

Gaging Natural Ventilation by Exploring Architectural Elements Developed in Contemporary Abodes of Warm and Humid Region

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Abstract

Contemporary built form is a manifestation of construction endeavours in which architectural elements plays a pivotal role of satisfying users from various parameters. The countenance present in built forms tries to address men – as user, building – as structure, and environment – as place or the context itself. This paper attempts to emphasize the interlude by anticipating the pertinent features of building's thermal comfort achieved through design intervention. I.e. how diverse elements can be utilized, in order to cater natural ventilation, for contemporary houses of warm and humid region of Gujarat, India. Recent anxiety for global warming has subsequently sparked a flame of inquisitiveness towards naturally ventilated buildings, due to its efficacious way of enhancing internal air quality, thus minimizing electrical dependency. Henceforth, has been sought after as a primary technique to minimize the carbon footprint of the building. Provision of features like openings can cater cooling to the building. It seems very obvious in case of ventilation, but the pattern which occurs is rather more complex, which is a field yet to be comprehensively explored by designers.

Existing built form worldwide remains entranced with the performance of structure as an organization, mostly via the prism of the amount of energy it utilizes. This indicates to the necessity for suitable acquaintance of the rudimentary principles of building physics. To satisfy the thermally comfortable environment the overuse of energy is evident and alternate mitigation possibilities are of greater concern. Hence, the study tries to address the possible design interventions in the climate by understanding the basics

of thermal comfort and possible iterations of design explorations. Through analysis of various case studies, it will review modern ventilation designs with respect to traditional ones.

Keywords: natural ventilation, relative humidity, thermal comfort, warm and humid climate, elemental manifestations

Introduction

The existing human population is constantly hastening towards an improved and more contented life, progressing forward in the silhouette of technology. Buildings cannot sustain pristinely by ignoring the modern technology. Henceforth they have to endow comfortable atmospheres for their inhabitants, through facilitation of various mechanical aids to adjust indoor temperatures, control moisture, odours and pollutants in the air, subsequently turning them into hefty utilizers of electricity. Accomplishing sustainability of buildings while staying in synchronization with the environment is a foremost anxiety in developing countries.

Currently, as a consequence of global warming and escalated consumption of fossil fuels, people's curiosity for utilization of green design principles in buildings, has escalated due to environmental awareness. Resultant of which, architects also have transferred their designs more attentive towards environment. In other words, climate and environment are two remarkable factors on buildings and their inhabitants. A climatic design strategy can manipulate a maximum of indoor comfort with least utilization of energy. To attain an energy efficient strategy, various aspects have to be combined and measured prudently. Orientation and placement of the structure and the category of building envelope, natural ventilation, and spatial organization of spaces as well as materials employed are certain significant aspects which affect building's thermal performance. Of which recently, natural ventilation as a tailored method for ventilating buildings has earned utmost importance. It has two primal principles, cross and stack ventilation.

Natural ventilation, as an alternative ventilation technique has been applied since many years. It was utilized in various old buildings, to fetch in fresh outside air, with the aid of pressure or temperature variances, occurring at inlet and outlet. As compared to earlier comfort level standards of inhabitants has

significantly surged majorly due to technological advents. Thus, just employing natural ventilation won't cater to recent needs. In order to suffice the demands, utilization of low-energy mechanical framework (for example fan-supported ventilation, chamber, wind tower, twofold skin façade etc.) can be done. If there raises an occurrence of deficient wind flow; administrative frameworks (manual and/self-controlling functional openings, vents just as ventilation channels) can be utilized to alter the internal wind stream; just as acoustical louvers, for the moderation of both inner and outside commotions. Due to its advantages, natural ventilation has recently earned prominence for ventilating buildings. Thus leading to an ephemeral review of various efficacious ventilation techniques classifying them into active and passive systems that have been utilized in existing structures of Surat and Bharuch, India primarily, and worldwide secondarily.

There are numerous approaches to study natural ventilation, varying from empirical approaches to high-tech technologies, like full-scale quantifying, scaled-model examination in wind tunnels, Computational Fluid Dynamics (CFD), as well as building energy simulation. These approaches and instruments permit designers and scholars to assuredly forecast and then integrate natural ventilation principles ingeniously within designs of modern structures.

Thermal Comfort

An ailment of human cognizance, which conveys gratification with regards to the thermal environment, is termed as thermal comfort. As specified by ASHRAE in (Standard 55 – 2010). Furthermore, the complexity can be related to:

Mean Radiant Temperature (MRT), overall Air Temperature, Relative Humidity as well as wind velocity, neighbouring decibels are the physical constraints affecting the thermal comfort.

There are several other constraints like particular features of inhabitants, gender, age, kind of activities being performed, are the physiological constraints, affecting the thermal comfort. Along with that Human clothing insulation, occupant's societal conditions, various types of activities happening, are several other constraints which can affect the thermal comfort.

There is a specific range of temperature of 37⁰C (98.6⁰F), at which human body is incessantly trying to maintain it at a persistent level, through several performing several activities or by employing several mechanisms. This is the temperature at which human form is contented. In order to maintain this comfort level, the body tries to exhale out excessive heat gains through evaporation from the skin, respiration, regulating the kind of clothing, varying the activities performed throughout the day.

Table 1

Parameters That Influence the Envelope Design, (Đukanović A. R., Material Aspect of Energy Performance and Thermal Comfort in Buildings., 2018)

FACTORS AFFECTING THERMAL COMFORT	OUTDOOR FACTORS	TANGIBLE FACTORS	PARAMETERS							
			Ambient temperature							
			Radiant temperature							
			Relative humidity							
			Air velocity							
	IN - TANGIBLE FACTORS	Metabolic rate								
		Cloth insulation								
INDOOR FACTORS	SCALE	Context (Surroundings)	Dimensions and orientation of external obstacles.	Solar radiation, reflectivity of surrounding surfaces.	Soil cover (vegetation) and the nature of the ground.	Local climate				
		Building	Orientation of the building.	Position relative to other buildings and to the noise source.	Form exploration.					
		Spatial organization of spaces	Position of spaces within building.	Volumetric explorations.	Absorption coefficient for solar radiation entering through the transparent component.					
		Material explorations	Wall thickness.	Density of material used.	Heat transfer coefficients of the materials used.	Light absorption and reflection coefficients of the surfaces	Sound transmission coefficient of material.	Porosity and roughness of the surface.		
			Construction of the surface.							

