

Base Case 1 (BC1): Natural ventilation

The location, form and type of windows /door (fenestration) have not been changed.

We will be taking or choosing the 3 common different configurations of the ventilation focusing on the wind ventilation which are also match the three users' behavior during different time of the day/ year and other non-climatic conditions such as outdoor noise, privacy need , air pollution (cars) ...etc. and we will see these arrangements/configurations and how they affect the air flew inside the building and we assume the optimal situation a breeze directly to the entrance; (North)2-4m/s ventilate.

BC1a :Barley ventilated classroom, all windows and door closed - only through air infiltration into the building fabric and cracked door and windows. December to Mars/heater on unbearable outdoor noise, privacy and focus necessity- 30%(Op)

BC1b :One sided natural ventilation through the door only on the northern wall.- Mild weather, student attention required, tolerable outdoor noise...etc.- 50%(Op)

BC1c: One sided natural ventilation through the door and two set of windows on the northern wall -May to July and quiet outdoors- 20% occupancy period.

Note/Observation: Even the classroom has windows on both walls, yet North / South cross ventilation option is Not feasible or undesirable due several inconveniences such as air pollution, noise from an adjacent road, no privacy /glare and direct sun rays...etc (all windows were sealed and/or coated with paint wallpaper, curtains).

Case 2(C2): Natural ventilation Mixing mode through large opening

C2a Replaced currant windows types(side-hung windows, top fixed) with horizontal-pivot window (Northern wall). When used for single-sided ventilation, which is our case air enters at the bottom half and leaves at the top if the external temperature is lower than the room temperature.

C2b By using the same type of window in ***C2a*** case on the northern wall however, this time it is used in cross-flow ventilation; air enters the top and bottom halves simultaneously. Air flow exhausted through the top part of a modified window (modified from top fixed to openable top- top-hung inward-) on the southern wall.

Note/Observation: The Current type of window has a top fixed part/ even if it openable top-hung inward or outward are always closed in classrooms either it is high to reach or broken. while it can improve the indoor air quality by allowing cool air in through the bottom part while pushing warm and stale air out through the top simultaneously especially in one sided ventilated classroom.(common types)

Case 3(C3): Natural ventilation Displacement mode/stack mode small penning

Tow mode of Displacement ventilation were chosen as possible air supply methods.

C3a Integrated small opening or trickle vents on the bottom part of the window frame Northern wall; Integrated small trickle/grid vents on the top part of the window frame southern wall. this case air flow by cross ventilation; air enters the from northern vents and exhausted through top windows halves on southern wall.

C3b Assisted Natural ventilation (enhanced natural ventilation)with exhaust fan /vent integrated on the southern wall and air inlets on the Northern wall base with filters, damper, grill and lovers.

Note/Observation: Ceiling fan can play a significant role in improving indoor air quality in both season winter and summer if it used appropriately.

Case 4 (C4): The same indoor setting of **C3b** with some enhancement on the building envelop and improvement of outdoor environment(micro-environment) thermal comfort, acoustics, air quality , daylighting, biophilic, energy and aesthetics aspect to name few.

"A commonly used standard for air movement says that, at minimum, 15 (cfm) per person should flow into a classroom; for Covid prevention, it's recommended 30 cfm. But studies show many classrooms have an average ventilation rate of only 6 to 11 cfm per person."

The boundary conditions for the inlets and outlets were set as volume flow. Each case was designed to satisfy the minimum ventilation rate Q = ***6 l/s per person***

The northern wall with windows were modeled and the outside temperature was set at 6 °C and 33°C, (6 °C which is the average temperature of the coldest month -January- and was set at 33 °C, which is the average temperature of the warmer month (July). In the case of natural ventilation, these temperature was also set as supplied air temperature. Solar radiation and air leakage of the building were not considered. Fig 113;114

*3.2.5.2..The Thermal outpost (students):*The Thermal output from schoolchildren was calculated according to Dubois (1916) body surface area:

$$A_D = 0,203 . H^{0.725} . W^{0,425} \quad ....(1)$$

Where H and W average height and weight of school children respectively.

In our field measurement we choose ***H*** =1.34m and ***w***= 30 kg as an average height and weight of a 9 year-old schoolchildren.

The teacher was considered as a standard person. where ***H***= 1.7m and ***w***= 74 kg

A_D(teacher)= $0.203.1.7.^{0.725}.\ 74^{0.425}$

A_D(student)= $0.203.1.34.^{0.725}.\ 30^{0.425}$

Body surface of a children is 1.06 m2.
Body surface of a teacher is 1.86 m2.
Metabolic rate for children is 1.06 to 1.30 MET.
Metabolic rate for the teacher was is 1.8 to 2.0 MET.
(1met=58w/m2 area~100w average person);50 g/(h occupant) of water vapor.
Therefore, heat output from schoolchildren was set at 74W and from teacher at 120W.

*3.2.5.3.**Carbon dioxide:*** The rate of production of carbon dioxide(CO_2) by human respiration, ***G***, is related to the metabolic rate by the equation :

$\mathbf{G=4\times10^{-5}MA_D}$......(2)...an average adult man G=0.006l/s (18l/h)

where : **G**=CO_2 production(ls^{-1}); **M**=metabolic rate(Wm^{-2})

$\mathbf{A_D}$=bodysurface area(m2).........(1) So;

An average sedentary children (**M**=74Wm−2and $\mathbf{A_D}$=1.06m2) produces about***0.003 l s−1***(***10.8lh/1***) ***(0.012m³/h)*** of CO_2 by respiration.

A standing teacher (**M**=120Wm−2and $\mathbf{A_D}$=1.86m2) produces about***0.009 l /s*** (***32lh/1***) ***(0.032m³/h)***of CO_2 by respiration.

- Lighting, radiators and other heat sources were estimated approximately.

Exhaled air was set for each person. **CO2** concentration in exhaled air was set at ***2,300*** ppm ......(2) and air temperature at +36. °C.

The Carbon dioxide concentration in the classroom filled with 36 schoolchildren and one teacher after a time (t =1h) was calculated as:

$$c= (q / (n V)) [1 - (1 / e^{n t})] + (c_0 - c_i) (1 / e^{n t}) + c_i$$ ----- (2) Where :

C: Carbon dioxide concentration in the room (m3/m3); q: Carbon dioxide supplied to the room (m3/h); n: Number of air shifts per hour (1/h); V: Volume of the room(m3) ;e: The constant 2.718...; t: Time (hour, h); Co: Carbon dioxide concentration in the room at start, t = 0 (m3/m3); Ci: Carbon dioxide concentration in the inlet ventilation.

- Common outdoor concentration 350 (rural)-450(urban) ppm
  In our case we took Ci =400 ppm ($0.0004m^3/m^3$)
- V equals the volume of the classroom $V_{(classroom)=}$ 6x8.4x3= 151m3
- In a classroom with 36 Children with low to normal activity the emission of carbon dioxide is in the range 0.02 to 0.08 m3/h per person (Table.TAIVC) was calculated to *0.012m³/h* to each children and for the teacher was calculated to $0.032m^3/h$.
- The total emission of the entire the classroom(0.012)(36)+0.032= $0.464m^3/h$
  so. q=$0.464m^3/h$

If the CO_2 concentration when 36 schoolchildren and one teacher enter the classroom and in the inlet air is close to zero, the CO_2 pollution concentration in a 151 m^3 classroom after one hour and with one air shift per hour, can be calculated as: (Equation ...(2))

C = ((0.464) / (1) (151)) [1 - (1 / 2.718 ((1) (1))] + [(0) - (0.0004)) (1 / 2.718 (1)(1)) + (0.0004)] *= 0.0026 m3/m3 =(2,300 ppm)* "

C = 0.0023 m3/m3 (2,300ppm)

One air shift per hour is not enough The ventilation rate per occupant is way below all standards (ASHRAE standard) where:

420-800ppm is optimal air quality indoors

1000ppm brain cognitive function may decrease by 15%

1400ppm brain cognitive function may decreases by 25%

1000 - 2500 ppm General drowsiness

The levels of co2 in the closed classroom is (2,300ppm) which can make children feel drowsy, adverse health effects may be expected. These levels may even worsen schoolchildren's performance on cognitive tests. Plus recycling the same air in enclosed place it's not a good idea especially if a airborne virus or bacteria, roaming indoors, we are certainly get infected by these bio-aerosols even in a building equipped with normal air central system (HVAC).

- Average CO2 concentration in all learning/teaching areas should not exceed 1,500 parts per million (PPM) during school hours.
- All occupied areas must provide a minimum of 3 liters of fresh air per second (l/s) for each person at maximum occupancy.
- The maximum CO2 concentration should not exceed 5000PPM during school hours.

*3.2.5.4.***.***Ventilation rates:* are often expressed as a volume rate per person (CFM per person, L/s per person). The conversion between air changes per hour and ventilation rate per person is as follows:

$$\boldsymbol{Rp} = \frac{(ACPH).(D).(h)}{60} \quad ....(3)$$ Where:

- R_p = ventilation rate per person (CFM per person); *ACPH* = Air changes per hour; *D* = Occupant density (square feet per occupant); *h* = Ceiling height (ft)

$$\boldsymbol{ACPH} = \frac{60.Q}{\boldsymbol{VOL}} \quad / \quad \boldsymbol{ACPH} = \frac{3.6.Q}{\boldsymbol{VOL}}$$

- ***ACPH*** = number of air changes per hour; higher values correspond to better ventilation
- *Q* = Volumetric flow rate of air in cubic feet per minute (cfm)/ liters per second (L/S)
- *Vol* = Space volume *L* × *W* × *H*, in cubic feet/ cubic meter

$$\boldsymbol{ACPH} = \frac{(60).(15)}{(7.85).(9.84)} .....(4) \quad \boldsymbol{ACPH=11.65 \approx 12}$$

That's mean the current classroom (BC1a and BC2b since BC1c barely is tightly related to unreliable outdoor conditions) need around 12 air change every single hour to compliance to standards, In other words every 5m the air should replaced with fresh air !!!, 15 cfm ventilation rate per occupant - aprox. 1000 ppm (school building ACH= 5-6) Double occupancy double ach...5-6 cfm ventilation rate per schoolchildren !!! it's difficult to achieve with just natural ventilation even in hybrid ventilation.

