Ventilative Cooling in International Case Studies – Lessons Learned

During cooling seasons, a progressively warmer and increasingly urban world is leading to hostile internal thermal environments in many high-performance buildings. Correctly implemented, Ventilative Cooling can mitigate unwanted building overheating while minimising cooling loads. Identifying different solutions with proven performance can be invaluable to the building community.

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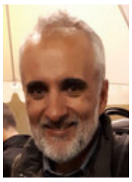

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The recent IEA-EBC Annex 62 State of the Art Review report recently defined Ventilative Cooling (VC) as, 'The application of ventilation flow rates to reduce the cooling loads in buildings. Ventilative Cooling utilizes the cooling and thermal perception potential of outdoor air. The air driving force can be natural, mechanical or a combination' [1]. Within Annex 62, the role of Subtask C was to analyse and evaluate the performance of real VC solutions as well as investigate design methods and tools adopted using similar criteria and methods. In doing this the objective was to identify lessons learned and develop recommendations for design and operation of VC as well as identifying barriers for the application and functioning of VC. In total 15 case studies were included in the Annex 62 project [2]. This article gives an overview of the characteristics and lessons learned of investigated case studies in Annex 62. A final project report is due to be published containing a detailed summary of the case studies along with a book of case study brochures. Further details are available at http://www.venticool.eu.

Overview of case studies: building properties, design and sizing

The 15 case studies that are presented here are located in 10 countries. Three were completed in 2014, four in 2013, two in 2012, four in 2011 with the two remaining case studies in 2003 and 2007. Over 85% of case studies were built after 2010. There are three office buildings, five educational buildings, four residential, one mixed use and one kindergarten. Eight of the case studies have rural surroundings and seven have urban surroundings. Four case studies were refurbishment projects. **Table 1** summarises the key categorical information of the case study buildings.

The average elemental U-value for all 15 case studies is 0.35 W/m²K, which appears high but there is a large spread in individual values, with an average standard deviation across all elements of 0.27 W/m²K. Six of the case studies can be classified as having heavy or very heavy thermal mass according to ISO 13790:2008.

Table 1. Building Type, size and year of completion for all case studies.

No	Country	Building	Type	Year (New or Refurb)	Floor Area m²	Strategy
01	IE	zero2020	Office	2012(R)	223	Natural
02	NO.1	Brunla Primary school	Education	2011(R)	2500	Hybrid
03	NO.2	Solstadbarnehage	Kindergarten	2011(N)	788	Hybrid
04	CN	Wanguo MOMA	Residential	2007(N)	1109	Mechanical
05	AT.1	UNI Innsbruck	Education	2014(R)	12530	Hybrid
06	AT.2	wkSimonsfeld	Office	2014(N)	967	Hybrid
07	BE.1	Renson	Office	2003(N)	2107	Natural
08	BE.2	KU Leuven Ghent	Education	2012(N)	278	Hybrid
09	FR	Maison Air et Lumiere	House	2011(N)	173	Natural
10	IT	Mascalucia ZEB	House	2013(N)	144	Hybrid
11	JP.1	Nexus Hayama	Mixed Use	2011(N)	12836	Natural
12	JP.2	GFO	Mixed Use	2013(N)	399000	Hybrid
13	PT	CML Kindergarden	Education	2013(N)	680	Natural
14	UK	Bristol University	Education	2013(R)	117	Mechanical
15	NO.3	Living Lab	Residential	2014(N)	100	Hybrid

Good air tightness is a recurring feature of most case studies with the average Air Change Rate (ACR) from infiltration at 1.13 h^{-1}, ranging from 0.51 to 1.85 h^{-1}. **Table 2** gives some insight into the design influences for each of case studies in urban or rural surroundings.

Ventilation system sizing

Information on the recommended aperture area when sizing natural and hybrid VC systems is critical for the building designer. For almost all case studies, natural ventilation was adopted as either the sole source of VC or as part of a wider strategy, with, for example, natural supply and mechanical exhaust. It is generally beneficial to identify possible dimensionless parameters that provide a characterization of the system, thus allowing for similarity investigations across multiple different systems. Owing to this and the inherent importance of the ventilation opening geometry to

Table 2. Design Influences (R = Rural; U = Urban; *= residential).

