Ventilative cooling design

Prof. Guilherme Carrilho da Graça

DEGGE, Faculty of Sciences of the University of Lisbon, Portugal

MSc (MIT), PhD (UCSD), researcher in building energy efficiency, natural ventilation design, thermal and airflow simulation. Consultant, since 2002, in high performance building design. Worked in Europe, US, South America and Africa.

Ventilative cooling (VC):

- VC is the application of the cooling capacity of the outdoor air flow by ventilation to reduce or eliminate the energy demand for mechanical cooling in buildings.
- Ventilative Cooling utilizes the cooling potential of cool outdoor air.
- The airflow driving force can be either natural, mechanical or a combination of the two.
- The most common technique is the use of increased daytime ventilation airflow rates and/or nighttime ventilation.

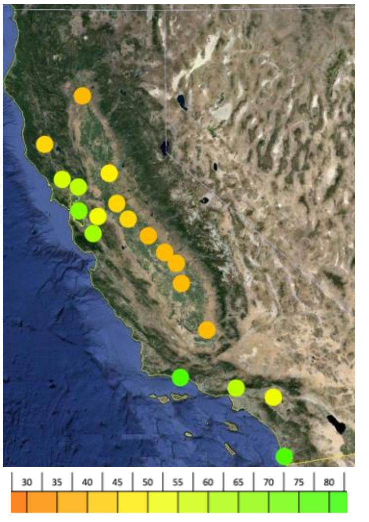
Introduction

Most modern office buildings use mechanical cooling in moments when an optimized ventilative cooling (VC) system could work.

Mechanical ventilation: 5-15W/m^2… + mechanical cooling… **HVAC energy consumption: 50%-60%** of total building energy consumption.

The best VC systems are able to replace mechanical cooling systems in the milder months of the year.

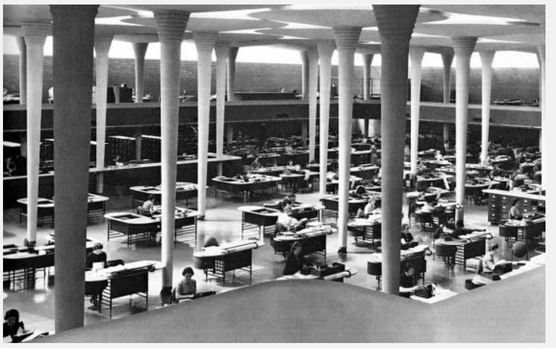
A successful **VC cooling system could halve office building energy consumption**.



Why is air conditioning a dominant feature in modern office buildings, even when natural ventilation (VC) has worked for centuries?

Early twentieth century offices were either narrow floor plan or large spaces with high ceiling.

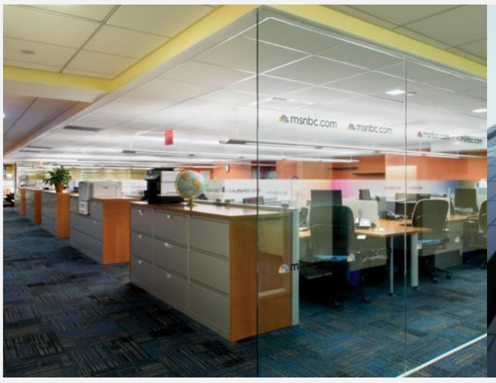
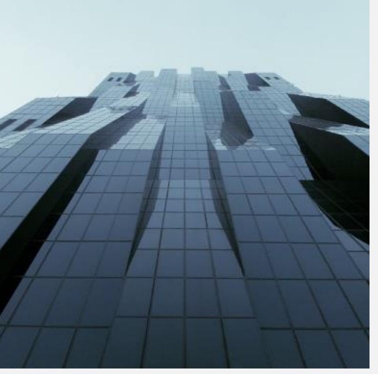
These configurations were good for VC either due to proximity of to window or the existence of an upper air layer to accumulate and exhaust indoor pollutants.



Why is air conditioning a dominant feature in modern office buildings, even when natural ventilation (VC) has worked for centuries?

The modern office is a harsh environment for VC.

NV cannot ensure thermal comfort in deep floor plans with high internal gains that, in many cases, are aggravated by a fully glazed solar collector like facade.

Natural light and spectacular architecture compromise VC systems…

In contemporary designs the desire to bring in natural light combined with the pressure for spectacular architecture leads to large glazed areas without proper shading that result in large solar gains that a VC system cannot effectively remove.


What can VC do and how are people doing it?

For non-domestic buildings VC can provide fresh air and limited cooling (sufficient in cold and mild weather periods) in spaces with limited depth or large height.

