Freevent : ventilative cooling and summer comfort in 9 buildings in France

Andres LITVAK[1], Anne Marie BERNARD *[2], Nicolas PIOT[3], and Damien LABAUME[4]

[1] CDPEA/APEBAT
Present address: Cerema Sud-Ouest, DAIT/GBAT
Rue Pierre RAMOND, CAUPIAN
33160 St Médard en Jalles FRANCE

2 ALLIE AIR
4 clos Ballet
01800 Meximieux, France
**annemarie.bernard@allieair.fr*

3 EGE
6, rue du Mas de Bonniol
34880 LAVERUNE, FRANCE
nicolas.piot@sege.fr

4 ALDES
18 avenue Charles de Gaulle
31130 BALMA, FRANCE
damien.labaume@aldes.com

ABSTRACT

Recent studies have shown that ventilative cooling reduces overheating, improves summer comfort and decreases cooling loads. Therefore, it is considered as one of the most efficient way to improve summer comfort. Although, HVAC designers still lack of guidelines to improve the energy and comfort efficiency of their installations.
This paper is issued from the research project FREEVENT that mainly deals with field measurement evaluations of summer comfort and evaluates the efficiency of ventilative cooling in French residential and office buildings. The objective of this work is to quantify and qualify the efficiency of the ventilation systems and the energy and thermal performance of buildings. For this, two field measurement campaigns were conducted: ventilation checks on 9 sites and full measurements and monitoring on 6 of them.
We present the results of FREEVENT project, including state of the art and onsite measurement campaigns. Onsite conditions, buildings' architecture characteristics, thermal inertia, solar shadings and various constraints are discussed as main designing choices for efficient ventilative cooling systems. We show how performance is linked to good sizing, design, correct use of thermal destocking, and - last but not least - correct fit in and correct take over, checking airflows as well as controls of the system.
Our study concludes with recommendations guidelines for designers, published in a French guide.

KEYWORDS

Ventilative cooling, summer comfort, energy efficiency, field measurement, ventilation

1 INTRODUCTION

1.1 Ventilative cooling, a solution to provide summer comfort in passive buildings

Trends to drastically reduce energy consumption in low energy buildings restrict active cooling modes for air conditioning. It can therefore negatively impact summer comfort in

such buildings. Indeed, many recent post-occupation evaluation studies revealed that new buildings with high thermal inertia, high insulation and airtight performances show very often overheating periods in summer or in mid-seasons with high indoor loads.
Solar protections and heat loads reductions have been identified as major contributions to reduce overheating risks. As a matter of fact, ventilative cooling ensures an interesting mode to promote summer comfort once all techniques and solutions of solar protection and load reduction have been exhausted. A study from Belgium (IBGE, 2010) shows the impact and the interest of integrating ventilative cooling in new buildings, either during occupation of the premises (free-cooling) or in night periods (night cooling).

1.2 Learnings from previous works

The relevance of ventilative cooling was studied theoretically and proved in most European climates (Pellegrini, 2013), and especially in cities where the urban heat island reinforces the cooling needs (Kolokotroni, 2013). A specific study (Pellegrini, 2013) shows that the relative potential gain over air conditioning and ventilation energy consumption can vary according to the climate : 83% in Athens (GR), 65% in Rome (IT), less than 6% in Berlin (D) and less than 1% in Copenhagen (DK). Besides theoretical studies, several case studies in Denmark (Foldbjerg, 2012), in Minnesota, USA (Coolson, 2011), in Cyprus (Florntzou, 2012), in France (Peuportier, 2013), in Italy (Grosso, M.) and Belgium (Pollet, 2013) prove the efficiency of ventilative cooling for a large variety of buildings. The ventilative cooling potential was proved in single family detached houses from the program MODEL HOME 2020 (Foldbjerg, 2013). Measurements in dwellings in Germany, Austria, Denmark and France in post-occupancy evaluation studies (Foldbjerg, 2012), (Foldbjerg, 2013), (Peuportier, 2013) show that by combining solar protection, windows opening and ventilative cooling automatized strategies, one can 1) avoid overheating periods in passive buildings without installing air conditioning cooling systems ; 2) reduce ventilation fan electrical consumption, through natural ventilation in summer and hybrid ventilation in mid season, at the same time ensuring acceptable indoor air quality (IAQ)

Since onsite measurements are difficult to implement, gains estimations are generally assessed through numerical simulations performed during the design phases. A data compilation of recent works synthetizes major findings (Bernard, 2017) :

- the gains announced in temperature are in the range of 5 ° C.
- ventilative cooling strongly reduces the hours of overheating in continental climate and lower consumption of air conditioning and ventilation of 10%
- ventilative cooling divides by two hours of discomfort and/or earn an average 40% off on energy consumption in Mediterranean climate.