Natural Ventilation and Thermal Comfort

Overview of Natural Ventilation

Natural ventilation fundamentally is a procedure of bringing new quality air to space, and removing stale, rotten or contaminated air from the space. Without suitable ventilation there won't be complete suffocation, (Battaglia, 2015) rather there would be a sensation of air getting warm and reeking. Air is a significant component identified with ventilation. Also, is dynamic in nature, generally not reliable. Because of which naturally driving forces have been an underutilized plan procedure, to control the indoor condition.

Sole purpose of utilizing ventilation, is to maintain a tolerable situation inside building. Variables to be controlled are:

- Temperature: Alleviation from warming.
- Humidity: Hindrance of condensation or murkiness.
- Odor: Weakening of smell arising due to smoking, body sweat, other processes etc.
- Contamination: Weakening or disposal of hazardous or blistering exhaust fumes as well as dust.

Driving Forces of Ventilation

Generally natural ventilation utilizes two different forces for its application, namely wind and buoyancy induced forces and sometimes wind turbulence. Wind induced forces generally, emerges where wind current about structures strays' speeds as per the modifications in building's envelopes, bringing about pressure variations over the façade. These pressure variations will draw outside air into the building through the windward face, whereas internal air is extricated from the leeward face. Buoyancy driven forces are a consequence of wind density variance amongst the temperature varieties of internal as well as external side of the building. Wind turbulence, is created due to resistance from hindrance on the ground. And furthermore, will develop minor pressure variances within structure envelopes to impact wind current all through any openings. Wind and buoyancy instigated forces can act simultaneously. In that state, overall instigated forces will be equivalent to the whole of the main instigations which are prompted by both buoyancy and wind.

Principles of Natural Ventilation

Natural ventilation comprises of various principles like:

Cross ventilation, is established through wind induced forces, and happens because of wind – initiated pressure distinctions at various openings, situated on inverse sides of an encased zone. Its force significantly relies upon the distinction in wind pressure shaped at the combinations of various opening inlets as well as outlets.

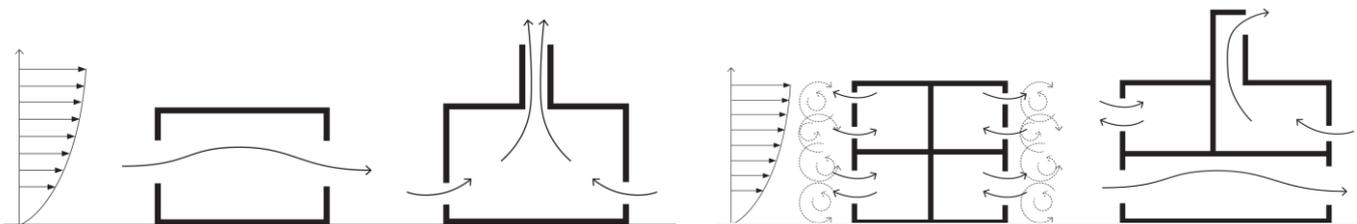
Stack ventilation, is established through buoyancy induced forces, and happens because of pressure variations engendered at various inlets and outlets, at different elevations, through temperature gradients. Flow path is shaped by, hauling cooler external air inside through lower situated inlets, while debilitating warmer internal air circulating outside, through higher elevated outlets.

Single-sided ventilation, is defined as a condition where one or more openings exist only at one façade of a closed room or building. Demonstration for this example is determined by singular room-scale effects induced through buoyancy, little wind instigated pressure variations and disturbances of external air.

Mixed ventilation approaches, this is an amalgamation of the above mentioned three methodologies for a solitary structure, in order to overhaul ventilation path through a particular room and condition.

Figure 1

Principles of Natural Ventilation, (Tran, May, 2013)



Architectural Design Criteria to Cater Natural Ventilation in Warm and Humid Climate.

There are various design criteria that can be utilized to cater natural wind flow through the design, like: Site assortment, Site development as well as landscaping, Wind orientation, Building forms, Building envelopes and structures, Openings, Opening regulators, Louvre design, Optimal shading, Shading with the aid of natural vegetation, Internal layouts, Supplemental ventilation designs, Atria, Double coating façade, Wind tower, Solar chimney, Auxiliary systems.

Natural ventilation is evidently the basic as well as affordable choice to cool down the structure. Due to its dynamic nature which constantly changes with weather, makes it most difficult to tap. To make it

happen, wise decisions should be taken at the design stage, so that it turns out to be a design element and not just a design outcome.

Building envelope, along with orientation are hypercritical elements affecting ventilation. For example, if the structure consists of light weight construction, then are chances of overheating in the morning sun coming from east facade. This is where solar shading can come in handy to save cooling load. Form of the structure is also a major contributor through its height, affecting stack ventilation. And its form in relation to local wind patterns and velocity, affects wind induced ventilation. Context also plays a pivotal role, as how surrounding buildings are reacting to prevailing wind as that would also decide the amount of wind coming to our structure, eventually affecting ventilation rate. As a result, there should be a very wise decision made on the type, location as well as the size of openings. Thus, it can be said that, as soon as form of the structure is finalized, effective planning for ventilation commences. As once built, these are the decisions which no one would like to have afterwards.

Advantages of Natural Ventilation

Efficiency over both HVAC, and automatic ventilation, natural ventilation has recently, became a vital issue. Major reason for such success, directs towards its cost affectivity at both installation and post occupancy levels. Primarily HVAC systems, are major consumers of electricity, be it at their working stage or at maintenance, it consists of various kinds of supplementary expenditures. Various architectural spaces can be easily optimized for wind flow patterns as well as for daylight optimization, to occur throughout the plan. Both the aspects of energy consumption and cost of installation can be counterpoised if natural ventilation is augmented to its best potential.

Barriers of Natural Ventilation

Generally, there are various aspects affecting the application of natural ventilation in any structure for thermal comfort. Like: context as well as the heights of solar exposure, and internal air quality index. Also, Relative humidity, high noise decibels convoyed with dust as well as pollution, and surged atmospheric temperatures, are the various climatic aspects which can generate hindrances, on the path of employment of natural ventilation. Moreover, aspects such as wind flow, which is unhinged in nature, can

pose a much extensive hurdle in the application. As it might not be possible, to always cater the level of comfort to the inhabitant, within a given period of timeline, as wind is very dynamic in nature.