- In a typical home, ventilation rates of 0.35–1 air changes per hour are recommended. **5-6** air changes per hour are recommended for schools. For an office it's approximately 2–3 air change per hour. However for areas with potentially high levels of viruses (like hospitals, or in a COVID context), the CDC recommends a ventilation rate of **6-12** air changes per hour.

3.2.6.Criterions for system comparison

Basic criterion for comparison of different systems considered Air Distribution Index (ADI) which used in similar comparisons of ventilation systems in schools.(by H.B.Awbi) ADI depends on such values as effectiveness of heat and contaminant removal, predicted percentage of (section 3). Dissatisfied by thermal environment (PPD) and;(2). Percentage of dissatisfied by air quality (PD). PD and PPD values were presented by Fanger (1972).
Heat Removal effectiveness and Contaminant Removal Effectiveness are defined as follow:

$$\boldsymbol{\varepsilon}_{\boldsymbol{T}}=\frac{Tr-T0}{T0z-T0} \quad \text{and} \quad \boldsymbol{\varepsilon}_{\boldsymbol{c}}=\frac{Cr-C0}{C0z-C0} \quad ....(1)$$

1.T_r, T_0 and T_{oz} are temperature in the return opening, temperature in the supply opening and mean temperature at the occupied zone, respectively.
2.C_r, C_o and C_{oz} are contaminant (CO_2) concentration at the same points.
C_{oz} value was estimated as average carbon dioxide concentration in the inhaled air for each person in the room.

Both ε_c and ε_T values are defined using steady state conditions.

ε_c value	Implication
$0 < \varepsilon_c < 1.0$	Air pollution accumulation
$\varepsilon_c=1.0$	Perfect mixing
$1.0 < \varepsilon_c < \infty$	Good dilution of air pollutant

Table 12.: Range of contaminant removal effectiveness values

1.PPD value predicts the number of thermally dissatisfied persons among the large group of people and is defined as a function of predicted mean vote (PMV) .The recommended acceptable PMV range for thermal comfort from (ASHRAE 55) is between -0.5 and +0.5 for an interior space. (CBE Thermal Comfort tool a helpful on line tool with graphs)

$$\boldsymbol{PPD} = 100 - 95.e^{-(0.03353PMV^4 + 0.2179PMV^2)} \quad …………(2)$$

(CBE Thermal Comfort tool a helpful tool to)

2.**PD** value is a percentage of dissatisfied with the indoor air quality and depends on mainly on ventilation rate V (l/s per person):

$$\boldsymbol{PD} = 395.e^{-1.83\, v^{0.25}} \quad ....(3)$$

Awbi (1998) integrated heat and contaminant removal effectiveness together with PD and PPD values to obtain criterions, representing both ventilation effectiveness and people response. Comfort number NT and air quality number NC was defined as:

$$\boldsymbol{N}_{\boldsymbol{T}}=\frac{\varepsilon_T}{PPD} \quad \text{and} \quad \boldsymbol{N}_{\boldsymbol{C}}=\frac{\varepsilon_C}{PD} \quad ....(4)$$

Where we can defend (ADI) wich is a comnition of both comfort and air quality number:

$$ADI = \sqrt{(N_T \cdot N_C)} \quad ....(5)$$

3.2.7.CFD prediction and calculation results

CFD results showed that the main problem in cold period occurs in the zone closest to the window (Fig. 10). In case of natural ventilation, children sitting in this zone would suffer from dropdown of cold supply air.

BC1a &BC1b* &*BC1c:: Existing System (Natural ventilation) with different arrangement (behaviors)

C2a & C2b: Natural mixing ventilation

C3a& C3b: Natural displacement ventilation (natural and hybrid)

(C4): C3 case with outdoor environment enhancement.

Cases	Q l/s per person	ε_c Contaminant Removal Effectiveness	N_C Air Quality Number	Mean PPD %	ε_T Heat Removal Effectiveness	N_T Comfort Number	ADI Air Distribution Index
BC1a	2	0.3	1.2	70	0.6	1.07	1.13
BC1b	3	0.7	3.9	50.3	0.9	1.9	2.72
BC1c	6	1.3	4.2	40.2	1.06	3.2	3.7
C2a	7	1.5	5.1	12.5	1.1	6.8	5.9
C2b	8	1.65	6.2	8.6	1.07	13.5	9.14
C3a	5	1.6	4.9	20	1.5	10.6	7.2
C3b	6	1.7	7.3	16	2.54	13.2	9.82
(C4)	6	1.9	-	-	-	-	-

Table.13: CFD prediction results for different air distribution strategies

In cases of natural ventilation; open windows induced cold air movement from north even in displacement ventilation with vents appears not only in the case when window air inlets are installed. Besides the prevailing wind is from the north and west. So draught may occur and air speed in occupied zone may exceed allowable limit of 0.15 m/s and reach up to 0.3 m/s.(especially in case (C2a, C2b and C3a)). ASRAE 55: interior air speed should not exceed 0.2m/s, extended to 0.8m/s

In case of displacement ventilation (hybrid or natural) and case C2b a distance of 0.5 minimum from the wall with vents especially in cold season. Yet adjustment on windows horizontal center pivot or lovers on the vents could control air intake.

From the Table:13 where CFD prediction results were presented the higher ADI value indicates better air distribution in classroom, which represent case (C3b) ADI value =9.82 followed by case (C2b) ADI value =9.14 and the worst scenario is case behavior BC1=1.13which could have health concerns on student especially if a contaminate roam indoors. A higher contaminant removal $\boldsymbol{\varepsilon_c}$ and heat removal effectiveness $\boldsymbol{\varepsilon_T}$ were perceived for (case C3b) Hybrid displacement ventilation, yet predicted average PPD values is quite high (up to 19 %) if we consider other cases with 12.5 and 8.6

The two height vales of PPD were perceived in two cases C2a and C2b (natural mixing ventilation) yet the disadvantage of this air flow pattern is the concentration of Co2 higher than recommend standards. (600 to 1000pm) which lead to cross- contamination of infectious disease if one occupant have a season flu or Covid 19. While with C3a and C3b cases for example (displacement natural and hybrid ventilation) are advantageous solutions.

The outcome of simulation models (.) shows that smart natural ventilation is able to meet all indoor thermal comfort of occupants and energy saving to some extents.

3.2.8. Determine the Required Ventilation Rate (C2b) and (C3a/C3b)

By Perceived air quality method: pollution ; health ; comfort

The pollution generated by such a standard person is called one **olf.** One decipol is the perceived air quality in a space with a pollution source strength of one olf, ventilated by ***10 l/s*** of clean air, i.e**.** *1 decipol = 0.1 olf/(l/s)*

In our case study the percentage of dissatisfied visitors as a function of the CO_2 concentration for spaces where sedentary occupants are the exclusive pollution sources. With a high occupancy which may change in a short time, CO_2 monitoring is a well-established practice for controlling the supply of outdoor air . Although CO_2 is a good indicator of pollution caused by sedentary human beings, it is often a poor general indicator of perceived air quality.

Note, It does not acknowledge the many perceivable pollution sources not producing CO_2 and certainly not the non-perceivable hazardous air pollutants such as carbon monoxide and radon.

The following procedure have been used to determine the ventilation requirement in in the classroom. The ventilation rate required for health and comfort were calculated separately and then we took the highest value for retrofit design. Q_c and Q_h

In practice comfort usually determines the required ventilation. Therefore, the ventilation rate required for comfort is usually calculated first. Our calculation begins with a decision on the desired indoor air quality in the ventilated classroom ; We selected category =***20%*** perceived air quality dissatisfied **;**perceived outdoor air quality **=** ***700*** (Table1, 5 TAIVC).

Required Ventilation for the classroom:

3.2.8.1.. Ventilation for comfort: The required ventilation from a comfort point of view was calculated as follow:

$$\boldsymbol{Qc} = 10 \times \frac{G}{Ci-Co} \times \frac{1}{Ev} \;\dots\; \dots \text{(The equation of healthy ventilation)}(1)$$ Where:

Qc**:** ventilation rate required for comfort (l/s);***G:*** sensory pollution load (019;***Ci:*** perceived indoor air quality, desired (decipol);***Co***: perceived outdoor air quality at air intake (decipol) ***Ev***: ventilation effectiveness.

Since the school is situated in a town with poor air quality C_O **= *0,5*** decipol and the level of outdoor air pollutants are of health concern adjacent to two roads.In such circumstances smoking, indoor combustion or any other source of air pollutants should be avoided(In such cases it may be necessary to clean the air before it is suitable for ventilation.)