Last, recent works presented at the workshop "Ventilative cooling"[1] in 2013 show that very few regulations in Europe value ventilative cooling. Although France appears to be ahead of this issue, it is still necessary to better account for the impact of ventilative cooling in national thermal regulations and practices.

1.3 Ventilative cooling and heat evacuation

The objective of a correct ventilative cooling design is to evacuate during the night the increase of temperature that occurs during the day and to ensure comfortable conditions during daily occupation (free-cooling) or in night periods (night cooling). Ventilative cooling depends on ***thermal energy (heat) evacuation capacity*** from a hot evening to a comfortable morning, taking advantage of the coolness of the night. This heat evacuation is characterized by the inside temperature drop during the night, and called temperature Gain (G). The main

[1] http://www.buildup.eu/en/news/international-workshop-ventilative-cooling-registration-programme-available

issue is to correctly design the ventilation cooling system, in order to have a not too hot or too cold indoor environment in the morning. Ventilative cooling can rely on different forms of ventilation Mechanical Ventilation / Hybrid or natural ventilation / Mixed ventilation.

The ***thermal cooling potential Π*** is the difference between indoor and outdoor temperature during the period of ventilative cooling, shown by the green area in Figure 1. The curve shows an example of two specific nights : during a heat wave and for a cooler period. Here, we can see how important it is on indoor temperature decrease to account for weather conditions and to design an adequate control for ventilative cooling (through manual, clock-based or temperature probes controlled technologies).

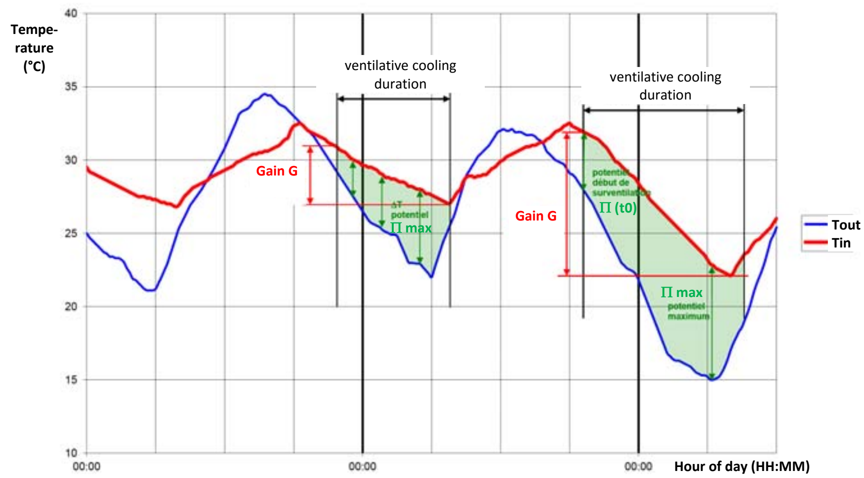

Figure 1: Thermal cooling potential Π and temperature Gain G based on outside and inside temperatures.

1.4 Objectives

We present the results of FREEVENT project, including state of the art and onsite field measurement campaigns. FREEVENT project is a French multi-partners research project[2] awardee in 2015 from ADEME's call for proposal "Responsible Buildings to the horizon 2020". The main objective of this research project was to monitor buildings with implemented solutions of ventilative cooling, and to analyze the results obtained in order to draw recommendations for professionals.

This paper focuses on the quantification and qualification of the efficiency of the ventilation systems and the energy and thermal performance of buildings. For this, two field measurement campaigns were conducted: ventilation checks on 9 sites and full measurements and monitoring on 6 of them. Our study summarizes ventilative cooling recommendations guidelines for designers that have been published in a French guide (Bernard, 2018) downloadable from a platform dedicated to sustainable construction (Construction 21 website).