Case Studies

In this study, there were four primary case studies analysed physically apart from other secondary studies. Specifically, two case studies are located in two cities of Gujarat, Surat and Bharuch. Both these cities are located in warm and humid region of India. Case 1, is a residence designed with cross ventilation principle. Case 2, is a residence designed with an atrium facilitating in stack ventilation of the house. Case 3, is a residence integrating cross ventilation as well as a wind tower to ventilate leeward side room. Case 4, is a residence utilizing a ventilation chamber along with cross ventilation at planar level. There was a CFD analysis performed of the above case studies, in Autodesk Flow Design. In this software 3D models of the case studies were analyzed at planar as well as sectional levels, keeping wind speed as per the local prevailing wind. Henceforth, facilitating in better understanding of all the stated case studies. Further secondary studies have been adopted through literature review of various other research papers.

Figure 2

(A) Exterior Elevation of Case 1, (B) Exterior Elevation of Case 2, (C) Wind Cowl Used in Case Study 3, (D) Stack Ventilation on Element Used in Case Study 4 (Photo Credits: Author)



Passive Wind Driven Ventilation.

This part explicitly ventures into devices and techniques that predominantly utilize wind induced effects for ventilation, and are passive in nature. Passive signifies they are not employing any mechanical

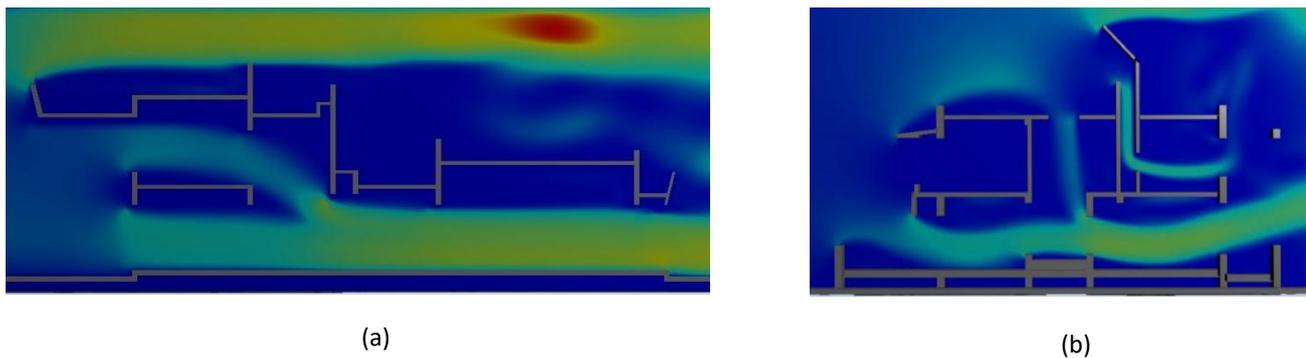
part for their functioning, although in recent techniques they have integrated some mechanical parts for enhanced wind flow.

Window Openings

Wind flow, throughout a building is well defined by the utilization of apertures, that are efficiently oriented, located, scaled and are of appropriate type. Not just the flow, it can also alter the pressure discrepancies and inertia of wind. Location and alignment of buildings to existing wind flow is necessary to tap in wind movement. There should be an appropriate location of inlet and outlet apertures at positive and negative pressure regions. Windows have to be located at the level of inhabitants, in order to attain comfort ventilation. For making a continuous wind flow, throughout the inhabited space, location of the openings should be such, that inlet is placed near the floor for fetching in renewed cool airflow, and outlet at the lowermost of slab, to exhale out warm stale air. At slightest two apertures situated on inverse flanks or parts of the building are favoured more for air circulation inside the building. Various buildings have been evaluated under these criteria, below are some CFD analysis of those buildings.

Figure 3

(A) CFD Analysis of Case Study 1. (B) CFD Analysis of Case Study 3



In Figure 3, case 1; is majorly designed on the basis of cross ventilation. Due to the employment of aptly sized openings throughout the design, it is evidently perceived of the ample low pressure created on the

front side of the building. Henceforth, indicating to a wind flow pattern from high pressure windward back side of the building to the leeward front side. As a consequence, effectually cross ventilating the whole building. With the aid of CFD analysis, the main intent of cross ventilating the structure throughout the year, because of which such huge openings were employed while designing is clearly evident.

A major setback of these techniques is the irregularity of the driving forces. Wind data employed during designing a building is very theoretical and averaged data of a specific area. This leads to dissatisfaction during extreme conditions, and can even lead to flow reversal. Wind induced ventilation techniques are capable of being enhanced using various design elements, like wing walls etc. Similarly, stack effect can also be enhanced. During phases of low intensity driving forces, naturally induced ventilation techniques inevitably entail an element of redundancy for their corresponding techniques like ceiling fans etc. There are cases where natural forces are solely playing the game of ventilation. Easy maneuvering as well as low tech nature are the only reasons for tolerance of openings in buildings. But when it comes to a larger scale building, they alone are not reliable for ventilation.

Whereas in Figure 3, case 3; it can be seen of how the designer has utilized both cross and stack ventilation techniques by employing appropriately scaled apertures, at specific areas. Thereby, reducing the dependency on mechanical frameworks for ventilation. Additionally, a wind tower has been utilized to ventilate the leeward side room, hence completely ventilating the house. Appropriate amalgamation of both the cross and stack ventilation techniques have been employed in this design by freeing the plan from unnecessary obstructions and by facilitating with a vertical shaft, wherever it was applicable.