Performance data from buildings with VC indicates that minimum fresh air is usually achieved in spaces with limited depth (up to 6m or 15m) or wider rooms with large ceiling height (>5m) and high level exhaust.

The cooling capacity of most NV systems is limited to 20-30W/m^2 in cold or mild weather. When its warm outside....VC cooling power may go down to 0W/m^2.

The **typical size of the openings used is ((A_{in}+A_{out})/A_{room}):**

- **1-2%** for systems operating up to 18-20ºC outdoor.
- **3-5%** for systems operating up to 25ºC outdoor.
- **Up to 10%** for NV systems that try to provide warm weather cooling.

Does stack always improve wind-driven VC?

Two different flow driving forces that combine to drive all natural VC systems.

Stack is weaker but more reliable, because it is self adjusting: sensible heat internal loads drive the ventilation flow in a proportional way.

Wind is stronger but suffers from constant fluctuations in intensity and direction on a yearly, daily and minute scale.

In a given instant, the typical urban atmospheric boundary layer turbulence intensity is 10-20%, leading to wind pressure fluctuations of up to 40% (even more considering changes in wind direction).

Since every location will have moments of nearly zero wind pressure every wind driven **natural VC systems need to be designed for a worst case scenario of operating only with buoyancy forces.**

International Energy Agency

Ventilative Cooling Design Guide

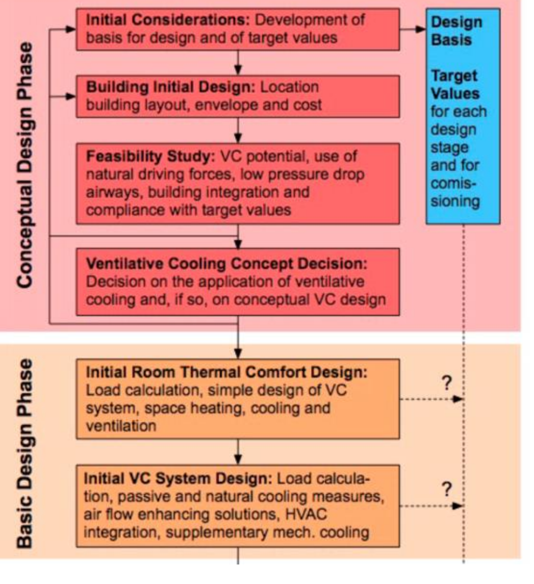
Energy in Buildings and Communities Programme
March 2018

Editor

Per Heiselberg, Aalborg University, Denmark (ph@civil.aau.dk)

Authors

Adam O'Donnavan, Cork Institute of Technology, Ireland
Annamaria Belleri, Eurac Research, Italy
Flourentzos Flourentzou, Estia SA, Switzerland
Gou-Qiang Zhang, Hunan University, China
Guilherme Carrilho da Graca, University of Lissabon, Portugal
Hilde Breesch, KU Leuven, Belgium
Maria Justo-Alonso, SINTEF Byggforsk, Norway
Maria Kolokotroni, Brunel University, United Kingdom
Michal Pomianowski, Aalborg University, Denmark
Paul O'Sullivan, Cork Institute of Technology, Ireland
Per Heiselberg, Aalborg University, Denmark
Peter Holzer, Institute of Building Research & Innovation, Austria
Theofanis Psomas, Aalborg University, Denmark



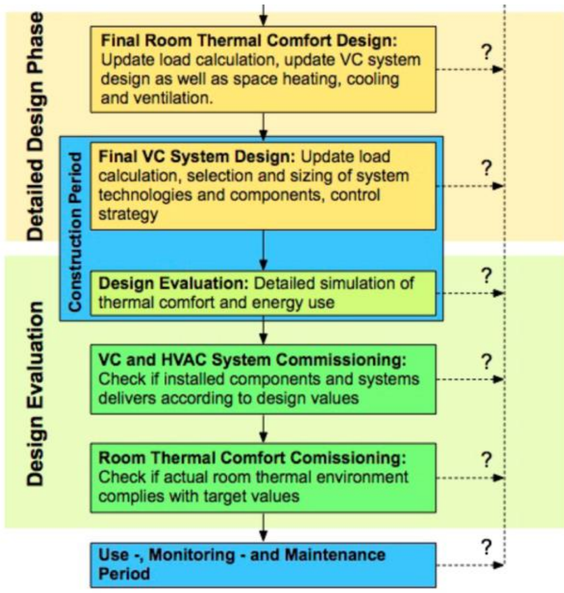


Figure 8. Design procedure for ventilation and ventilative cooling.