2 METHODOLOGY AND RESULTS

For the FREEVENT project, 9 French buildings equipped with ventilative cooling systems have been selected to be audited through user surveys, onsite measurement campaigns and numerical simulations. Subsequently, a further analysis through extensive field measurement monitorings was conducted in 6 of the latter sites in order to assess gains on summer comfort from ventilative cooling systems. All sites have been chosen in South of France, in order to account for challenging summer comfort conditions. Measurements were monitored during

[2] ALLIE'AIR, ALDES, SEGE, ACA-O and CDPEA/APEBAT

summer periods. The table below shows all the diagnosed operations characteristics. More details on operations are reported elsewhere

Building / Site	Period of Field measurements	Characteristics of ventilative cooling
Day nursery in Vitrolles	2015.06.15 to 2015.07.31	Natural ventilation with motorized openings (simple and balanced ventilation)
Office building in Valence	2015.08.31 to 2015.09.13	Mechanical ventilation (extraction in halls and windows openings) windows manual control and openings, night automatic activation
Elementary school	No	Ducts natural ventilation (monodraught towers)
Dojo – Martial art Sport gym	2015.07.31 to 2015.09.19 2016.06.27 to 2016.09.22	Balanced mechanical ventilation
Office building near Toulouse	2015.08.01 to 2015.08.31	Balanced mechanical ventilation ; Façades motorized openings in offices and meeting rooms, Manual and programmable controls (temperature, wind and rain sensors)
Single family air conditionned house (in Ain)	2015.06.24 to 2015.09.15	Single flow ventilation (Insufflation). Programmable controls with possible manual over-ride in the room.
single family house (near Toulouse)	June 2015	Balanced mechanical ventilation: heat exchanger by-pass / insufflation in rooms. Programmable and manual controls.
Single family house in Marseille	No	Windows openings
Single family house in Bordeaux	No	Windows openings

Table 2: Site characterisitics of ventilative cooling equipped buildings

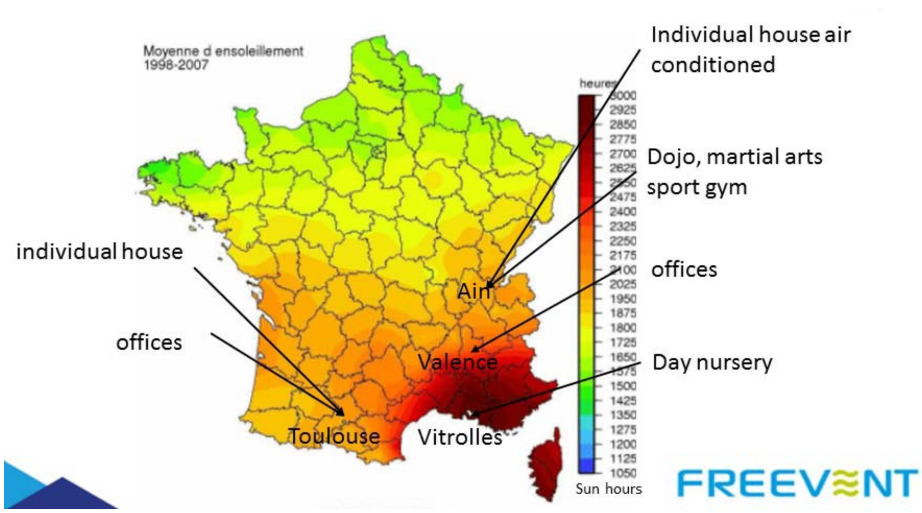

Figure 2: Description of experimental protocol : site locations as function of solar resources (in hours)

2.4 Measurement protocol

Six buildings have been monitored. The monitoring consisted in : 1) temperature measurements in some premises ; 2) When possible, relative humidity measurements and CO_2 measurements in these premises ; 3) assessment of the ventilation airflow rate in case of mechanical ventilation ; 3) When possible, assessment of the absorbed power of the fans ; 4) characterization of windows openings and assessement of natural ventilation airflows.

We used either initial embedded sensors (measures stored in Building Management System) validated at the time of diagnosis or specific sensors for the study. The details of the instrumentation are given in each site report (contact authors).

