Can Naturally Ventilated Buildings be Safe in a Fire?

A study of fire propagation in naturally ventilated buildings using computer simulation.

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Fire Safe Buildings: From Prescription based safety to Performance based safety.

Buildings catching fire have become a common occurrence. Smoke happens to be the major killer in a fire incident, along with high heat and flame. Experts worldwide are taking measures to curb the threat caused by it. Traditionally we have made spaces in the building isolated from one another. We have then used fire extinguishing techniques in these spaces. This was the first principle of fire safety called compartmentalization. Taking compartmentalization for granted, fire has been dealt using prescriptive fire codes. These are 'beforehand' instructions, on compliance of which, the buildings are presumed to remain safe. There have been cases where such prescription based safety in buildings ill performed. The fault is not in the codes, but in the fact that the integrated effect of fire on the building as a whole may have not been evaluated. This gave rise to 'performance based codes' (Watts, 1994). The problem with the prescriptive approach to fire safety is that *'it might not work for new architectural features say super tall buildings, green or sustainable buildings, new fire protection systems, and using more new materials whose fire behaviour has not been tested properly.'* (Chow, 2005) Apart from the above concerns, there are concerns with regards to change in style of living. This concern revolves around increased time spent in indoor controlled environment and also increase in occupant loadings in buildings like shopping malls. This trend raises concerns and provides the path for performance based design (Chow, 2005).

Natural Ventilation: Its need, use and types.

Natural Ventilation happens through two modes: Stack and Wind Based. (ASHRAE, 2013) (Givoni, 1994) (Heiselberg, 2004) (Standards, 2004) Stack Ventilation is used for bringing in fresh

air and removing odour (health reasons). It depends upon inlet area; stack height and temperature difference only. (Heiselberg, 2004) (Lomas, 2007) (Standards, 2004) (Standards, 2004) Wind-based ventilation is used to give suitable wind changes per hour which create comfort due to cooling effect in tropical climates. (Givoni, 1994) (Heiselberg, 2004) (Standards, 2004) This is either stand-alone where segregated spaces are cross ventilated or this happens across floors and spaces where large common spaces are created (Bansal, et al., 1994) (Chow & Wan, 2009). Stack ventilated buildings improve the conditions of work in the otherwise poorly ventilated buildings (Hossain, et al., 2014). They may also end up in consuming less energy for 'space conditioning than typical mechanically ventilated or air-conditioned buildings.' (Lomas, 2007) This is advantageous for gaining a higher score in the GRIHA code. (GRIHA, 2016). Work done by Building Technology Research Group at MIT¹ has established that the Naturally Ventilated buildings fall into the five types of typologies: Single Sided, Cross Ventilated, Central Atrium, Chimney Type and Ventilation Shaft type.

Figure 1: Natural Ventilation Typologies.

¹ (Prof Leon Glicksman. Gang Tan PhD'05, Jinchao Yuan PhD'07, Rebecca Rich MEng'11, Alejandra Menchaca PhD'12, Dominguez PhD'15, Cheng MSc'13)

Natural Ventilation and Fire Safety: Are both possible together?

With the onset of Green Buildings, experiments with Natural Ventilation began. The whole building started to act as one space. This was done by a continuity provided to the flow of air horizontally as well as vertically. Common Central Atria started to be prominently used in building designs. While one group of researchers state that natural ventilation systems will not be accepted by the fire authorities and it may prove to be expensive in order to meet the codes (Short, et al., 2006) others say that co-existence of fire safety and natural ventilation may be possible (Huang, et al., 2016)

Evaluating smoke spread using computer simulation.

For fire growth and spread studies, the earlier techniques after the empirical ones used computers using the 'zone' models where two zones were analysed in a given space (Hasib, et al., 2007) (McGrattan & Miles, 2016) (Salem, 2010) One such 'Zone Modelling Software' is CFAST: Consolidated Fire and Smoke Transport which simulates the impact of past or potential fires and smoke in a specific building environment.

Steps of Investigation using Computer Simulation:

1. The Naturally Ventilation Buildings were classified into five general typologies, namely:
 - a. Single Sided
 - b. Cross Ventilated
 - c. Shaft Type
 - d. Chimney Type
 - e. Atrium Type

This classification was derived from literature study.

2. MIT Coolvent was used for the Natural Ventilation analysis. The Individual typologies were tested for Natural Ventilation and all the above stated positive movement of air through the spaces provided for natural ventilation. It may be noted that this is limited to investigating a continuous flow of air in the spaces.

3. The models of all the typologies of Natural Ventilation derived from the above study were replicated on the Fire Software: CFAST.
4. Similar Fire Inputs were provided to all the typologies and simulations were run in the same conditions. A Control for the experiment was set in the form of a Compartmentalised building of the same matching with all the typologies of Natural Ventilation. Additional iterations with a varied condition in each typology were also performed.
5. The results were compiled and analysed based on the parameters which determine the safety of any inhabitants of the buildings. These are:
 - a. Max Temperature in Fire Zone.
 - b. Height of the smoke layer from the floor. This zone is the critical zone.
 - c. The temperature in the critical zone
 - d. Critical Time for evacuation. This was dependent upon the critical height. Critical Height refers to the height from the floor where a person can crawl in the presence of smoke in the room.

From the above output, the analysis was made on whether a specific condition of the typology/or a typology was safe and whether it afforded enough time for evacuation.