An indoor air quality of category ***B*** is desired, that's mean ***20%*** dissatisfied or ***Ci =1.4*** decipol which correspond approximately 7 cfm.olf Classrooms and conference rooms ***15 cfm*** per occupant" (Table1 TAIVC)"

Sensory pollution load ; No smoking , ***=1.3olf***/occupant (Table:3 TAIVC) and the occupancy is ***1.36*** occupants /(m2floor) ***0.5*** from the (Table 4 TAIVC)

Standards materials were used in the classroom ***0.1 olf***/(m2 floor)(Table:2 TAIVC)

Displacement ventilation is applied with and estimated ventilation effectiveness is ***Ev***= $\boldsymbol{Ev} = \frac{\boldsymbol{Ce}}{\boldsymbol{Ci}}$ = ***1.3*** (Table:6 TAIVC)

Ideal situation 24 students - teacher occupancy in space equal **0.5** occupant /m2 floor......(I)
Occupants sensory load (1.3) .(0.5) = ***0.65*** olf/(m2 floor) .....(1)
Classroom building sensory load (***0.1***)....(2)
Total sensory pollution load equals ***G***= (1)+(2)= 0.65+0.1= 0.75 olf/(m2 floor) **G=0.75**

Current situation 37 students occupancy in space equal **0.73** occupant /m2 floor...(C)
Occupants sensory load (1.3) .(0.73) = ***0.95*** olf/(m2 floor)...(1)
Classroom building sensory load (***0.1***)....(2)
Total sensory pollution load equals ***G***= (1)+(2)= 0.95+0.1= 1.05 olf/(m2 floor) **G=1.05**

Required ventilation rate for Comfort :
In case of Displacement ventilation distribution **Ev** = 1.3 ------... Case ***C3B***
With 25 occupants(standards $2m^2$ to students)
$Q_c = 10 \times \frac{0.75}{1.4-0.5} \times \frac{1}{1.3}$ = ***6.4*** l/s (m^2 floor)
With the current situation 37 occupants ($1.36m^2$ to students)
$Q_c = 10 \times \frac{1.05}{1.4-0.5} \times \frac{1}{1.3}$ = ***8.9*** l/s (m^2 floor) ....(sD)
In case of Mixing Ventilation distribution Ev = 1 -----.-Case ***C2B***
Q_c = ***8.3*** l/s (m^2 floor) ... (25 occupants)
Q_c = ***11.6*** l/s (m^2 floor) ... (37occupants) ....(sM)

Note. $Ev = \frac{Ce}{Ci}$ Ventilation effectiveness **(Ev)** defined as the relation between the pollution concentration in the exhaust air **(Ce)** and in the breathing zone **(Ci).** The ventilation effectiveness depends on the air distribution and the location of the pollution sources in the space. It may, therefore, have different values for different pollutants. If there is complete mixing of air and pollutants, the ventilation effectiveness is one. If the air quality in the breathing zone is better than in the exhaust, the ventilation effectiveness is higher than one, and the desired air quality in the breathing zone can be achieved with a lower ventilation rate. If the air quality in the breathing zone is poorer than in the exhaust air, the ventilation effectiveness is lower than one and more ventilation is required. Thus inlet and outlet opening have effects on Ev, which is also affect ACh/h and occupant comfort.

3.2.8.2. Ventilation for Health: The required ventilation from a health point of view was calculated as follow:

$$Q_h = \frac{G}{Ci-Co} \times \frac{1}{Ev} \quad ....(\text{The equation of healthy ventilation})(2) \text{ Where:}$$

Qh**:** ventilation rate required for health (l/s);***G:***pollution load of chemical; ***Ci:*** allowable concentration of chemical (µg/l);***Co***: outdoor concentration of chemical at air intake (µg/l)
Ev: ventilation effectiveness ;***Ci*** and ***Co***, may also be expressed as ppm (vol/vol). In this case the chemical pollution load; **G** has to be expressed as l/s
Form a health perspective formaldehyde form chipboard used in the classroom is of health concern. the area of chipored is (19 table(2.4x19)+closet ... = 60 ≈$2m^2$/(m^2 floor). The chipboard with an initial emission 60 µg/h. m2. curtains =0+wallpapers 20ug/h.m^2=0

The chemical pollution is thus (2).(60)/3600= 0.033 µg/s.(m2 floor). WHO's exposure limits are for the general population ***Ci=100*** µg/m^3 (30min) and for especially sensitive groups ***Ci=10*** µg/h. m2(36). ***Co*** and other outdoor air pollutants were not considered, so ***Co=0***. and ***Ev =1.3*** .

Required ventilation rate for Health :
In case of Displacement ventilation distribution **Ev** = 1.3 ------ Case ***C3B***
With 25 occupants(13 table...G=0.016)

$$Q_h = \frac{0.016X1000}{100} \times \frac{1}{1.3}$$ = ***0.12*** l/s (m^2 floor) .....General Population

$$Q_h = \frac{0.016X1000}{10} \times \frac{1}{1.3}$$ = ***1.23*** l/s (m^2 floor) ...... Sensitive groups

With the current situation 37 occupants (19 table....G=0.033.)

$$Q_h = \frac{0.033X1000}{100} \times \frac{1}{1.3}$$ = ***0.25*** l/s (m^2 floor) .....General Population.....(s1)

$$Q_h = \frac{0.033X1000}{10} \times \frac{1}{1.3}$$ = ***2.53*** l/s (m^2 floor) ...... Sensitive groups ......(s2)

The ventilation rate required for comfort:
In case of Displacement ventilation distribution

Q_c = ***8.9*** l/s (m^2 floor) ....(sD) was selected for design or retrofit since this is higher than the ventilation rate required for health (S1) even for sensitive groups (S2).

.In case of Mixing Ventilation distribution

Q_c = ***11.6*** l/s (m^2 floor) ....(sM) was selected for design or retrofit since this is higher than the ventilation rate required for health (S1) even for sensitive groups (S2).
Air flow, **q** or **Q** , and Air exchange rates, **ACH,** are closely related. The required air exchange rate during the typical summer week is **6 ACH.**
Q = Ach x **V** where **Ach =** air change rate **and v=** room volume
Volumetric flow rate

Q **= v.A** (V: flow velocity v, A: cross-sectional vector area)
The volume house is **1559 m3** so Required ***flow rate*** **q** =**Q**= 6 x 1559 m3≈2.1 m3/s

3.2.9 Results and discussion

1.According to teachers account and school children, more than 90% the windows on southern wall are closed all year around due to noise and air pollution from the adjacent road plus the glazing and ray sun even the school was designed to perform natural cross-ventilation.
2. The most critical parameter in tested schools was temperature. The results of measurements show that the average temperature in 64 % of tested classrooms was not within the optimal zone or comfort range.
3. Most Inadequate natural ventilation in tested classrooms resulted in high CO2 concentrations; Teachers always gave priority for thermal conditions instead of air quality. eg. especially in winter in the coolest season January all windows plus the door were shut to keep the heat in , the teacher prefer the thermal conditions than the good air quality.

3. SBS symptoms such as dry skin and tiredness, which some students complained about may have been caused by poor air quality and unventilated classrooms or other IAQ factors. load noise and even poor light was mentioned as one of the most frequent complaints identified by students.
4. Both measurement results and CFD predictions indicate limitations of natural ventilation in classrooms when outside temperature is below 4 °C. Cold air supplied through window mounted air inlets will cause a draught for children sitting close to the window.
5. The best ventilation strategy according to predicted ADI value was considered displacement ventilation, but further predictions and field measurements are needed to satisfy thermal comfort conditions by keeping PPD value below 10%.
6. Numerical simulations indicates that mixing ventilation fits thermal comfort requirements best. though contaminants are removed best if the displacement ventilation is used in the classrooms. 8.Implant evergreen trees in the north faced for fresh air /micro-climate and block noise coming from the courtyard. plus to manage the prevailing wind to enter into the vent bellow the window, plus they can benefit the panoramic view or biophilia advantage for health and well-being.
9.Shrubs beside supply fresh air and they can manage the vent velocity and direction.
10.Since the prevailing wind is comes from west (parallel to windows positions) using wings can detour the air flow into natural driven cross-ventilation.
11.Implant deciduous trees in the south facade to absorb the air pollution from the road, block noise and to let daylight penetrate into the classroom.
12.Double skin facade is a potential for take advantage of the sun in the full-south to generate energy either by solar planets or algae technology.
13.Benefit from aluminum facade to induce stack ventilation or use dark colors to paint the double-skin facade.

3.2.10.Recommendation:

<u>1 Short-term interventions and recommendations</u>

- Opening windows and ventilating spaces naturally it should be at the heart of efforts to prevent sick building syndrome or the spread of COVID-19 for instance..
- I recommend horizontal center-pivoted windows in one-sided ventilation classroom.
- With horizontal lovers vents to block direct sun rays on the southern windows and provide best privacy.
- Sometimes the problem due to the behaviors or management of windows not to the building design, Actually the type of windows installed in the classroom are efficient if teachers have some knowledge of air flow and indoor air quality. so read!!!
- Ceiling fan a good alternative and efficient tool to improve indoor air quality when all strategies failed. plus doesn't consume energy just like light boulbe 50 to 80 w. and we can operate it from clean energy solar panel installed on the roof facing southern facade.
- Architect must take advantage of natural ventilation combined with the effects of bouncy of air motion plus force convection to get the building naturally air

ventilated, take advantage of all aspect of the building even the color of ex walls,because it all connected in some way or another to affect the quality of IAQ.

- Using helpful devices such Co2 monitor to track the air quality index. is recommend in such buildings,(education) which required focus and concentration especially children.

2. Long-term interventions and recommendations

1- Some of the Disadvantages/challenges to use natural convection:

-Restriction on building's external condition (noise, pollution level, privacy.)

-lower control of internal environment.

2-Advantages of using natural convection:

-No cost or low costs of moving air through building.

-Reduction of building's total energy use.

-Increased comfort lower noise due to lack of fans and mechanical machine.

- In the same time we need to take into consideration multiple elements that may hinder the use of natural ventilation, some of them are like restrictions of buildings external conditions like in a middle of a busy street (pollution source) so it’s a good thing to keep ventilating the whole thing with open windows, or there a lot of noise going on, for example close to an busy street even if the air quality is very good. at the same time another thing that we may end up with is that you might have a little lower control of the environment inside the building, for example if we end up in an extremely hot day and we want to use only the natural ventilation techniques to cool the air inside of the building it might be a big challenge so having Hybrid or mechanical ventilation support might also be in.
- Hybrid ventilation ,a Ceiling fans are considered a better way to improve IAQ.
- Considering helping devices to better control the air quality; The Internet Of Things, BMS, monitors, sensors .

3.2.11. Conclusion

Computer simulations were used to analyze the ventilation rate and flow, indoor operative temperature, relative humidity, and CO2 concentration in the base Case(BC) classroom and after the implementation of the proposed retrofitting techniques. Simulation results were compared with those obtained in the base case to determine the most efficient natural ventilation retrofitting technique. The best results were obtained by using a solar chimney to assist a natural ventilation, which resulted in an increase in the comfort hours during the occupation time, an improvement in the average monthly ventilation rate range, a decrease in the CO2 concentration, and an improvement in the relative humidity ratio.