Country	Building	Surroundings	Lower Initial costs	Lower Maintenance Costs	Lower Energy Costs	Reducing Solar Loads	Reducing Internal Loads	Reducing External Noise	High Internal noise propagation	Elevated Air Pollution	Avoiding Rain Ingress	Insect Prevention	Burglary Prevention	Reduced Privacy	Air Leakage
IE	zero2020	R	H	M	H	H	L	L	L	L	M	L	H	M	M
NO.1	Brunla School	R	H	H	H	L	M	L	L	H	M	L	L	L	H
NO.2	Solstadbarnehage	R	L	L	H	L	L	L	M	H	L	L	L	L	H
CN	Wanguo MOMA*	U	H	M	H	H	L	L	L	L	M	L	M	L	H
AT.1	UNI Innsbruck	U	H	H	H	M	L	M	L	L	M	L	L	L	H
AT.2	wkSimonsfeld	R	H	H	H	M	L	L	L	L	L	L	L	L	M
BE.1	Renson	R	L	M	L	H	H	H	L	L	L	L	L	L	L
BE.2	KU Leuven Ghent	U	H	L	H	H	H	L	L	L	M	L	L	L	H
FR	MAL*	U	M	M	L	H	M	L	L	H	L	L	M	L	M
IT	Mascalucia ZEB*	R	H	M	H	H	L	L	L	L	L	L	M	L	M
JP.1	Nexus Hayama	R	M	M	H	H	L	L	L	L	M	H	H	M	M
PT	CML Kindergarden	U	H	L	L	M	M	L	L	L	M	M	M	M	L
JP.2	GFO	U	H	M	L	L	L	L	L	L	L	L	L	L	L
UK	Bristol University	R	H	H	H	L	H	L	M	L	M	M	H	L	L
NO.3	Living Lab*	U	L	L	H	H	M	L	M	L	H	L	L	L	H

the delivered airflow rate, a parameter calculated as the percentage opening area to floor area ratio, or POF, was obtained for each case study. The opening area used is the maximum available geometric opening area and does not incorporate the flow effects of the opening. We see a large spread of values for the case studies. 65% of buildings had POF values less than 4%. There seems to be no correlation with building category. The two highest values are from climates with hot summers. Two of the lowest three values are from fully naturally ventilated offices. Natural ventilated buildings had a POF of 3.6% while hybrid buildings had a POF of 4.6%, or 6.0% when the Italian case study is included. Although several building regulations impose a minimum floor to opening area ratio of 5% there is a generally accepted rule of thumb for designers when sizing openings at the concept stage of 1-3%. The low end of this range appears inadequate when compared with these case studies. A range of 2-4% seems more reasonable.

VC strategies, control and performance

Table 3 gives an indication as the VC strategies used for all case studies. Most control strategies for occupied periods used the internal zone temperature and an external temperature low limit as controlling parameters in ventilation strategies. The overall range of indoor set-point temperatures were observed to be between 20-24°C where the mean internal air temperature set-point was around 22°C. The range of low temperature limits for outside air was between 10-18°C, with a mean external low temperature limit set-point of around 14°C. Around 54% of the case study buildings had a manual override switch or allowed occupant-controlled ventilation during occupied hours as part of their typical occupied control strategies. All-natural ventilation case studies allowed a form of occupant interaction with the ventilation system while 60% of hybrid systems allowed occupant interaction with the ventilation system. For systems that controlled depending on relative humidity an average set-point of 60% was observed. There were differing ranges of acceptability depending on whether the VC system was mechanical or natural. 69% of the case studies investigated incorporated a night ventilation strategy as well as an occupied ventilation control strategy. Typically, night ventilation strategies had different control parameters than ventilation strategies during occupied hours. The night ventilation strategies incorporated typically had a set-point for the zone as well as a limit on the properties of the air brought into the building also. The range of internal temperatures used for night ventilation strategies was between 15-23°C while the low limits on the external air temperature were between 10-18°C. Night ventilation was also dependent on the presence or absence of rain and wind speeds above a certain value. Typically, the wind speed had to be below 14m/s or 10m/s respectively and with no rain for night ventilation systems to operate. In cases where relative humidity was the control parameter night ventilation would not be activated unless the relative humidity was below 70% for a given zone.

All case studies completed performance evaluations involving various different measurement campaigns. Each case study adopted different approaches and investigated different phenomena. This included ventilation rate measurements, thermal comfort studies, analysis of internal thermal environments, investigation of the performance of specific solutions such as displacement ventilation, chimney-stacks, hybrid systems, cross flow

Table 3. VC Strategies in all Case Studies.

		VC Strategies								
Country	Building	Natural Driven	Mech. Supply Driven	Mech. Exhaust Driven	Natural Night Ventilation	Mech. Night Ventilation	Air Conditioning	Indirect Evap. Cooling	Earth to Air Heat Exch.	Phase Chang eMaterials
IE	Zero2020	X			X					
NO.1	Brunla Primary school	X			X					
NO.2	Solstadbarnehage	X		X	X	X				
CN	Wanguo MOMA		X	X		X	X			
AT.1	UNI Innsbruck	X		X	X					
AT.2	WkSimonsfeld	X		X						
BE.1	Renson	X			X					
BE.2	KU Leuven Ghent	X		X				X		
FR	Maison Air et Lumiere	X								
IT	Mascalucia ZEB	X			X				X	
JP.1	Nexus Hayama	X					X			
JP.2	GFO Building	X				X	X			
PT	CML Kindergarden	X			X					
UK	Bristol University					X	X			X
NO.3	Living Lab	X								

ventilation etc. More information on specific studies can be found at http://www.venticool.eu. The project identified that in order to assess the minimum performance of the VC strategy one cooling season of internal air temperatures data should be obtained. This data should then be compared with an overheating risk criteria. Two static thresholds were chosen with each case study quoting the percentage of hours exceeding this value. **Table 4** presents a selection of results from the case studies.