2.5 Thermal Performance indicators

In order to characterize thermal performance of ventilative cooling in the analyzed buildings, we defined the following indicators :

Ventilative cooling temperature gain G(°C) is defined during the ventilative cooling period as :

$$G\,(°C) = (T_{in\_t_0} - T_{in\text{-}mini}) \quad \text{where,}$$

- T_{in_t0} is the inside temperature when ventilative cooling starts
- $T_{in\text{-}mini}$ is the minimum temperature during the ventilative cooling period

The average ventilative cooling potential Π(°C) is defined as the average difference between inside and outside temperatures during the period:

$$\Pi\,(°C) = \Sigma\,(T_{in}-T_{out})/\text{number of measurements}$$

Energy recovered Crec (kWh) during the ventilative cooling period :

$$Crec\,(kWh) = \Sigma\,(P_{rec})\,/1000 = \Sigma\,(|1{,}22.Q.(T_{out}-T_{in})|)\,/\,1000 \quad \text{where,}$$

- Q is the ventilation airflowrate (l/s) : $\Sigma\,(|1{,}22.Q.(T_{out}-T_{in})| - Pabs)\,/\,1000$

Energy Efficiency Ratio EER(-), assessed as the ratio between the recovered Energy and the absorbed Energy by the fans during the ventilative cooling period :

$$EER = Crec/\,\Sigma\,(P_{abs}.nh/1000) \quad \text{where}$$

- P_{abs} : absorbed power (W) by the fan (P_{abs} =0 for natural ventilation).
- nh (h) is the number of hours of the ventilative cooling period

The occupants comfort, assessed with the PMV and PPD indicators, according to the definition of the corresponding norm (ISO, 2005).

2.6 Detailed onsite measurement results

Monitoring detailed results are presented in Table 2 and Table 3, below.

	Ventilative cooling airflowrate (m³/h)	**Ventilation temperature gain with/without (°C)**	**Π average ventilative cooling potential (°C)**	**Number of hours ventilative cooling (h)**	**Energy recovered (kWh)**	**Energy Efficiency Ratio EER (-)**	**Comments**
Dojo (2015)	3900/3400	-3.6 / -2.3 °C	6.5 °C	143 h	873 kWh	2.6	Ventilation undersized
Dojo (2016)	4600/CO2	-3.6 / -1.1 °C	4.0 °C	786 h	2078 kWh	1.1	Improved heat evacuation and comfort
House in Ain / mechanical ventilation	65	N.A. (AC)	16.0 °C	Approx.. 440 h	82 kWh	13	Night ventilation, in order to avoid AC
House in Ain / windows opening	21	N.A. (AC)	11.0 °C	Approx. 200 h	19 kWh	NA	Night ventilation, in order to avoid AC when mechanical fan was interrupted
Offices in Valence	4719 (5 ACH)	-1.8 °C	4.3 °C	120 h	155 kWh	1.2 (8.9)	Windows openings in several offices
House in Toulouse	100	-2.3 / -2.3 °C	5.0 to 6.0 °C	10 h/night	42 kWh	12.5	Ventilative cooling airflowrate too low as compared to the surface
Offices in Toulouse (ground floor)	Natural	-1.8 / -0.5 °C	3.0 °C	0 to 10 h/night	NA	∞	No energy consumption linked to night ventilation
Offices in Toulouse (first floor)	natural	-2.5 / -1.5 °C	4.0 °C	0 to 10 h/night	NA	∞	No energy consumption linked to night ventilation
Day nursery	1500 (1 ACH, theoretical for ΔT = 6°C)	-4 °C / no meas.	5.7 °C	12 h/night	40 kWh per night	NA	No energy consumption linked to night ventilation. Undersized ventilation as regards to daily loads (Tmax 31°C at the evening / Tmin 27°C the morning)

Table 2: Results for thermal performance indicators of ventilative cooling

	Ventilative cooling airflowrate (m^3/h)	**G (°C) with | without ventilative cooling**	**PMVevening / PPDevening**	**PMVmorning / PPDmorning**	**Comments**
Dojo (2015)	3900/3500	-3.6 | -2.3	NA	NA	for warm days
Dojo (2016)	4600 (CO_2)	-3.6 | -1.1	NA	NA	
Office building in Valence	4700 (5 ACH)	-1.8 | NA	NA	NA	
House in Toulouse with ventilative cooling		-2.3 | -2.3	-0.6 / 12%	-1.0 / 25%	
Offices in Toulouse (ground floor)		-1.8 | -0.5			
with ventilative cooling			-0.8 / 19%	-1.1 / 32%	
without ventilative cooling			-0.5 / 10%	-0.7 / 14%	
Offices in Toulouse (first floor)		-2.5 | -1.5			
with ventilative cooling			+0.1 / 8%	-0.7 / 14%	
without ventilative cooling			+0.4 / 8%	-0.1 / 5%	
Day nursery	1500 (1 ACH)	-4.0 | NA	2.2 / 85%	0.6 / 12%	Comfort just about acceptable in the morning ; discomfort the evening (AC installation)