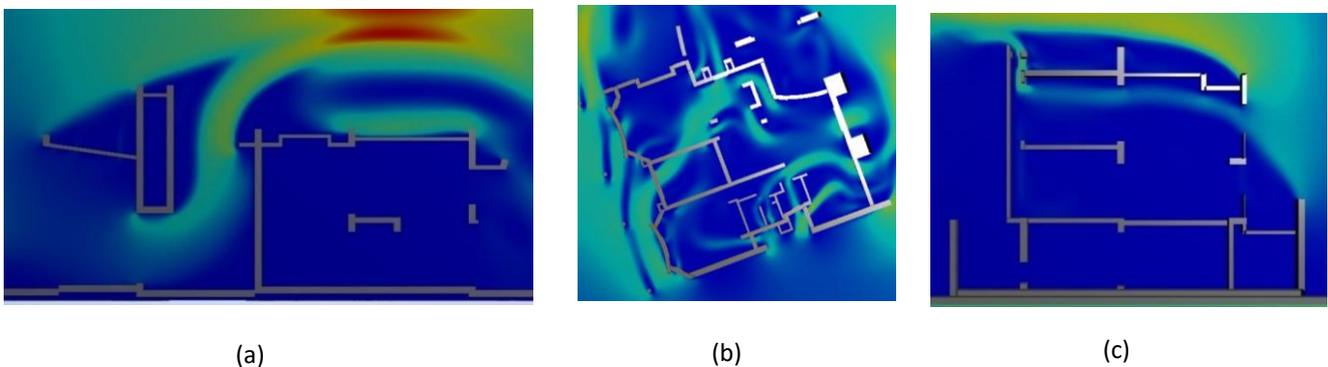
Atria and Courtyards

There is a variety of canopied semi-external spaces, consisting of glazed surfaces called as atrium. Further there are several other bifurcations to this main category like: single sided, two sided, three sided, linear as well as four sided atrium. Generally, atrium is utilized so as to facilitate the building with a double height stack chamber, which can aid in capturing fresh air from bottom window, and extract the warm stale air from the opening at the top. It is viable due to stack ventilation principle, or else can be an amalgamation of both stack and cross ventilation.

By utilization of atrium spaces, it benefits the inhabitants by permitting a free use of openings that are interlinked with the atrium spaces. Warm air, has a tendency to rise up, and let cool air takes its place. Identical principal works for stack ventilation that is happening in atrium. But the issue that is generated, because of this effect is, warm air will be congregating at the top level, which in fact can cause discontentment, for the occupants of upper floors. Thus, in order to evade that, internal height of atrium can be escalated, by the usage of clerestories, rather than glazed roofs, or by employment of appropriate passive cooling techniques. Generally, there is a low external wind speed experienced in warm and humid climate. Also, there is a noticeable temperature variance, in low rise buildings where atrium has been utilized, with establishment of a suitable linkage between atrium and wind tower. Assisted mechanisms or conduits, on its top can aid in enhancing stack as well as cross ventilation through the atrium.

Figure 4

(A) Sectional CFD Analysis of Case Study 4, Located in Bharuch. (B) Planar CFD Analysis of Case Study 4. (C) Sectional CFD Analysis of Case Study 2, Located in Surat



In Figure 4, case 4; it is evident that the architect has placed a wind chamber, and has tactically placed important spaces around it, thereby aiding ventilation in all the neighbouring spaces. Warm air escapes from the chamber, leaving a low pressure behind in the spaces, thus leading to fresh air gush in, thus ventilating the spaces. Appropriate placement of scaled apertures plays a pivotal role in this system. As well as in case 2, the designer created an atrium and placed all the rooms around it, so that there can be an effective stack ventilation throughout the building. Warm stale air rises up from the chimneys located on the leeward side of the house. Thus, creating a low pressure inside the building, as a result pressure variance occurs, leading to effective wind flow from high pressure windward side.

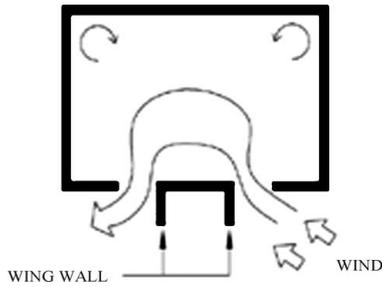
Wing Walls

A wing wall is generally utilized on openings placed on windward facade to enhance single sided ventilation. It functions with a basic aim of explicitly creating positive as well as negative pressures on either side of two projections emanating from the aperture, thus aiding in the flow rate. (Naghman Khan, A review on wind driven ventilation techniques, 2008) have proved that, with the utilization of this technique average wind velocity inside the building surges up to 40% of the external incident wind speed, whereas in case of its absence it drops to meagre 15%. Wing dividers can also be included in the structural plan, for their efficient functioning during adjustable breeze bearings.

Wing dividers generally, are situated near to the opening; even a trivial wind flow in contradiction of the divider makes a high-pressure zone on one fringe, and contrasting on the other. The pressure variance lures outside air through the opening and exits through the contiguous one. This method is viable for wind heading points ranging from 20° to 160°. For single-sided ventilation deprived of a wing divider, escalated airspeed is initiated close to the apertures, and the speed diminishes considerably with the profundity of the space.

Figure 5

Airflow Enhancement Due To Wing Wall (Naghman Khan, A review on wind driven ventilation techniques, 2008)



Wing walls have been proven effective in many single sided ventilation techniques. However still there is a setback to its integration, such as its integration would lead to blockage of sunlight. Utilization of transparent materials which can play from both sides of enhancing and directing sunlight inside the building can be the possible solution, for the above-mentioned problem. Limited usage of single sided ventilation, has led to less research in the specific area. However, wherever there is a need for distinct as well as opposing pressures, this can be utilized.

Wind Towers

Wind towers have been an integral part of design in Persian architecture, and are compatible in arid as well as warm and humid climate. Their application is primarily founded on both cross and stacks ventilation.

Figure 6

Different Wind Towers, A-Uni-Directional; B-Bi-Directional; C, D, E-Omni-Directional (Tran, May, 2013)



Furthermore, there can be a bifurcation of wind towers into several types, on the basis of number of openings, like uni, bi and omni directional. Application of uni-directional towers is effective when it is oriented in the prevailing wind direction. Whereas, in other cases, there will be an opening for the inlet of air, in either position it is oriented. Working dynamics of a wind tower is a very elementary process of wind exchanges happening throughout the day. Following is the elaborated process of those exchanges happening through it:

Design intent:

- In wind tower, warm external air arrives inside the pinnacle through the apertures located on the pinnacle. Air gets condensed, and accordingly gets heavier consequently descends downwards.
- The tower as well as openings of connected spaces will prompt condensed wind flow, by creating pressure variation.
- Subsequent of a day full of air exchanges, tower walls remain warm during nights.
- During dark, condensed surrounding air comes in contact with the bottom of the tower through the openings of the connected spaces.
- The pinnacle dividers ingest heat throughout daytime and discharge it at night time, heating the condensed nocturnal air in the pinnacle.
- Warm air surges, making an ascendant current, thus hauls condensed nocturnal wind through the openings into the building. This is known as night time cooling. This aids in reducing the cooling load of the building for the leading morning. As the air is cooler as well as denser, this leads to a reversal in chimney effect, in which the air will flow into the building.

Modern designs consist of incorporated advanced building principles as well as technologies.