Lessons Learned -Design and construction

Designing a building to incorporate VC can be challenging and may require a lot of detailed building information. While each challenge was different the main key lessons were as follows:

- Detailed building simulation is important when simulating VC strategies. Most case studies analysed highlighted the need for reliable building simulations in the design phase of a VC system. This was considered most important when designing for hybrid ventilation strategies where multiple mechanical systems need harmonization. Some studies also said that simulating the window opening in detail was important.
- Customisation may be an important factor in designing a VC system. In order to ventilate certain buildings, it may be necessary to design custom components. Some case studies highlighted the need to have custom design systems that were specific to country regulations and the use of a building or space. Some consideration should also be given to the clients' expectations around specific issues like rain ingress and insect prevention.
- VC systems were considered a cost-effective and energy efficient in design by most case studies, but particularly with naturally ventilated systems. It was indicated that designing with the integration of manual operation and control was important, particularly in a domestic setting.

Lessons Learned - Operation and Post Occupancy

While systems may be designed to have high levels of comfort, IAQ and energy performance, achieving this was difficult. All case studies emphasised that monitoring

Table 4. Preliminary results of VC performance evaluation.

Country	Building	Summer Design Values		Overheating criteria / note	% Occ hrs above threshold		Occ hrs
		T_e	$T_{i,o}$		28°C	25°C	
IE	zero2020	26.0	25.0	T_i<28°C for 99% occ hrs	0.7	5.5	2600
NO.1	BrunlaSchool	25.0	26.0	T_i> 26°C	0.0	0.0	2600
NO.2	Solstad	25.0	24.0	T_i> 26°C	0.0	0.0	2860
AT.1	UNI Innsbruck	34.0	27.0	T_i< 26°C for 95% occ hrs	1.1	16.2	2600
AT.2	wkSimonsfeld	34.5	24.0	T_i> 26°C zone / T > 29 gallery	0.0	5.0	3250
JP.1	Nexus Hayama	26.0	26.0	T_i< 28°C for 99% occ hrs	1.0	40.0	8736
PT	Kindergarden	30.0	26.0	80% acceptability 99% hr occ	2.6	16.0	3640
UK	Bristol Uni	26.0	25.0	Adaptive TC Model	–	–	2600
BE.2	Renson Builing	–	–	Tz < 26°C for 95% of hocc Tz < 28°C for 99% of hocc	0.3	11.4	2600
BE.1	KU Leuven Ghent	–	25	T_i < 26°C for 95 % hr occ	0.3	5.1	1560
NO.3	Living Lab	25	26	T_i> 26°C	24	2.6	832

a buildings performance post occupancy is important if not essential in building performance optimisation. While some key lessons were more specific than others the following general observations were made:

- Engaging with the building owners or operators as soon as possible is integral to guaranteeing building performance for IAQ, comfort or energy savings. For some case studies this specifically meant educating or working with the facilities operator or manager for the building, for others it meant educating the building occupiers themselves.
- It was suggested by some that this engagement should occur already in the design stage.
- VC in operation is generally a good option. Case studies comment on the reduction of overheating and improvement of comfort conditions in the buildings that used outside air. However, correct maintenance and calibration of the systems is integral to maintaining performance.
- Some case studies highlighted the need to exploit the outside air more with lower external air control limits during typical and night-time operation. Others suggested that exploiting the thermal mass of a building was key. However, it was noted that care must be taken with considering these low temperatures as some case studies, particularly in cold climates observed more incidences of overcooling than overheating.
- Each brochure includes lessons learned in a dedicated section at the end of the brochure.

More details related to specific lessons learned can be found in the final summary reports for IEA-EBC Annex 62 at http://www.venticool.eu.

Conclusions

In the last two decades, the use of VC has been slowly increasing. The best contemporary designs combine natural ventilation with conventional mechanical cooling. When properly designed, and implemented, these hybrid approaches maximize the VC potential while avoiding overheating during the warmer months. Yet, despite the potential shown in the case studies presented here, and other existing examples, the potential of VC remains largely untapped. The characteristics of each case study appeared unique due to the need for the approach to respond to a specific climate, the building usage, morphology and client criteria. Hybrid systems are the most common type of system for VC and the use of mechanical fans to compliment a passive system should be strongly considered where possible. A combination of automated and manual control seemed to be the most adaptable and reliable solution to providing a system that worked well with its users satisfied with its operation. The use of simulation in the VC system design phase can reduce the uncertainties that are usually associated with natural ventilation systems. A POF value in the region of 2–8% was recorded and choosing a value on the larger end of this range at the concept design stage may be appropriate. ■

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