For spaces with high occupancy rates, use carbon dioxide (CO2) as a proxy for ventilation effectiveness. Carbon dioxide levels are easy to check with a low-cost, auto-read instrument. Ideally, keep CO2 levels at or below 800 ppm during occupied hours especially in pandemic. According to the research, the increase in ventilation was responsible for 97% of the decrease in transmission. Since the corona virus is spread through the air, higher CO2 levels in a room likely mean there is a higher chance of transmission if an infected person is inside. Based on the study above, I recommend trying

to keep the CO_2 levels below 600 ppm. A CO_2 meters is always good way to make sure the air is clean.
When considering ventilation system strategy, it is therefore increasingly important to consider air behavior. From the our case of study it can be concluded that ‘displacement ventilation with a satisfied-sized natural inlet or assisted is preferred as it can move stale, contaminated air directly and co2 to the exhausts of the classroom, The Displacement ventilation, which encourages vertical stratification remove the polluted warm air near the ceiling, seems to be the most effective at reducing the exposure risk while Mixing ventilation distributes the air throughout the space and does not provide any potentially clean zones.
I hope that while looking at retrofitting of our existing school building stock the design of efficient ventilation system "Occupant health" should be high on the agenda. Displacement ventilation through natural means offers several critical benefits for schools including better virus mitigation in the short term, and lower operating costs in the long term if it properly designed.

3.2.12.Case Study Part TWO (Energy efficiency, comfort and performance)

Overview and presentation "Block of Architectural studies *University of Blida 1*"

The University of Blida 01 is a university located in Blida, Algeria. Founded in 1981 and named after Saad Dahlab an Algerian nationalist and politician. It is comprised several schools and institutes. Fig.115

Fig.115. Aerial photograph of school site and university Campus/Ave

Fig.116.Blida university campus; view shows part of its academic buildings.

In this research, the computer simulation results of the IAQ and natural ventilation technique for a typical Architecture classroom located at Blida University are presented. The department was built in 2006 and located at (36°30 N and(2°52E); altitude.203m.

Fig.117. View toward south of academic block of Architectural and Urbanism studies.

The climate/micro-climate of the campus is hot arid, which means that it is dry-hot in the summer and wet-cold in the winter. Buildings in such climates can benefit from natural ventilation through passive strategies such as the stack effect, to draw air through evaporative cooling systems or by wind pressure at night to enhance cooling of the building during the night (Badran, 2003). The construction system used in the University's buildings in general is brick and concrete system, which can be used for nocturnal convective cooling. However, opening the classroom windows is not sufficient to bring the classroom comfort environment to the comfort zone during the operation hours especially in harsh weather, outdoor noise or/and overcrowded hours; Fig118.a set of pictures show the building fabric and its fenestration, where a typical classroom is shown in Fig.119, Fig121.

Fig.118.Set of pictures were took during the field study "University of Blida 01-D.A.U.

Besides, to the low comfort hours, and due to noise issues coming from the adjacent courtyards and corridor the classrooms’ occupants tend to close the windows and thus impede the cross-ventilation process through the two doors OR one-sides ventilation through north windows, and for other many reasons Fig.120. The solution to install split-unit air conditioning systems to adjust the thermal environment of the classrooms to be within the comfort zone is impossible although can solve the problem of noise, but .one of the major obstacle is its initial price, maintenance and operation such a system may increase the total energy demand yet did not allow the control of other IAQ variables such as odors and CO2 levels and may also aggravate the situation in case of presence of contagious airborne viruses as flue or Covid 19.

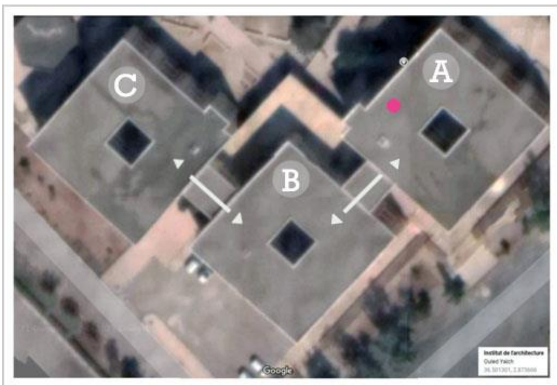

Fig.119. Aerial photograph of the Academic building of Architecture and Urbanism shows the 3 connected building blokes with 3m width corridors and a location of a class A100.

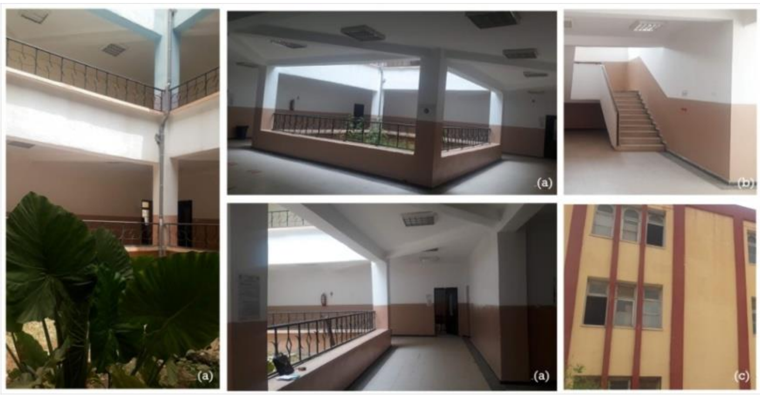

Fig.120.. (a) (b) show the Interior views of one of the blocks hall/atria (A)

Fig.121. Typical North facing classroom (Ex-classroom A100.)

The characteristics of the simulated selected classroom that was used in this study are the following: the typical simulated classroom is located on the ground level with single-

loaded corridors, which open on skyline atria (abounded courtyard). The selected classroom is located in block (A) and all its external windows oriented toward the north.
The classroom dimensions were 12.65/ 6.30 /3.15 m (L/W/H), with a volume of 251 m3, with no false ceiling cavity and no vents on the corridor side as shown in Fig_122. and had two doors at the southern wall of the classroom to improve the air movement inside the classroom(cross ventilation). The dimensions and locations are illustrated in Fig 122
The single-loaded corridor had a width of 2.74 m at the southern side of the classroom. The external windows of the classroom were facing north, 0.70 m wide and 1.60 m high, with a total window-to wall ratio of 21.7%. 100% of the total windows' area was operable yet few of them are not operate properly either they are broken or difficult to reach. The thermal transmittance (U values) of the classroom envelope are as shown in Table 14,

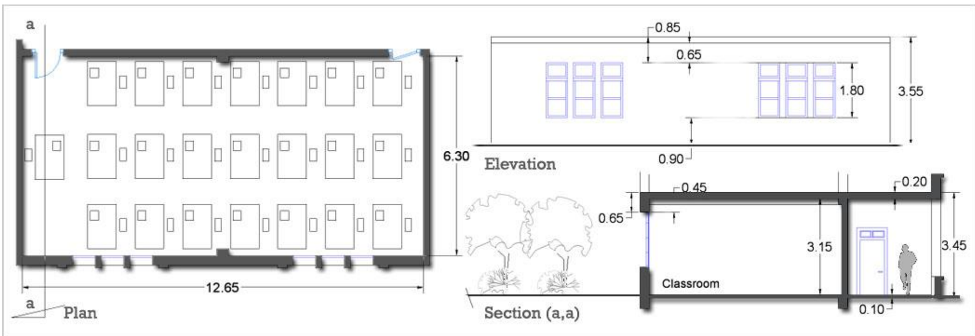

Fig.122. Plan elevation and cross-section of a typical classroom (A101)showing the location, dimension, types and form of fenestration openings.

The typical capacity of the classroom workshop is 26 occupants with an occupant density of 0.18 (5.5 m2/occupant)The department operation schedule is presented in Table 15. The buildings occupancy period is five days from Sunday to Thursday (9:00 AM–5:00 PM). Plans; Elevations for the base Case (BC) study were elevated from the site in Juan 2020.

3.2.14. Material and methods

a. *Proposed passive ventilation retrofitting techniques*

To select the best natural ventilation retrofitting techniques to improve the IAQ in our case study. An inclusive passive design approach (Three tier approach to passive design methotodology) in addition to seven-steps guidance were followed. The seven-steps could be adapted to evaluate other passive strategies of retrofitting any sick-building.
To select the adequate and efficient natural ventilation retrofitting strategies. Different natural ventilations strategies were considered and evaluated. Below Some facture were took into consideration in the process to select the best strategy. is explained in Fig 6.

- Form and orientation of the building, fabric (envelop) materials; Window configuration placement on the walls and their designs(form and types);
- Air quality and thermal comfort; The equipment that emit heat like persons and electronic devices; Natural lighting;
- Minimum change on the architectural or initial layout of the buildings building man activity "education ",also Aesthetic aspect should be took into consideration
- Budget and economical status of the school panel; Maintenance and feasibility of the new system; Energy consumption (utility bills)

- Time and ratio of occupancy and common behaviors of occupants.
- Effectiveness of wind ventilation depending on window configuration
- The outdoor climate and microclimate; presence of water bodies and green surfaces. courtyards; Earth thermal temperature;
- Take into consideration of bad smell, like landfill or even spaces such as restaurant, wc; also, the direction of wind the prevailing one or a strong corridor.
- Eliminate outside noise class in the university and deal only of ventilation, to fully use the benefit of open windows.
- Using hybrid/mixed ventilation system or mechanical and controlled system as a last resort when presence of health concern and the occupant health in danger.

Step 1: Presenting the Base case *BC* , the climatic and micro-climate data, the building envelope, skin and form; the users and their occupancy schedule, and thermal evaluation of the indoor air temperature..

Step 2: Using computer simulation software and validate the results of the simulation and the weather data used by the software, and the results of bioclimatic and climatic analysis.