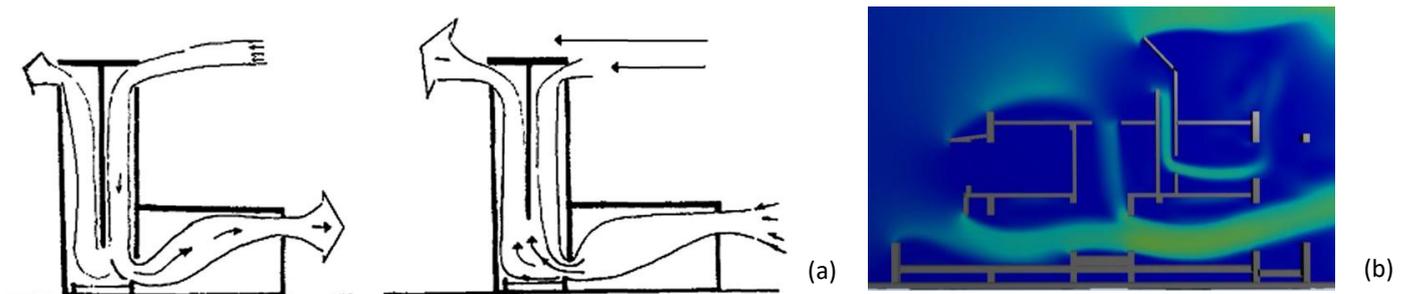
- Buildings consisting of evaporative cooling towers can drastically escalate the cooling capacity of incoming wind. This might usually involve mechanical pumps to pour in the moisture in the system, which will decrease passive efficiency of the building.

- In order to cater the exact amount of audience, within a space through these towers. Utilization of natural ventilation principles can aid in dictating the exact dimensions of the tower, thus efficiently catering the crowd.
- Tower heads can efficiently take in air from every direction, without wind flow shortage.
- Volumetric flow rate can be inflected with utilization of control dampers as well as diffusers.
- In case of scarce wind flow, solar collectors can be utilized, to aid in stack effect through the tower.

Their utilization has a few merits such as; they can (be intended to) function autonomously, regardless of prevailing wind bearing. They can shield outlet openings from downpour and snow entrance. Followed by some demerits such as; the framework functions adequately during hot and dry climates where vacillations are up surged. A wind tower functions admirably for singular units, rather than that for multi storied condos. In dense urban contexts, wind towers must be sufficiently higher to have the scope of capturing sufficient prevailing wind.

Figure 7

(A) Operating Principle of a Wind Tower. (Naghman Khan, *A review on wind driven ventilation techniques*, 2008). (B) Sectional CFD Analysis of Case Study 3



In Figure 7, case 3; it is evident how the designer, have efficiently placed a wind tower or wind catcher of appropriate dimensions, in order to cater natural ventilation to the leeward side room. Which otherwise had no scope of ventilation. Height of the tower has been deliberately kept higher, than neighboring buildings in order to capture as much wind as possible. Furthermore, an addition of overhang, is aiding in the ventilation. By cutting the prevailing wind flow and directing it down the tower to the room. Or

either way round, make enough pressure variance at the tower outlet, so that the wind can come from beneath the tower and exit from above, and create a reverse ventilation effect. Dimensions of openings also play a very vital role in this ventilation technique.

Double Skinned Facades

Facilitating a void for air-flow, as well as enhancing various ventilation principles, are the two layers of skins which amalgamate to form a double skin façade. Both the atrium and this façade technique, have a common scope of work respectively, except that the second technique has no link established with inner spaces, as compared to that of the atriums. Utilization of this technique has various merits like, regulatory openings, averting penetration of external pollution and noise, as well as optimizing the daylight. Its tendency of transferring heat upstairs, and escalating the heat exchange amongst adjoining spaces through reflection of light in void created, as well as generating its maintenance problems, are few drawbacks of its application.

In order to, effectually adjust heat exchanges happening amongst different layers, as well as all over building spaces. Employment of solar shadings can be an effective assistance. According to recent studies, by application of suitable colour and location of solar shadings, it can have an influential effect on internal thermal comfort, consequently affecting energy consumption of the building. If given appropriate contemplation at initial stage of designing, these devices can also be utilized as service passages, to effortlessly clean the cavities. Additionally, mechanical systems or solar chimney can be associated with these, to further enhance wind flow.

Merits:

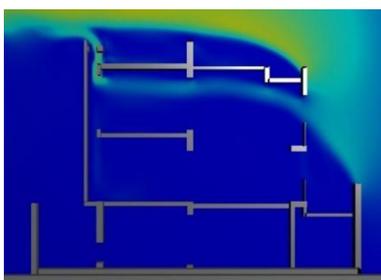
Twofold façades utilized for ventilation could be utilized as inlet or outlet ways in anyone of the three characteristic ventilation standards. They propose numerous points of interest:

- The void is secured against atmospheric air as well as open-air clamor. Along these lines, operable apertures can be permitted independent of wind and commotion all things considered, even on the higher levels of tall structures.

- Sunlight based concealing gadgets are shielded from the breeze when situated in the pit.
- Sun oriented warming of the wind flow is facilitated on bright days when the void is utilized as wind source pathway.
- Because of the secured condition in the hollow part, transmission misfortunes through the divider are diminished and contrasted by a conventional outer layer. At the point when utilized as a flexible airway, a portion of the transmission heat misfortunes through the divider will be caught by the bay wind flow in the hole; in this way, a warmth recuperation impact is given.
- Because of the secured atmosphere in the cavity, openings in the spaces within will be hotter, diminishing condensed downward drafts and irregular radiation.

Figure 8

Sectional CFD Analysis Of Case Study 2



In Figure 8, case 2; the designer has utilized a double facade, on the leeward side along with an atrium on the windward side. Major advantage being, leeward side is the major heat gaining side, as a result solar radiations are facilitating with stack effects. Because of which the whole windward facade can be opened, with double volume atrium, to capture in as much wind as possible. Configuration of apertures, as well as their manoeuvrability is crucial for functioning of this system. For determining its efficiency wind flow as well as its velocity plays a pivotal role.

Different kind of other secondary stacks were also studied in this study. Result of which, it was found that passive stack working alone under buoyancy driven forces, wasn't able to suffice the ventilation needs of the inhabitants, thus necessitating an excess mechanical force. This force can be in terms of a DC fan to extract air that was suitably placed above on the stack, to create an uptake effect. And an appreciable

enhancement was achieved in the ventilation. We can see how, through addition of a hybrid solution powered by solar PV panels, ventilation was enhanced. Wind towers generally are constricted to where they can be located. Like, it is not ideal consisting of a wind tower in a dense urban fabric, with high rise structures in the vicinity. However, employment of double skinned facade described in above case, is an ideal way to deal with. There are certain conditions, where there is a lack of appropriate temperature as well as pressure variances, during such times, an amalgamation of convection and radiation will aid in enhancing wind flow through the chimney, thus improving natural ventilation.