Ciências ULisboa

Table 8. Evaluation of the need for mechanical assistance in driving the air flow.

Ventilative cooling: Need for fan assistance?						
Outdoor environment	**N**		**M**		**Y**
Cold – Winter (heat recovery needed)					
Cold – Summer					
Moderate					
Hot and dry – Winter					
Hot and dry – Summer (low temp. difference)					
Hot and humid – Winter					
Hot and humid – Summer (mechanical cooling needed)					
Dense urban area with low wind speeds (low natural driving force)					
Dense urban area with high night temperatures (heat island)					
High pollution level in the area (air filtration needed)					
Noisy surroundings (high noise insulation needed)					
Building heat load level	**N**		**M**		**Y**
Low heat loads < 20 W/m² during occupation – Cold (> 10°C from comfort zone) (heat recovery needed)					
Low heat loads < 20 W/m² during occupation – Temperate (2-10°C from comfort zone)					
Low heat loads < 20 W/m² during occupation – Hot and dry (-2°C …. +2°C from comfort zone)					
Low heat loads < 20 W/m² during occupation – Hot and humid					
Medium heat loads 20 -30 W/m² during occupation – Cold (> 10°C from comfort zone) (heat recovery needed)					
Medium heat loads 20 -30 W/m² during occupation – Temperate (2-10°C from comfort zone)					
Medium heat loads 20 -30 W/m² during occupation – Hot and dry (-2°C …. +2°C from comfort zone)					
Medium heat loads 20 -30 W/m² during occupation – Hot and humid					
High heat loads > 30 W/m² during occuation – Cold (> 10°C from comfort zone) (heat recovery needed)					
High heat loads > 30 W/m² during occuation – Temperate (2-10°C from comfort zone)					
High heat loads > 30 W/m² during occuation – Hot and dry (-2°C …. +2°C from comfort zone)					
High heat loads > 30 W/m² during occuation – Hot and humid					
Thermal comfort	**N**		**M**		**Y**
High requirements for 95% of occupancy hours					
Normal requirements for 90% of occupancy hours					
Normal requirements for 80% of occupancy hours					
Requirements adaptive to outdoor conditions					
Integration with other natural cooling solutions	**N**		**M**		**Y**
Chilled slab by ground water exchange					
Earth to air heat exchanger					
Evaporative cooling					

Ciências ULisboa

Table 9. Evaluation of the need of supplementary natural or mechanical cooling solutions.

Ventilative cooling System: Need for supplementary cooling?						
Outdoor environment		**N**		**M**		**Y**
Cold (> 10ºC from comfort zone)		■				
Temperate (2-10ºC from comfort zone)			■	■	■	
Hot and dry (-2ºC …. +2ºC from comfort zone)				■	■	■
Hot and humid						■
Dense urban area with low wind speeds (low natural driving force)			■	■	■	
Dense urban area with high night temperatures (heat island)			■	■	■	
High pollution level in the area				■	■	■
Noisy surroundings				■	■	■
Building heat load level:		**N**		**M**		**Y**
Low heat loads < 20 W/m² during occupation	Cold (> 10ºC from comfort zone) (heat recovery needed)	■				
	Temperate (2-10ºC from comfort zone)	■	■	■		
	Hot and dry (-2ºC …. +2ºC from comfort zone)			■	■	■
	Hot and humid					■
Medium heat loads 20 -30 W/m² during occupation	Cold (> 10ºC from comfort zone) (heat recovery needed)	■	■			
	Temperate (2-10ºC from comfort zone)		■	■	■	
	Hot and dry (-2ºC …. +2ºC from comfort zone)				■	■
	Hot and humid					■
High heat loads > 30 W/m² during occuation	Cold (> 10ºC from comfort zone) (heat recovery needed)		■	■	■	
	Temperate (2-10ºC from comfort zone)			■	■	■
	Hot and dry (-2ºC …. +2ºC from comfort zone)					■
	Hot and humid					■
Thermal comfort:		**N**		**M**		**Y**
High requirements for 95% of occupancy hours				■	■	■
Normal requirements for 95% of occupancy hours			■	■	■	
Normal requirements for 80% of occupancy hours		■	■	■		
Requirements adaptive to outdoor conditions		■	■			
Building and system:		**N**		**M**		**Y**
Low level of exposed building thermal mass			■	■	■	
Moderate level of exposed building thermal mass		■	■	■		
High level of exposed building thermal mass		■				
High space- and use-flexibility			■	■	■	

Ventilative cooling design

Thanks!