Step 3: Based on the outcome of climatic analysis and data from step (1)Selecting the appropriate natural ventilation retrofitting techniques.

Step 4: Evaluating the other IAQ variables related to the incorporation of the selected strategy chosen in step 3.

Step 5: Weigh the outcome of step 4 against relevant and international standards.

Step 6: Determining the most adequate natural retrofitting strategy considering any limitations preventing the feasibility of the proposed systems IEQ, e.g., noise, privacy, ...

Step 7: Estimating an energy evaluation and Performing an economic evaluation for the selected strategy to determine the budget of the investment.(Sustainable design) besides, estimating the building Co2 foot print on the environment(Green building. zero co2).

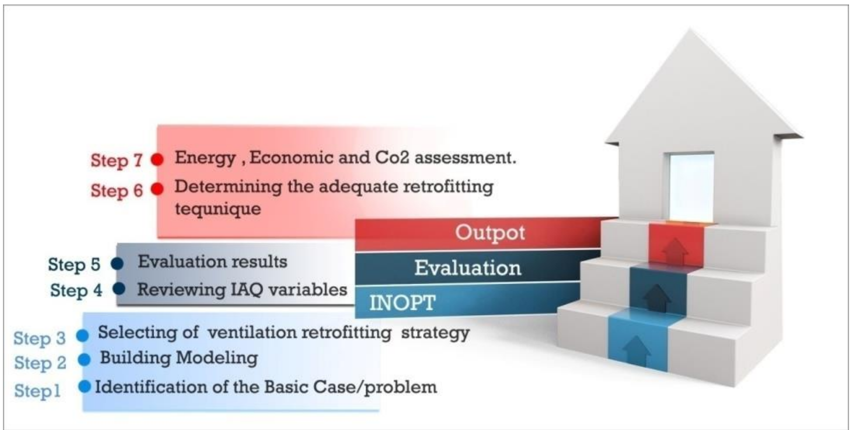

Fig.123.The Seven-Steps guidance for selecting an ideal natural ventilation retrofitting strategy.

3.2.15.The Numerical Models

IES-VE and ANSYS are the main two software used in the modeling and simulation of the indoor environment of our model BC (thermal condition and the airflow).

ANSYS was used to investigate the behavior and movement of airflow in indoor settings. whereas , IESVE was used to investigate the proposed natural ventilation retrofitting techniques that analyzes and the performs of different building strategies and allows their optimization considering comfort and energy; there simulation packages were used to perfume the simulation ; (1)*Revit* and *ModelIT* for modeling the Base Case block and proposed modifications, (2)*Apache thermal* calculation and simulation, and *Macro flow* for natural ventilation and air movement analysis.

Validating the weather data file

Climatic and bioclimatic results analysis were used to determine outdoor climate of our case study temperature , wind speed, and direction...etc

Wind direction is variable (Fig126). The winds come most often from the north-east (25% of the time), south-west (50of the time), and north (15% of the time). Minor winds often come from the west (8% of the time) and northwest (2% of the time).

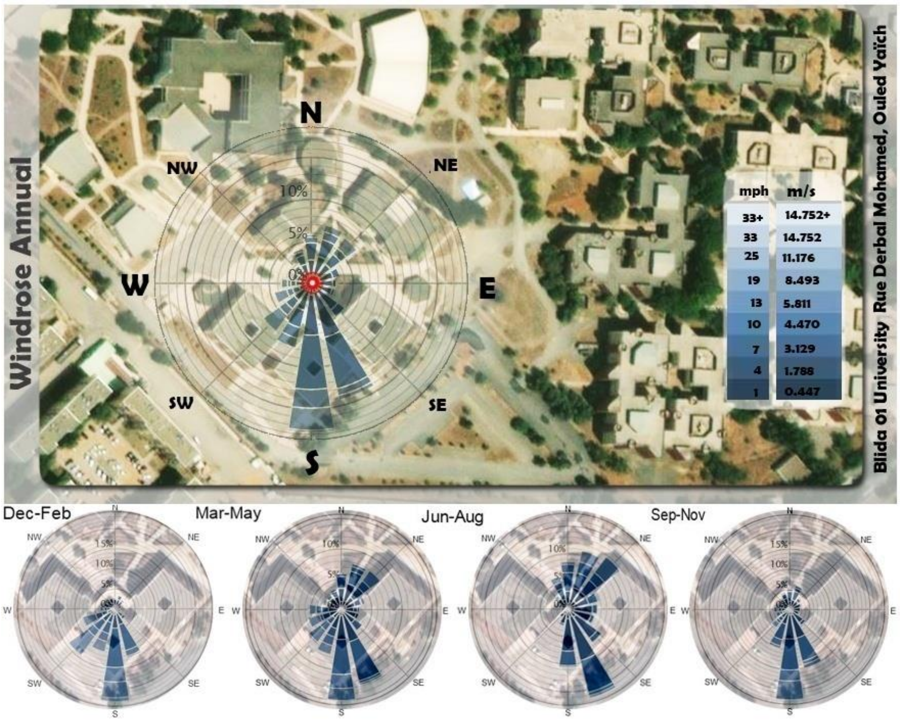

Fig.126. Wind rose (*weather* app.formit. autodesk tool)of Institue of Architectue.Blida

Building Element	Material	U-value (w/m2-k)
External walls	Brick thickness 0.3m Ciment	1/0.66
Internal walls	Brick thickness 0.2m Ciment	2
Ceiling	---	0.13
Window	Single windows glazed	6.3

Table.14. Material's and U-value of a typical classroom fabric.

In accordance with the WHO, organization's guidelines the air quality in Algeria is considered unsafe. The most recent data indicates the country's annual mean concentration of PM 2.5 is 39 µg/m3 which exceeds the recommended maximum of 10 µg/m3; for example AQ index is 50-150 (PM2.5 is 15-60 µg/m3) near the US embassy in Algiers.

Especially in big cities which is considered unsafe where the levels PM 2.5ranged between 68-80 µg/m3. (38/106 countries ranked in 2020).
Air Quality Index (AQI) of Blida is classified as Good to Moderate 0-50-100 . where MP2.5 range 25.8-24 µg/m3 , (AQI-Unhealthy 100-150 unhealthy for sensitive groups) Pollution can increase during the autumn and winter (October to January) due to the use of poor quality fuels, the low pressure weather condition and on work days especially Sunday In addition of to the emission from the industrial district that not far from the campus university, especially with the presence western wind the PM2.5 level can exceed 60 µg/m3 due. This classification and data are based on the air quality personal monitor, "AirVisual" network air quality, WHO historic data and U.S EPAAQI Standards.

College of architecture	Academic Period	Nº of students	Occupancy
1est semester	Mid September-Mid January	≤1100	100%
2end semester	Early February-Late Juan	≤110.	100%
3ed semester	Late Julay and Eraly September	≤600	60%

Table.15.College of architecture' Schedule

Base Case simulation model

The simulation was set to perform annual energy, thermal, and natural ventilation. The simulation software produces energy and comfort analysis for the building during the occupancy months. In addition, during this time, the software considers the loss of efficiency that occurs overnight or the overheating during some days. The results presented in this simulation were selected to illustrate the effectiveness of the proposed systems during the selected months of cooling and heating seasons.
The simulation results showed the iT's, VR, and RH of the indoor space CO_2 concentration, during the occupancy hours . Two months were selected for simulation during the summer season (July) and the winter season (January).

Month	Average Monthly outside DB temperature, Blida(2020)											
	Jan	Feb	Mar	Apr	May	Jun	**Jul**	Aug	Sep	Oct	Nov	Dec
DryBulb *Average*	**7.5**	**8.0**	**12.5**	**16.4**	**20.1**	**22.8**	**26.2**	**24.6**	**21.9**	**20.3**	**12.3**	**10.2**

Table.16 Dry Bulb temp mean average degrees Cº(2020)

Based on my research field measurements and my frequent visit to the university as a student in many times in a week and in different seasons, I can confirm that the indoor air temperature and RH measurement values are within the range of results obtained from the simulation program with an average error of 3–6% during the whole week. yet CO2 concentration is difficult to validate without a co2 monitor. However on the whole there were an agreement between the results According to the adaptive model indicated in Figure 127, and based on the weather data of the Case study, the acceptable iTs ranges for the selected months; January and July are as summarized in Table 17.

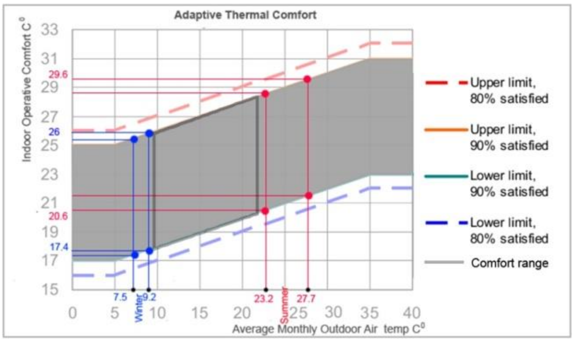

Fig.127.Ranges of adaptive comfort, in Blida region, according to the average monthly outdoor temperature (Sourece: ASHRAE Standard 55: 2004.adapted by the author.)

Month	Mean monthly outdoor air temperature	Comfort range for indoor operative temperature (fig..)
January	6.3-8.2	18.5-23.5C°
July	27.1-30.6	24-28C°

Table.17. Range of acceptable indoor air temperature according to ASHARE adaptive model

*3.2.15.1***.** *Proposed passive ventilation retrofitting techniques:* Based on the micro-climate analysis, the fabric, the form and the location of the model Three natural ventilations retrofitting strategies were considered to improve the ***IAQ*** thus the ***IEQ***. As a remark, displacement airflow was selected as the common airflow distribution used in all proposed strategies. One or two retrofitting strategies were ruled out or neglected (double-skin wall, ventilated roof, ...etc) beforehand, either the strategy is inconsistent or irrelevant with the form or the fabric of the case study which would affect greatly the initial layouts of the project.