Wind Floor and Air Inlets

In order to naturally ventilate high rise structures, a novel approach was formulated in Japan, was the addition of a wind floor. This floor basically comprises of all four open sides, to the nature, letting the wind flow continuously through the apertures. This functions like a suction cowl, in the floor. By generating a negative pressure which helps the wind flow through the intentionally designed central core that utilizes stack effect. As a result, there is an 30% increment in flow rate. Still there are very little evidences to come to a conclusion. Generally, air inlets as well as inlet grills have a pivotal role in facilitating wind flow to a naturally ventilated building.

Directed Passive Wind Driven Ventilation

Wind Cowls / Scoops

Wind cowl is normally termed to a roof ventilating structure. Both the terms scoop and cowl are generally utilized synonymously. Basically, a scoop is an open ended, weatherproof instrument that scoops wind from the prevailing current, guiding it inside the building. Same phenomena works with cowls, exception being the opening is facing the leeward side. This takes advantage of the partial negative pressure created when wind flows across openings or if the cowl rotates. These both are generally utilized in complimentary with wind towers.

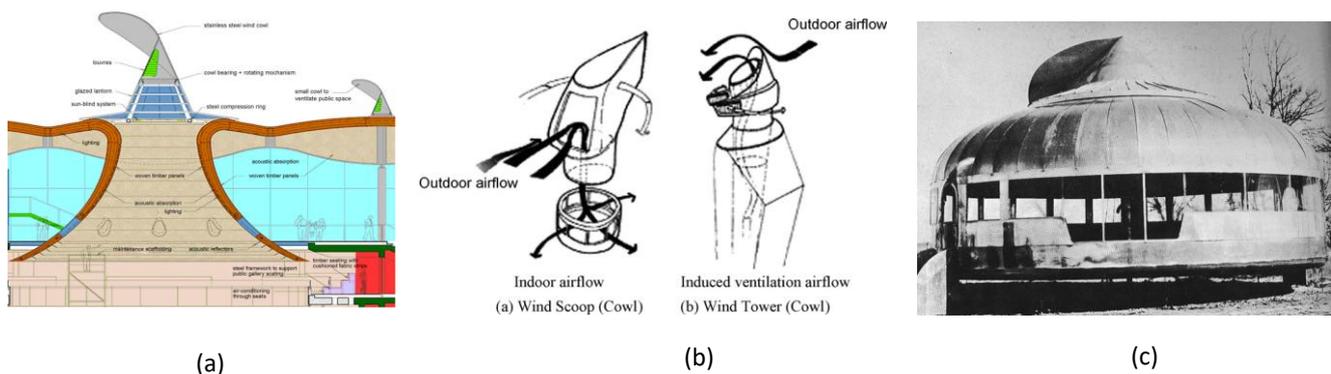
(Adekoya, 1999) Bifurcates into two variants of cowls; first being the pressure cowl, which faces the wind and generates positive pressure. Other being, the suction cowls that backs the wind flow further generating a negative pressure for air exhaust. Kelly et al. in which both the cowls have been analyzed, to

form a comparison. As a result, pressure cowls were found to be efficient at generating positive pressures rather suction cowls which were generating negative pressures. Kelly et al. concluded the analysis with a clear win of pressure cowls being two and a half times more efficient at generating pressure needed for wind flow.

Another notable example being the ICI chemicals visitor center situated in Runcorn, UK. Notable feature being the rotating wind cowl utilized for ventilating intentions. Material selection of steel and marine sail cloth, for the cowl sail has aided in efficiently turning the cowl. It is 9 meter high and rotates on steel wheels. Furthermore, louvers were employed to naturally ventilate the building, which was designed to harmonize natural as well as mechanical manifestations; as a result, a leaf shaped sail was attained. The wind cowl was erected back in 1999. This was a highlight of the usage of rotating cowls on a larger scale to enhance ventilation. They can be integrated within design from an early stage and can be utilized as an integrated design element to other concepts like atrium or other hybrid ventilation systems for optimum performance. Fig no. 9(a), Depicts the design of a public sector building in Wales. It consists of a large rotating cowl consisting of steel, and employing louvers to exhale out air. Structure erected to support it, is a lantern-based design. That is functioning on achieving dual goals of bringing in natural daylight into the structure as well as ventilating it. Another supplementary cowl has been installed to a stack, which is of height to that of the building. This is for facilitation of other spaces with natural ventilation.

Figure 9

(A) Diagram Of Wind Scoop and Cowl (Tran, May, 2013). (B) Public Sector Building in Wales. (C) Dymaxion Dwelling Machine. (Naghman Khan, A review on wind driven ventilation techniques, 2008)



Several parts of the building consist of mixed mode systems which incorporate mechanical cooling systems required for necessary operational phases. Natural ventilation is the sole and primary mode of ventilation throughout the building, that also consists of ground sourced heat pumps as well as biomass boilers to gain total advantage of renewable energy. Buckminster Fuller, a famous architect as well as an inventor proposed and erected the Dymaxion Dwelling machine.

It can be clearly highlighted that; natural ventilation has been the primary design principle of the building. We can see how the wind cowl has been utilized as a rotating roof. The rotating principle can be seen in Fig. 9 (b). A centrally supported column has been placed in such a way, that it supports the necessary services, including plumbing as well as ventilation, etc. Due to the rotating suction cowl placed on the head of it, acts as a stack and aids in facilitating ventilation in the house. Due to the placement of a baffle identical to a wind vane, keeps the exhaust facing away from the prevailing wind at all times. As a result, negative pressure is formulated on the leeward side of the cowl, which extracts wind from the central column. It was in fact, two columns situated in a concentric arrangement, smaller situated inside the bigger one. Incoming wind flows through the larger section, while the extracted wind flows through the smaller section. This process permits heat recovery as both the wind flow patterns are passing by each other at varied temperatures. Without any mixing with fresh incoming wind, the warm air loses its heat through the metal column. Being based on natural ventilation principles, still wasn't enough to clear the environmental control aspects and popularize this technology to gather sufficient funds, thus Fuller's ideas were never developed. Still, there is a last remaining structure situated in Henry Ford Museum, in USA.