Figure 2: Steps of Investigation

Base Case Simulation

The First case is the Base Case which acts as our control. Here in case of the fire we could clearly see that the smoke gathers only in the ground floor where there is a presence of fire.

Figure 3: The Fire Simulation in the Base Case

Single Sided Ventilation Simulation

This is much similar to the base case simulation except for the fact that the Single Side Ventilation has two openings one top of the other on the wall. The details have been provided in the section before. The output is much like the case of the Base Case.

Figure 4: Single Sided Ventilation Fire Simulation.

Cross-Ventilated Case Simulation

This is the scenario of Cross Ventilation in case of a doubly loaded corridor situation. The results clearly show a spread of the smoke into the corridor and the adjoining room. Apart from this, there is no spread of the smoke to the higher floors due to inter floor compartmentalisation.

Figure 5: Cross Ventilation Fire Simulation

Shaft Type Ventilation Simulation

This is an example of the shaft which goes vertically connecting the various floors. The shaft is the carrier of the air and it very effective for the ventilation due to stack effect, but due to the same reason we see its ill effect on the spread of smoke and fire. In the simulation we see that the smoke on the Ground floors gathers on the second floor. The key point here is the opening size of the shaft ceiling. If the shaft ceiling size increases to fully open, there is exhaust of the smoke and no smoke gathers in the First or the Second Floor.

Figure 6: Shaft Type Ventilation with Base Case Fire Simulation

Figure 7: Shaft Type Ventilation with Iteration 2 where the Ceiling openings have been blocked

Figure 8: Shaft Type Ventilation Fire Simulation where the Ceiling openings are fully open

Chimney Type Ventilation Simulation

In this type also, we clearly see the spread of smoke into the upper floors of the building. What is worse is that the upper floors have the smoke at uniform height throughout the space whereas the fire source space has the smoke at only the higher level. This is critical to the safety of the humans who would be located in the higher floors of such buildings.

In the iteration, we can see that the ceiling opening of the shaft has been completely sealed and there is more smoke built up and more exhaust from the upper floors.

Figure 9: Chimney Type Ventilation Fire Simulation as the Base Case

Figure 10: Chimney Type Ventilation Fire Simulation where the ceiling opening is completely sealed

Atrium Type Ventilation Simulation

Atrium is a very common way of Enhancing air continuity of spaces in a building. It also enhances the aesthetics of the building. In this simulation we clearly see the easy spread of smoke into all the spaces due to the fire in the lower floor. It is a clear indication of the risk attached to use of open spaces connected to each other. This has been quantified later in the Final Chapter.

The Iteration has been done where the Ceiling Vent of the shaft has been sealed to see the enhanced outlet of smoke from the second floor of the Building.

Figure 11: Atrium Type Ventilation Fire Simulation Base Case

Figure 12: Atrium Type Fire Simulation where the Atrium has been completely sealed at the Ceiling

Results and Discussion:

The Results were in the form of Colour coded visual flow diagrams which were analysed and the key parameters were tabulated as follows:

Table 1: Table enumerating the key outcomes of the fire tests.

S. No.	Description	Max deg C in Zone	Height in Zone(critical)	Max deg C in critical	Safe: Y/N	Time Safe	Crucial Time (s)
1	Control: Fully Compartmentalized	>180	<1m	N/A	Y	Y	200
2	Single Sided Ventilation	>240	>1m	N/A	Y	Y	450
3	Cross Ventilation	>240	<1m	150	Y	Y	190
4	Shaft Type Ventilation: Default	>105	<1m	38	N	Y	670
5	Shaft Type Ventilation: No Opening in Ceiling	110	<1m	40	N	Y	740
6	Chimney Type: Default	>150	<1m	>78	N	N	40
7	Chimney Type: No Opening in Ceiling	>100	<1m	>75	N	Y	170
8	Atrium Type: Default	>110	<1m	>40	N	Y	170
9	Atrium Type: Without Ceiling	>100	<1m	>50	N	Y	175
10	Atrium Type: Half Atrium Open	>110	<1mS	<35	Y	Y	180

11	Courtyard Type	>350	>1m	<30	Y	N/Y	60
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In the above Table: Description means the Typology of the Naturally Ventilated Building along with a Parametric Iteration of the same, if any. Max deg C in Zone means the maximum temperature in the Zone which is on fire. Critical Zone means that zone which is most affected by the fire in all the zones. Here the temperature is provided along with the safe length of area available for evacuation without the smoke. Critical time is the time within which either people should fully evacuate or the fire extinguishing systems should start to work. Safe Y/N means whether the zone is safe at the end of simulation. Time safe means whether the zone is safe to evacuate within 2.5 minutes²

On the basis of the above results, the following recommendations may also be followed by architects:

- The Ratio of Ceiling to Window Openings should be in the tune of >6.25 in order for the Smoke to escape through the Ceiling and not be delay trapped in the spaces itself.
- Even after application of the thumb rule, EVERY Naturally Ventilated Building should be subjected to a Performance-Based Simulation Test. Following only the prescriptive codes (like Byelaws) can be fatal as they are made assuming buildings to be compartmentalised. Every Atrium, Central Courtyard space, Chimney should have an outside exhaust and should NOT be completely sealed. In this case, the top-most floor will act as an outlet, preventing loss of life.
- The National Building code 2016 recommends all the buildings with an Atrium to go through a Simulation based test. Such recommendation should be adhered to.

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² Thumb rule based on “Fire grading of buildings”, No. 29, Part III, Personal Safety, Post-war Building Studies, London, UK (1952).

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