1.RP Case 1 "A combo wind-tower with central glazed-atria "

Two Wind tower were implemented on the west-northern side of the classroom against to the external wall between each three set of casement windows of the classroom. The wind tower had two main vents, one on the top facing "West and West-North " the prevailing wind and the other vent at the foot of the wind catcher towards the classroom interior. The proposed architectural model had a height of 5 m from the top of the last floor (15) with cross-section of *0.60 X 0.60m.* Two other wall exhaust vent (opening)were added on the opposite top part of the wall, they were opened on corridor and the existing patio. The model was illustrated and detailed in 3D model

2.RP Case 2 ” A combo of Solar-chimney and courtyard micro-climate "

Two solar chimneys were mounted on the roof of the classroom building facing south; the tower descend to the bottom of the classroom, and other two small vent were added to the other opposite wall in the bottom part; the two small vents were connected with fresh air from the evergreen existing courtyard by underground PVC tubes ducts. The purpose of the solar chimneys were to induce hot air from the classroom and let in more cool air through underground tubes, from lavish biophilic micro-climate courtyard which supposed to supply cool and fresh air (self-shading most of the day and protected from hostile weather , further comfort from transpiration from plants). The model was illustrated in Fig.123; Fig.124

3.RP Case 3" The combo Central Atria/light-well and the Canadian-well"

A Canadian well or an underground ventilation system was installed ,the airflow passing below ground through a tube (20cm d) , about two meter deep. The tube were driven to the classroom interior through two outlet opening protected with a net to prevent entry of insects, and shutters with movable blades to control the air intake .The capture of air were installed in the main courtyard (outdoor fresh air) about 26m distance from the classroom. Two other wall exhaust vents were added to the wall facing the patio. Since atria offers good potential for stack ventilation, an introduction of glazed atria were added to the excising patio of the building to induce and drive the build-up of stale air exhausted from classrooms through the interior opening. Fig.123; Fig.124

3.2.16. Energy and Economic assessment

Due to the significant of energy consumption and the initial budget of a conventional mechanic ventilation systems and its burden on economy as a whole. Integrating a low-energy or passive ventilation system have been always a point of interest by many architects , owners and decision making.. Thus , we analyzed the quantitative data of the economic life cycle assessment of integrating the proposed system. We performed an economic life cost assessment (*LCA*) using the method described in (Randolph and Masters, 2018).

3.2.16.1.. Simple payback period (SPP) ***SPP*** equation :

$$SPP = IC/(AES * Pr) \qquad (1)$$

Using this method to calculate the number of years it will take for the initial cost of a system to be recouped based on energy saving;

IC is the initial capital cost in Algeria Dinar (AD), ***AES*** is the annual energy savings (kWh/yr), and Pr is the energy price (AD/kWh).

3.2.16.2.. Net present value over life cycle: There are many limitations when using ***SPP*** over a long time period and high discount rates, as it ignores the time value of the money and the operation and maintenance cost. However, despite these limitations, it is still a useful economic measure for cost effectiveness. To address the limitations, dynamic methods such as net present value (***NPV***) are preferred for calculating the economic life cycle cost as the present value life cycle assessment is used. ***NPV*** is a standard method to calculates the total money savings of the energy investment in present-day money.

A ***positive NPV*** value indicates a *good investment* and an appropriate choice for the retrofitting option (Eq. 2).

$$NPV = PVS - IC \qquad (2)$$

PVS: is the present value savings (Eq. 3):

$$PVS = (AES * \Pr - O\&M) * UPVF \qquad (3)$$

in which: ***O&M*** is the annual operation and maintenance cost (AD) and

UPVF: is the uniform present value factor (Eq. 4):

$$UPVF = (((1+d)\hat{n} - 1)) / (d \ [\![(1+d)]\!] \ \hat{n}) \qquad (4)$$

d: is the discount rate.

3.2.16.3. Benefit-cost ratio

The benefit-cost ratio ***(B/C)*** compares the annualized money savings and the annualized cost of the system to provide a ratio of benefits to cost (Eq. 5). A larger ratio indicates a more cost-effective investment.

$$B / C = PVS/IC \qquad (5)$$

3.2.17.Results and discussion

- *Indoor air temperature (iT)* *February and July*

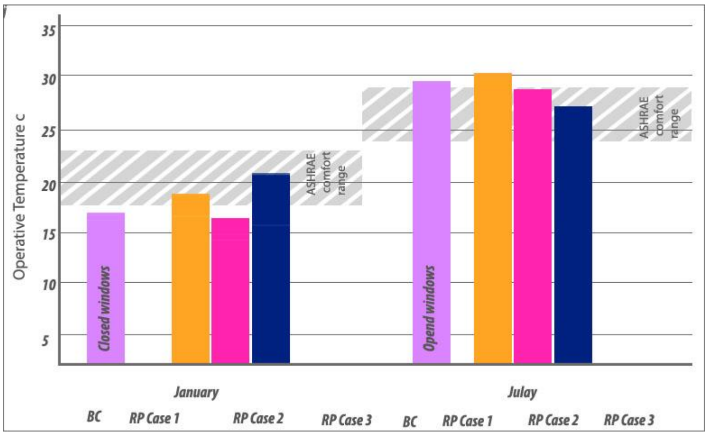

Fig.128. Different strategies comparison(IT)

The comparison of Base Case ,No.1to Case No.2, and Case No.3 indicated that opening the windows did not have a significant effecton increasing the number of comfort hours during the occupation time. Opening the windows reduced the iTs outside the occupation hours, making the night cooling ventilation more effective. It was found that:

- In January, the heating season, the percentage of comfort hours in the B.C are limited: 20% of the total occupation hours when the windows are closed and 30% when the windows are open. In addition, during the cooling season, July, the percentage of the comfort hours in the B.C is 10%and 15% from the total occupation hours, when the windows are closed and when the windows are open, respectively.
- Cooling and heating strategies system is necessary to keep comfortable indoor environment and increase the number of comfort hours to make the classroom more thermally comfortable.
- In the heating season, the introduction of low DB temperature air to the space would help to increase the number of comfort hours. However, increasing the amount of added air would decrease the iTs below the comfort range, thus reducing the number of comfort hours.
- In the cooling season, the number of comfort hours will be increased when more low DB outdoor air is added to the space. However, as the outdoor air becomes colder during the night, outside of the occupation hours, the comfort hours would not be significantly increased during the occupation hours. However, this may help in nocturnal convection cooling if the building is designed and constructed for this strategy.

The simulation results of the proposed passive techniques could significantly increase the number of comfort hours. The implementation of these suggested techniques would help to reduce the number of operation hours of the HVAC system, thus saving energy and reducing the running cost; Natural ventilation systems and strategies could increase the number of comfort hours in hot arid areas.

Because opening the windows creates a noise issue, Case No.1and Case No.3are feasible to be implemented in this case .Case No.1would result in a dramatic increase in the percentage of comfort hours in January; from 16% to 57%. However, the improvement of the percentage of comfort hours during August would only increase from 3 to 19%.Case No.3would result in a significant improvement in the percentage of the comfort hours during February and August; 16%– 54%, and 3%–58%, respectively. Case No.3 is the recommended strategy that should be implemented.

- Relative humidity (RH): The annual RH for the B.C and after simulating the suggested retrofitting modifications are presented in below Fig.129 In all cases, the RH was mostly on the recommended limits determined by ASHRAE standard 30; 70%).

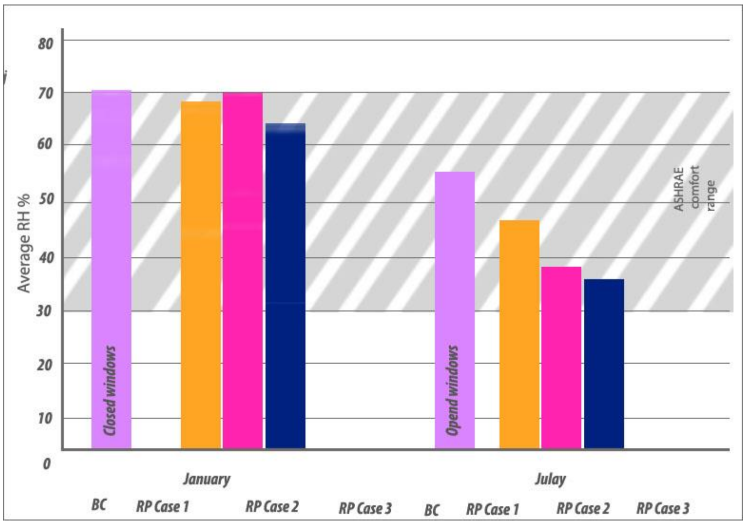

Fig.129 Different strategies comparison (RH)

Ventilation rate: The annual comparison of the monthly average VR in the B.C and after simulation of the suggested retrofitting modifications is shown in Fig124. According to the figure, the average VR was not sufficient in the B.C and in Case No.1in all months, as it was below ASHRAE standard_62–2019; 4.3 L/S/P. In other cases, the average monthly VR would in-crease in all months. The wind tower will harness and circulate the air through space, thus the amount of air entering the space will increase. Also, when the solar chimneys extract the air from the interior it would allow more air to enter the space through the wind tower. Increasing the area of the operable windows would increase the amount of air entering the space. Increasing the VR inside the space needs further investigation with detailed computational fluid dynamics (CFD) analysis to study the introduced air inside the space in terms of time, air behavior inside the space, and air velocity. According to ASHRAE 55–2017, in spaces where occupants are without control over the local air speed, the average air speed should stay with the following limits:

a. Operative temperatures above 25.5

C; the upper limit of the average air speed should not exceed 0.8 m/s.
b. Operative temperatures between 23.0 and 25.5C; the upper limit of the average air speed should follow this equation:
Va¼50.49–4.4047 (to)þ0.096425 (to) 2 (m/s,C) …….(6)
in which Va: average air speed, to: Operative temperature c. Operative temperatures below23.0 C; the limit of the average air speed should not exceed 0.2 m/s.
It was found that: The monthly average of VR in B.C was between 2–3.5 L/s per person, which is below the recommended rate of ASHRAE standard 62.1–2019.
The wind tower had a positive effect by increase the air change in the classroom, because it increased the amount of air passing through it. And when solar chimneys were used to assist the wind tower, the wind tower became more efficient and increased the VR as the solar chimneys helped extract hot air from the space and worked as an exhaust shaft.
Other parameters related to VR such as air speed, air behavior inside the space, and corresponding time are needed to get a full picture of the introduced air and the compatibility of the strategies with other comfort standards. Fig 124

- <u>CO2concentration:</u>The annual CO2concentration for the B.C and after simulating the suggested retrofitting modifications are presented below Fig124.