Chimney Cowls / Exhaust Cowls

Chimney cowls are an efficacious implementation for alleviating ventilation with a cognitive content of dispersing warm stale air into the atmosphere in addition to creating hindrance to the downward draft, insects, rain water, etc., into the building being the supplementary objective. Additive negative pressure which is resultant of revolving cowls, sometimes also be created at fixed cowls. As such they are designed for such forces, as the effect is negligible. This effect is directed by three essential factors; its type, flow rate as well as predominant wind conditions.

Exhaust cowls are generally available in following arrangements. First one has been designed with a primary aim of preventing downdraught in stack. Whereas, the second one has been designed to protect against insects, pets, birds etc. Only drawback factor being its comparatively lower resistance to downdraught.

Figure 10

(a), (b): (a) *Anti-drown Draught Static Vent. (ubuy)*. (b) *Static Cowl With Mesh. (daveschimney)*

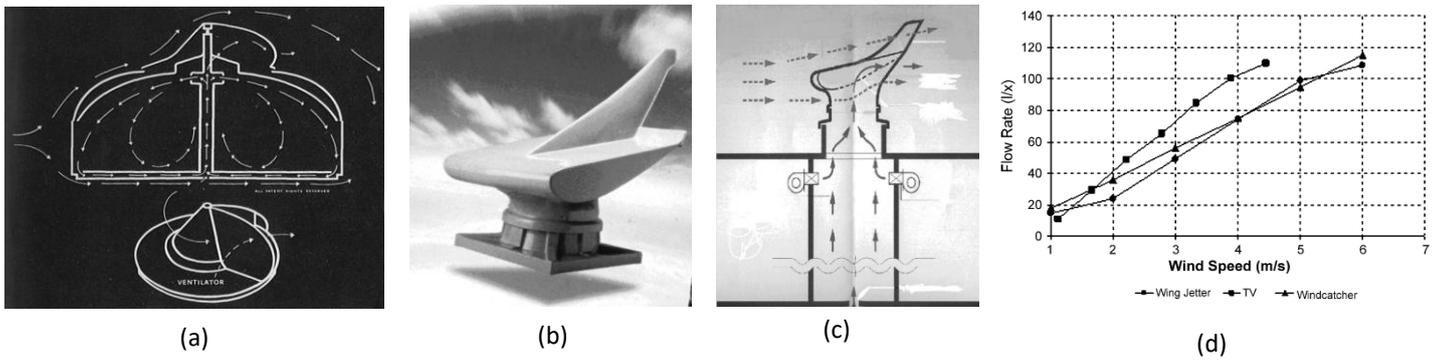


Wing Jetter System

Another ideal ventilation system is the wing jetter, which has been designed by the HASEC Corporation in Japan, Fig. 11 (b) It utilizes wing theory to escalate wind flow from beneath the system, leading to a negative pressure that throws out air, similar to that of an inverted aircraft wing. Fig. 11 (b), exhibits the working principles. In order to make sure, that the wind jetter is always facing the prevailing wind flow, large rudder is utilized. Airfoil section being the major component that is inverted but slightly below horizontal of the prevailing wind. Wind flow is diverted into two splits, as soon as it reaches the front of the system. A drag is formulated on the upper side, leading to a positive pressure. Whereas, a negative pressure is created due to lift forces on the underside, where it links with the duct.

Figure 11

(A), (B), (C), (D): (A) *Airflow Pattern in the DDM*, (B) *Wind Jetter*. (C) *Comparison Of Wind Catcher, Wing Jetter and Turbine Ventilator*, (D) *Operating Principles of the Wing Jetter System*. (Naghman Khan, A review on wind driven ventilation techniques, 2008)



System depicts a vibration free as well as noiseless operation that depicts the 8000 units installed. They are situated at a height of 1.5 m and 1.5 m wide, weighing up to 50kg. Above graph makes a comparison of three natural ventilation devices. Wing Jetter is depicting an adequate level of performance over a vivid range of wind speeds, and reaches 110 l/s at 6 m/s. However, rotating turbine ventilator which is much smaller works more efficiently. Has a throat diameter of only 400 mm, which is one-third of the Jetter and weighs only 4.5 kg. A much better comparison can be the wind catcher, that consists of much similar size, and facilitates with an exhaust flow rate of 115 l/s, on same wind flow. Due to very little, research done on wing jetter system and lack of field data makes comparison with others redundant.

Active Wind Driven Ventilation

Turbine Ventilators

Turbine ventilator is generally a wind driven air extractor. Meadows had patented its design in 1929. Turbine ventilator basically comprises of a multiple of vertical vanes (straight or curved blades) arranged in a spherical or cylindrical array mounted on a frame, Fig. 12. An all-weather protection roof is placed on the top. Rotating top section is connected to the base by a shaft and bearings. Its mechanism is based on the drag and uplift forces, generated due to incident wind on aerofoil vanes. Because of which a negative pressure is generated inside the turbine that extracts air. There is an axial movement of air at the base, whereas a radial movement at the exhaust. In absence of low prevailing forces, turbine ventilator can greatly enhance ventilation through stack effect.

Figure 12

Turbine Ventilators. (indiamart)

Havens simulated a turbine ventilator as a combination of curved centrifugal fan with wind turbine. The main reason behind such combination was that, a turbine ventilator would indulge and utilize wind power, as a result wind turbine approximation. This model simulated the tip speed, which is directly proportional to the ventilator rotational speed, as a function to wind intensity. As well as, it exhales out air through an attic while in motion, as a result a fan analogy of searching the airflow as a function of rotational speed. This system has been well explained in (Havens, 2004). However, the given model is majorly dependent on coefficient of torque as well as power for a specific turbine ventilator. Lack of knowledge, about these coefficients is a major drawback for its unpopularity.

A flow visualisation study by Lai displays the wind flow pattern around a turbine ventilator. The wind flow fragmented into two streams when it passed through the ventilator. One flow was in the direction of rotation and thus became the motive force for rotation whilst the other was in the opposite direction of rotation and dampened the ventilator rotation. The rotating blades threw the extracted air away to mix into these two wind flows, which converged in the wake region on the opposite side of the incident wind. The same study tested 3 different sized ventilators of 6, 14 and 20 in. diameters under wind speeds of between 10 and 30 m/s in Taiwan. Lai found that larger diameter ventilators would induce greater ventilation rates as expected, but surprisingly the difference between the 14 and 20 in. ventilators were 'insignificant'. Lai also tried adding an inner vane enhancement which was perceived in Taiwan to add value to the extraction process of ventilators. However, it was shown there was no significant enhancement to flow rate contrary to popular consumer beliefs although there was some benefit.