Table 3: Results for occupants comfort of ventilative cooling

3 DISCUSSION

Assessing the ratio G/Π between the *Ventilative cooling decrease of temperature* and the *potential of decrease* indicates if a better use of the site potential could be achieved. This ratio indicates if the site potential has been fully used to its maximum. Assessed as an average on season, it can then qualify the system performance or indicate that increasing airflow, for instance by mechanical assistance, could be useful.

For example, a low ratio G/Π indicates that with higher airflow we could cool more the area (the system is under-sized) while a high ratio indicates that for this climate, it's not really useful to increase more the airflow (the system might be over-sized). Yet the real decision is made checking with comfort conditions inside, are they fulfilled or not.
In addition it may be possible to reduce day load (solar protections, indoor loads management…) to improve comfort. This indicator doesn't neither check the comfort achieved (i.e., it may be good for a night ventilation and temperature too low in the morning when occupants arrive) nor for the energy used to obtain this result (ie fan absorbed power if relevant).

As a matter of fact, the following findings may help for a better understanding :

- A very good ratio obtained with inside T° at 17°C in the morning (too cold) is not what we try to achieve. The use of night ventilation should be stopped when indoor temperature is achieved by a correct temperature control.
- A very good ratio with inside T° drop from 36°C in the evening to 26°C in the morning is still not comfortable (too hot). The potential is used though and on this site, it is not possible to improve the system a lot anyway. Internal loads, solar protections to reduce the temperature increase at day have to be checked. If not, switching to active cooling may be necessary
- A very low T° drop from 26°C to 24°C would characterized a very good building with high inertia and thermal capacity that will never heat higher than 26°c during the day : bad ratio but perfect comfort.
- A poor ratio with inside T° drop from 36°C in the evening to 26°C in the morning is still not comfortable (too hot), but the night ventilation doesn't use all the site potential. It can be improved by increasing airflow (mechanical assistance for natural ventilation, sizing of components…)

The G/Π ratio is interesting to design summer comfort solutions with ventilative cooling, among other indicators. But taken alone, it doesn't give enough information to give a full description of the building's performance.

As a matter of fact, the main challenge consists in providing comfortable conditions with an optimized energy approach. The *EER coefficient* has an infinite value for natural ventilation (since Fan absorbed energy ~ 0 kWh), while values of $4 < EER < 10$, are usually observed for mechanical ventilation. Lower EER may indicate either poor efficiency on fan absorbed power or not enough temperature difference between outdoor and indoor when using ventilative cooling (definition of running conditions/control). The EER optimization doesn't mean the potential of decrease is fully used. As a matter of fact, a performant EER doesn't mean necessarily an efficient ventilative cooling.

4 CONCLUSION

When one wants to optimize the thermal and comfort performance through ventilative cooling one has to handle the following parameters: thermal decrease, EER and indoor comfort. Hence, for the optimization of thermal performance and comfort it is necessary :

- To characterize the ventilative cooling performance : heat evacuation and EER
- To account for all the comfort issues related to ventilative cooling :
  - Temperature : preventing indoor environments from over-heating in the evenings or too cold mornings
  - Acoustics (inside, outside)
  - Air velocity

The findings relative to our field measurement campaign on ventilative cooling operations are mixed. Yet, one can notice an improvement in comfort when the supplied airflow rate appears to be sufficient. The concept of heat evacuation potential allows the designer to determine the expected performance of the system. On these sites, the effective ventilative cooling heat evacuation was 2 to 4 ° C while the potential of destocking was 4 to 16 ° C (in very peculiar conditions for the latter).

The main difficulties and barriers identified were:

- Undersizing design of ventilative cooling airflow rates
- Stopping or declining ventilative cooling airflow rates (due to noise, cleanliness of filters, or the absence of the manually operated air supply...)
- wrong settings of regulations and controls

However in all cases, the recovered energy and the assessed performance (EER) shown interesting potentials.