In all cases, the CO_2 concentration was below the maximum limit determined by ASHRAE standard 62, as the monthly average outdoor CO2concentration obtained from the local authority was in the range between 350-450 ppm. Also, the monthly CO_2 concentration was below the set point recommended by REHVA (1500 ppm) and CIBSE (1000 ppm). Increasing the VR and having more fresh air helped to decrease the maximum CO_2 concentration (658 ppm in the B.C) by approximately 195 ppm, 201 ppm, 201 ppm, and 202 ppm in Case No. 1, 2, 3, and 4, respectively.
It was found that:The values of the CO2concentrationwerewithin the acceptable range of ASHRAE standard 62–2019, REHVA, and CIBSE Application Manual AM10 for all cases.

3.2.18.Conclusions

The potential for the application of this approach to this building operation still needs further investigation. Additionally, its application requires that internal heat gain and CO_2 emissions, which depend on human population density, as well as the room usage schedule, should be considered. As a main principal of our retrofitting strategy methodology , all proposed retrofitting techniques were designed by taking into consideration the existing construction, architectural design, and other layout with minimal impact and disruption of the building envelope and aesthetic aspect.
The different passive ventilation retrofitting systems to improve the IAQ of existing classrooms were evaluated through simulation scenarios. A classroom on ground floor in the institute of architecture was used as a model to evaluate the effectiveness of passive ventilated techniques through computer simulations, where three cases were proposed and evaluated using computer simulations. The simulations results were used to assess the performance of each Case.
The IAQ performance was evaluated in terms of a number of factors iTs, VR, and CO_2 levels. The passive ventilation retrofitting techniques were evaluated over a year during

the usual occupied hours (9.00 AM- 5.00 PM), taking the month of January as an example of cool season and the month of August as the hottest season. The months were selected to coincide with the Blida university annual academic year.
The all three strategies solutions were better than those obtained in the base case. However the best or most efficient natural ventilation retrofitting technique a 2 ” A combo of Solar-chimney and courtyard micro-climate " were obtained by using solar chimney to assist a wind tower, because wind has weak speed and unpredictable driven force. However, the buildings have many advantages such the central lightwell and the garden which can be a source of fresh air to the whole block if it planted with the right plants (see annex). besides can become a good biofhila element especially when all interior wall classrooms equipped with fix and acoustic big glazes.

3.2.19 Synthesis

The IAQ in classrooms has a significant impact on the health and academic achievement of students. However, improving the IAQ of existing classrooms is challenging if minimum architectural modifications are allowed and absence of codes and standards make it a challenging work . Therefore, architects need to be better go through a thorough climate and bioclimatic analysis and be better equipped during the early design phases with both knowledge and design tools to predict dynamic performances of air movement to achieve good indoor air quality, high-performance and net zero energy buildings. Different natural ventilation retrofitting techniques were proposed to improve the IAQ in existing classrooms at Ain defla and Blida , which is located in different microclimates and contexts. Computer simulations were used to analyze the ventilation rate, indoor operative temperature, relative humidity, and CO_2 concentration in the base Case classrooms and after the implementation of the proposed passive retrofitting ventilation techniques, an improvement in indoor air quality has been witnessed.
And while natural ventilation is preferable, our assessment to both cases have shown that school users often don't open windows as needed to provide adequate ventilation for several reasons. This may also be an issue in a built-up area where opening a window results in noise and air pollution (Urban site) first case of study or noise as the second case study. However, The simplest and most cost-effective retrofit strategy is often to install operable windows or change a window type (first case) and the range of acceptable indoor temperatures can be greatly managed through the use of occupant-controlled fans.Or improved natural ventilation (windtower, or solar chimney)will be ventilation solutions strategy to complicated cases where automatically opened vents and windows may be needed. In other words to avoid complication and to prevent ventilation heat losses, for instance some form of mechanical ventilation should be considered to control air movement, instead of unreliable occupants behaviors (Hybrid ventilation).
All work on retrofitting buildings requires an approach which is specific to their context , site and microclimate and using renewable energy is always a bonus. thus different buildings and different occupants benefit from same approach but different interpretation. Besides, to internal sources of airborne pollutants, outdoor pollution can impact the air quality within a school Then impact the system of ventilation (intervention retrofit should varied from city to city even to school to school). For instance Air pollution levels vary by city, and one of

the main factors that can influence both indoor and outdoor air quality is the amount of traffic in a given location. To provide good indoor quality we should provide an adequate ventilation system in one hand fit for the building and the occupant activities and age, and fit for micro-climate and the generate by clean energy as a hybrid ventilation solution. However, some buildings occupants can play an important way of reducing environmental impact (First project) than technical interventions and a whole retrofitting which can be costly and interfered with other layouts; and here other important point to considerate

- Occupancy zone for University students 120-180cm and children school 120-140cm is varied therefore windows and vents design should varied too.
- Shrubs besides they supply fresh air in both projects they can manage the vent velocity and direction to the vent selected.
- Wind and buoyancy can complement each other, however in both cases it proved that designing natural ventilation systems to rely primarily on stack effect unless wind direction and speeds are reliable whereas winds frequently varied in direction, resulting in a system with limited functionality.
- Build classroom perpendicular or within 90 160 degree to prevailed wind for cross-ventilation or use wings and trees to manage wind and air flow.
- The best window for classroom is pivot horizontal for both case one sided or two sided ventilation, wind driven or stack ventilation.
- Avoiding building classroom facade at an urban street which lead to one-sided classroom even the initial design come with cross -ventilation classroom , thus a tall windows are good choice in case of one-sided ventilation (fresh air side) which is the less efficient natural ventilation strategy due to privacy, noise or air pollution. Students exposed to high levels of air pollution, such as those associated with high-traffic areas, have shown slower increases in cognitive function than students in areas with low air. So we should choose the right system for such city or such context. According to micro climate and outdoor air quality because it matter when design a strategy of ventilation.

Our vision of passive retrofitting buildings that we try to advocate in this work is beneficial for, student, professor and school panels because NV has proved to have great potential, combining energy savings and occupants 'satisfaction in many several studies regarding IEQ covering schools of different levels of education with natural ventilation systems (single-sided or cross ventilation), in continuous or purge ventilation. Additionally, it is beneficial for the large-scale economy and our planet.

This work demonstrates that passive retrofitting strategies (natural or mixed-mode) ventilation into Educational Buildings in Algeria can provide both significant energy savings and improved occupant indoor environmental satisfaction. With this tool specifications Guidelines, we hope to inspire architects to design, retrofit or develop not only educational buildings to improve educational indoor environment, but all type of building that would have a positive influence on their surroundings and people who use them. An energy-efficient, comfortable, and health-centric design based almost on natural and affordable systems and elements which in turns mitigate HUI. and global heating.

4. General Conclusion

The relationship between humans, build environment and nature needs to be redefined. While the current discourse on sustainable architecture focuses on creating built environments that lessen the impact on the surrounding environment and occupants' health, we should take courageous steps toward an architecture that establishes a healthy, respectful relationship between buildings, their occupants and the environment.

The focus on passive ventilated strategies in this study was intended to provide an example of such a relationship. The collective effect of the adaptive strategies and techniques employed, in both educational buildings provided the occupant's building with the capability to naturally achieve the desired level of fresh air and thermal comfort in harsh climates, and the ability to use their clean energy which is available all year around.

In fact we could meet more than Sustainable Development Goals set by UN Fig. 130 However, in the build environment sectors , the issue of energy was never a constraint. yet, this has changed with the considerable harm caused by the excess emission of CO2 into the atmosphere., climate change and global warming, and now it is a crucial issue in building design. One of the main challenges today is to meet the energy needs of our society in a sustainable way. Given the variability of important renewable energy sources such as sun and wind, systems exploiting these sources should be designed and operated as components of an integrated whole, Architect as a principal actor he must consider the micro-climate in which he is designing. It is no longer acceptable to design a building suitable for a specific micro-climate and adapt it for another climate by the use of more energy. For example, thick adobe walls kept houses cool in the summer and warm in winter, courtyards and verandas gave shading and wind towers were excellent ventilators. All of these natural strategies contributed to indoor comfort (employing proper shading, using double skins, adequate types of windows, well ventilated with thick thermal mass). If this consideration had been addressed properly, then most of our stock buildings would now save energy and money this way we can hit the jack pot. Thus, It's urgent to intervene to rescue planet by managing and assessing build environment. To reduce its negative impact on public health, energy use, which drain and depleted our economy and natural resources and stopping destruction our planet. In my country for example we need to establish a long and short term road map it may begin by establishing a good architectural practice 'enforcing bioclimatic cods" and encouraging this path by all means; the teaching of architecture in our universities must change to encompass the need to reduce CO2 emissions, air pollution, and use renewable energies to counteract climate change and global warming because what we see and read these days about catastrophes are in a way or another are our irresponsible practices.