Rotating Chimney Cowl

These are basically smaller versions of turbine ventilator. They independently rotate in the prevailing wind as well as extract air major advantage being, the prevention of down draught into the chimney. Major feature being the rotating body which comprises of 'helicoidal' blades arranged in a spherical manner connected with the bearing assembly and a base duct. Mostly, they are employed in chimneys exhausting flue gases from combustible procedures. Flow rate through a chimney is directly proportional to the chimney diameter as well as wind speed. Large sized chimneys can be compared with smaller turbine ventilators in terms of flow rate.

Eco Power

A major new invention on the vertical vane ventilator is the hybrid Eco power turbine ventilator, developed by Edmonds of Australia. This innovation was an after effect of an ever-surging demand of ventilation rates and low efficiency of traditional turbine ventilators, because of varying prevailing wind flow. Eco power has a major advantage of functioning on both mechanical as well as natural way. It consists of an inbuilt motor inside the dome. Both the motor as well as ventilator consists of same bearing assembly, that can be activated by any control indicator such as temperature or humidity sensors. By kicking in motor, it can work efficiently during low prevailing wind flow. Thus, increasing its popularity. In absence of electricity, under free flow of prevailing winds, it can easily outperform the standard Hurricane vent of a similar scale by at least 15% (Edmond's Report). An electronic commutating motor facilitates energy efficient ventilation as well as sustains the throat open area by being located in the dome of the ventilator. Other attempts to add redundancy to a turbine ventilator have always focused on placing DC fans in the base duct which significantly reduces the extract flow rate.

Vawtex

Vawtex is another Vertical Axis Wind Turbine Extractor. It is a vertical axis wind turbine, that functions without any electricity, and no fuel cost leading to a pollution free ventilation. It consists of a peculiar feature, of having two wings that generates a lift and can function in a very turbulent, urban situations. Vertical axis of the turbine is connected directly to a fan that rotates with the turbine and extracts air. The first prototype is 10 feet tall consisting of a speed of 3 mph. It has been intentionally designed to

work less efficiently during the gusty winds, to minimize potential hazards, while thunderstorm. The Arts block at the Harare International School located in Zimbabwe housed the first vawtex machine. It has been employed to eradicate heat gains during the day as well as working in tandem with granite chambers underground that cool during the night, as a result keeping the building cool during the day. As a result, the classrooms are up to 8.8-degree Celsius cooler without any mechanical systems installed. However, still flow rates produced through vawtex is a less explored field, thus prohibiting its use commercially.

Figure 13

Vawtex Machine. (williams)



Conclusion

Ventilation plays a major role in giving relief to internal built environment in humidity rich areas. As air movement is the only solution in warm and humid climate for achieving thermal comfort, suitable mechanisms must be adopted for the same. The design strategies adopted for natural ventilation as a part of CFD analysis in case studies has proven to be an effective means. Similarly, an alternative means of ventilation must be adopted to increase the thermal comfort and as an alternate for energy saving.

Miscellaneous wind driven ventilation techniques have been analysed as well as classified in this study. A summary of their features and typical flow rates is depicted in Table 2, as a part of summary.

Table 2

Classification of Wind Driven Techniques

Wind driven Ventilation Techniques	Features / Application	Typical Flow Rate	Reference
Passive			
Natural Ventilation	Wind pressure and stack effects are gaining more popularity in modern structures. Primary method in most domestic buildings, indulges window openings.	Can be the sole method for ventilation.	(Faye. C,2005);(O.S. Asfour,2007)
Atria & Courtyards	Architectural integration within structures. Majorly employed in warmer regions for cooling structures.	Scale of courtyards and atriums plays a major role in depicting ventilation.	(A.Aldawoud,2008); (I. Rajapaksha,2003)
Wing Walls	Employs wind pressure in domestic buildings, to facilitate natural ventilation.	Upto 40% of outdoor airflow within the space,whereas 15% in its absence.	(C.M.Mak,2007); (M.Kolokotroni,2002)
Chimney / Exhaust cowls / Roof vents	Situated on head of chimneys and roofs, employs wind induction and stack effect.	Various depending on scale and application. Can facilitate a whole building ventilation.	(A.Pfeiffer,2007); (J.T.Montero,2001)
Wind Towers	Wind pressure/stack effects. Typically employed in warmer regions, now integrated as a part of natural ventilation strategy.	Depending on air flow, direction and height: up to 73 ac/h/300 l/s for 4 m high tower head.	(C. Karakatsonis); (E.Gratia,2007)
Windcatcher	Wind pressure/stack effects. Integrated in Schools, commercial spaces, residential structures, industrial buildings.	Reported supply of 100 l/s and 80 l/s extract at 3 m/s wind speed.	(R. Priyadarsini,2004); (Monodraught)
Wind floor air inlets	Wind floors are employed on top of high rise structures to provide natural ventilation. Air inlets are key ingredients of natural ventilation design.	Little data available.	(Building Ventilation)
Directed passive			
Cowls and Scoops	Employs wind pressure, either through tackling it or preventing the prevailing flow (static).	150 and 260 l/s at 6.5 and 9 ms/ wind speeds. Chimney cowl on a hybrid system provided up to 55 l/s.	
Rotating roof	Dymaxion dwelling machine with a rotating roof similar to a wind cowl. Used to naturally ventilate whole structure.		(W.R. Marks,1960)
Wing Jetter	Employs drag as well as lift forces to generate a negative pressure and extract air.	Up to 110 l/s at 6 m/s wind speed in laboratory conditions. Lack of field data.	(HASEC Inc.,2007)
Active			
Turbine ventilators	Combined wind turbine and extract fan design. Applied in both residential and industrial use.	Depending on size and wind flow up to 300 l/s per unit. 20–50 l/s for residential structures for a small sized ventilator. Rotating chimney cowls provided 35–90 l/s dependent on size and wind speed	(V.H. Meadows,1929); (C. Lai,2005); (J.D. Dale,1993); (C. Lai,2005);
Rotating Chimney Cowl	Small spherical rotating ventilator placed on top of chimneys. Good at preventing down draughts.	Between 35 and 87 l/s depending on size aswell as wind speed.	
Vawtex	Vertical axis wind turbine attached to extract fan.	No data available. Vawtex is being installed in various structures on a pilot study.	(greenbiz)

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