It is recommended to pay special attention to the design and installation but also at the reception of the ventilative cooling systems, with the analysis of its operation to ensure good performance. Indeed, the ventilative cooling is a sensitive asset, especially in the recent constructions, but asked to be properly considered to enable the expected gains.

The results of this work highlight the following recommendations:

- Over all : Importance of architectural solar protections with automatic controland adequacy of the inertia of the building; the absence of these passive protection makes insufficient any recourse to the ventilative cooling for summer comfort.
- Malfunctions observed on expected airflow rates, related to the BMS or local controls, highlight the need to implement the quality of follow-up-maintenance procedures in time.
- Gains can be significant from the calculation of the EER in refurbished individual houses
- Attention to specific acoustic discomfort related to the noise of the fans (indoors if running when occupied, outdoor to neighbourhood).
- Specific product innovations on operations at the level of the opening on the façade openings or interior joinery to provide the specific ventilative cooling airflow rates and the safety/security conditions during the night.

Finally, we underline the following key points for success:

- Upstream bioclimatic design : ventilative cooling will not compensate a poor design of internal and external loads.
- Adequate sizing that accounts for all comfort criterias
- Involvement of owners / maintainer and occupants in the first years for fine-tuning operation.
- Development of devices specifically dedicated to over-ventilation

5 ACKNOWLEDGEMENTS

This work was supported by ADEME. The views and opinions of the authors do not necessarily reflect those of ADEME. The published material is being distributed without warranty of any kind, either expressed or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall authors, ADEME be liable for damages arising from its use. Any responsibility arising from the use of this report lies with the user.
Authors also thank Valérie LEPRINCE for her valuable help in the state-of-the-art study and the owners and occupants of the inspected buildings for the field measurement campaign.

6 REFERENCES

Bernard, A-M. et al. (2017) *Développement de la surventilation dans les bâtiments à très faible consommation ; Phase 2 – Evaluation sur site de surventilations* - ADEME

Bernard, A-M. et al. (2018) *Surventilation et confort d'été, guide de conception, collection clés pour agir*, ADEME, ISBN 979-10-297-1120-6 , juin 2018, 75 pages

Coolson, C. (2011) *Passive House &LEED: A school building in Minnesota Case study*, Certified Passive House Designer, 15th International passive house conference 2011, 27-28 Mai 2011, Innsbruck, p151

Flourntzou , F. (2012) *Hybrid ventilation and cooling technics for the new Nicosia Townhall*, 33rd AIVC Conference, 11-12 October 2012, Copenhagen, Denmark, p233

Foldbjerg, P. et al. (2012) *Strategies for controlling thermal comfort in a Danish low energy building: system configuration and results from 2 years of measurements*, 33rd AIVC Conference, 11-12 October 2012, Copenhagen, Denmark, p56

Foldbjerg , P. (2013) *Ventilative cooling of residential buildings: strategies, measurement results and lessons-learned from three active houses in Austria Germany and Denmark*, Peter, Thorbjorn Asmussen (Velux), 34th AIVC Conference, Athens, 25-26 September 2013, Greece, p65

Grosso, M. (2013) *A ventilative cooling system in a School Building, Imola, Italy* , Ventilative cooling Workshop 19-20 Mars 2013, Bruxelles

IBGE, (2010) *La Free cooling par ventilation intensive* IBGE– Bruxelles Environnement

ISO (2005), *EN-ISO 7730. Ergonomics of the thermal envionment ; analytical determination and interpretation of thermal comfort using calculation of PMV and PPD indices and local thermal comfort criteria.* Geneva (Switzerland) : International Organization for Standardization

Kolokotroni, M. (2013) *Urban heat island, climate change and impact on ventilation for cooling*, Brunel University, UK, « Ventilative cooling » Workshop 19-20 Mars 2013, Bruxelles

Pellegrini, P. et al. (2012) *Improvement of summer comfort by passive cooling with increased ventilation and night cooling*, 33rd AIVC Conference, 11-12 October 2012, Copenhagen, Denmark, p197

Peuportier, B. et al. (2013) *Evaluation of ventilative cooling in a single family house (France),* 34th AIVC Conference, Athens, 25-26 September 2013, Greece, p67

Pollet, I. (2013) *Ventilative cooling experiences by Renson: lessons learned and solutions*, Renson Ventilation, Belgium, « Ventilative cooling » Workshop 19-20 Mars 2013, Bruxelles