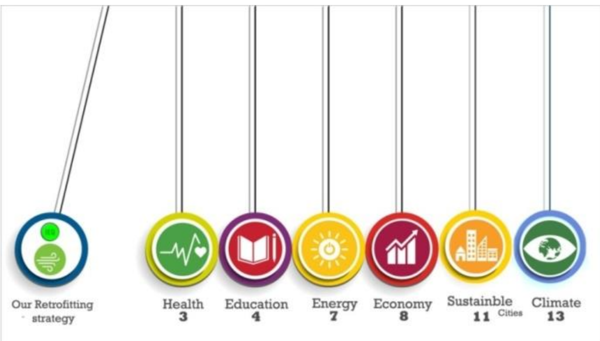

Fig. 130.At least Six promising objectives of S.D.G are met by our passive retrofitting strategy

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Term-Definition

AHU- Air Handling Unit
AIVC- Air Infiltration and Ventilation Centre is the International Energy Agency information centre on energy efficient ventilation of buildings.
ASHRAE - American Society Of Heating, Ventilating And Air-Conditioning Engineers
ASHRAE Standard 55- Specifies conditions for acceptable thermal environments
ASHRAE Standard 62.1- Specifies ventilation for acceptable indoor air quality
BMS-A building automation system (BAS), is a computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems, and security systems.
BSRIA- Building Services Research and Information Association
CIBSE- Chartered Institution of Building Services Engineers
CFD- Computational Fluid Dynamics
CO - Carbon Monoxide
CO_2- Carbon Dioxide
DTR- Documents Technique Reglementaire –Regulatory Technical Docments “Algeria”
EPA – US Environmental Protection Agency
FLUENT- CFD Software, developed by ANSYS, Ins.
GHG- Greenhouse Gases.
HSE-Health and Safety Executive, regulation and enforcement of workplace health, safety and welfare agency in the UK
HVAC - Heating, Ventilating and Air-Conditioning
HEPA High Efficiency Particle Air

IAQ - Indoor Air Quality
IEQ – Indoor Environmental Quality
IOT- The Internet of things, describes physical objects (or groups of such objects) that are embedded with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks.
ISO - International Standard Organization
ONM-Office National de la Météorologie- National Office Of Meteorology "Algeria"
ONS- Office National des Statestiques-National Statistics Office "Algeria"
MHE.SR- Ministry of Higher Education and Scientific Research "Algeria"
MNE-Ministry of National Education"Algeria"
MRT - Mean Radiant Temperature
NV-Natural Ventilation, Naturally Ventilated
PMs-Partial matters
PMV - Predicted Mean Vote
PPD - Percentage Predicted Dissatisfied
SDG- Sustainable Development Goals
SBS- Sick Building Syndrome
TVOC - Total Volatile Organic Compounds
UHI - Urban Heat Islands
VAV-Variable air volume (VAV) systems enable energy-efficient HVAC system distribution by optimizing the amount and temperature of distributed air.
VOCs - Volatile Organic Compounds
WHO - World Health Organization

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Appendices

1. Climatic and Bioclimatic analysis (Screenshots)

The architecture and engineering community is well aware of the fact that a large portion of building energy consumption is used to condition the indoor environment of buildings (ventilation or by heating or cooling outdoor air to provide thermal comfort and improved indoor air quality). Much of this wasteful consumption could be avoided by changing the way buildings are designed. The best way to reduce energy consumption is to design for human comfort by exploiting natural forces around the building site. (Ulrike Passe & Francine Battaglia.2015).

1.2.Solar energy and sunshine Wind energy and prevailing wind :Analysis

It is useful to be based on monthly meteorological data taken at the meteorological stations, in our study we have taken several meteorological data from various resources during different periods of time; Data were taken from (1) National Office of Metrology (ONM), (2)climate data.,(3) Meteoblue (4), Weather atlas(5), Weather spark (6) Climate Consultant (7) and app.formit.autodesk.com tools.

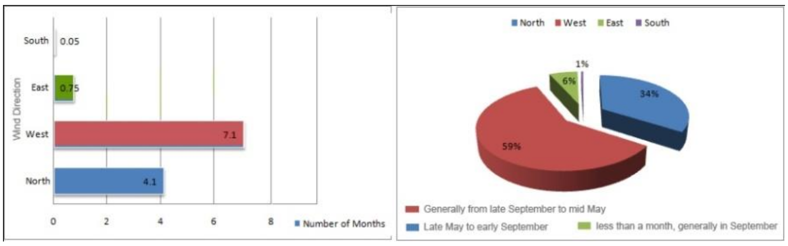

Fig.131.N of months and wind direction Blida (ONM, Weather atlas, weather spark)

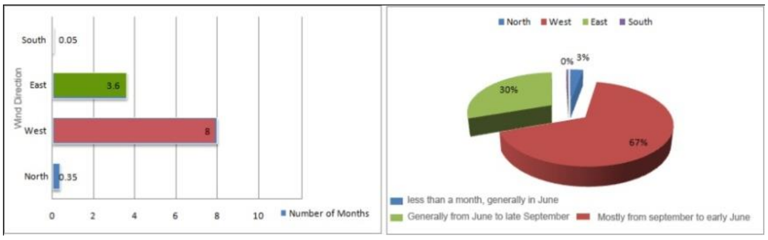

Fig.132. N of months and wind direction Ain defla (Source: (1),(4),(5)adapted by author)

1.3 Application of the method of Triangles comfort diagram of Evans

Presents the Triangles developed by the author (Evans, 2003) based on the original proposal in Evans and de Schiller (1988), showing the four different zones identified, labeled A, B, C and D, for sedentary activities, sleeping, circulation and extended circulation respectively.

The diagram also includes the following bioclimatic strategies which are applied to improve comfort when the conditions are outside the respective comfort zones:

- Sensible air movement: air movement that can de sensed due to the cooling effect.
- Thermal inertia, combining time-lag and thermal damping.
- Use of solar radiation.
- Thermal insulation to conserve internal gains
- Selective ventilation: use of intermittent ventilation to cool or heat interiors.

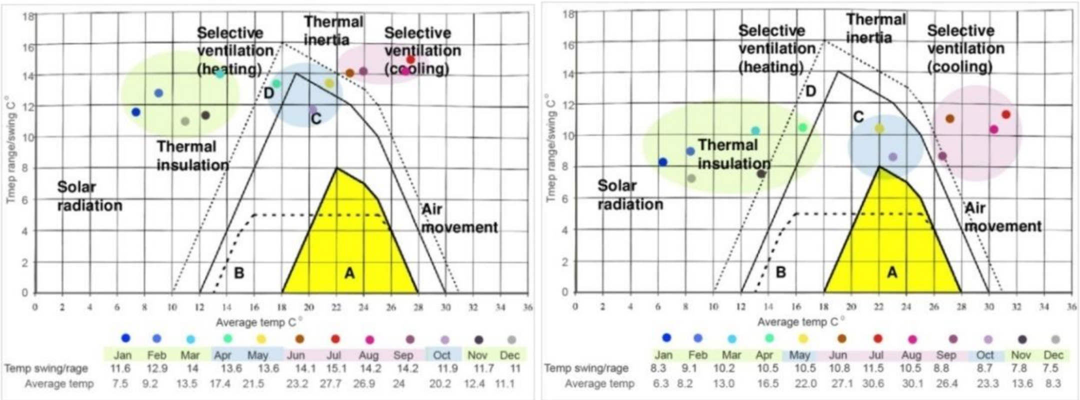

Fig.133 The Comfort Triangles, as published in Evans (2003) in the Blida and Ain defla region with design strategies added .Screenshots; (Source author)

1.4.Application of the BcChart tool.

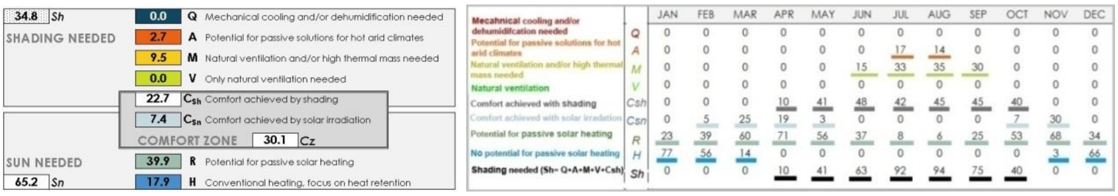

Fig.134 Bioclimatic potential analysis in Blida by bcChart tool. Screenshots; (Source author)

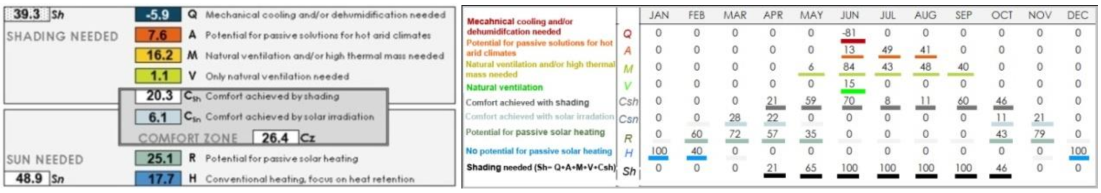

Fig.135 Bioclimatic potential analysis in Ain.defla by bcChart tool. Screenshots; (Source author) (See Appendix-CD for more details graphs, tables..etc)

2.List of Leading Research centers on natural and hybrid ventilation:

List of Leading Research centers on natural and hybrid ventilation:

This study found that the following research centers are highly active in hybrid and natural ventilation research: (Zhai et al., 2010).

- Aalborg University, Hybrid Ventilation Center - Denmark
- De Montfort University, Institute of Energy and Sustainable Development – UK
- Fraunhofer Institute for Solar Energy Systems – Germany
- Harbin Inst. of Technology, Inst. of Indoor Env. Science and Engineering – China
- University of Nottingham, Institute of Building Technology, - UK
- Lawrence Berkeley National Laboratory – US
- Massachusetts Inst. of Technology, Building Technology Program - US
- National Institute of Standards and Technology (NIST) - US
- National Renewable Energy Laboratory - US
- National University of Singapore, Department of Buildings – Singapore
- Osaka University - Japan
- Universite de La Rochelle, LEPTAB – France
- University of Athens – Greece
- University of Cambridge, BP Institute for Multiphase Flow – UK
- University of Hong Kong – Hong Kong