Ventilative cooling strategies to reduce cooling and ventilation needs in shopping centres

Marta Avantaggiato*[1,2], Annamaria Belleri[1], Michele De Carli[2], Roberto Lollini[1]

1 Institute of Renewable Energy
EURAC Research,
Bolzano

2 DII-Department of Industrial Engineering
University of Padua
Padua

**marta.avantaggiato@eurac.edu*

ABSTRACT

Because of the customer need of best possible comfort condition and satisfaction, shopping centers are conditioned by means of basic HVAC systems, often without considering the potential of natural ventilation to contribute to air change rate, and to reduce the cooling demand. Mechanical ventilation systems are also preferred to natural ventilation because more controllable and reliable since they are not affected by the uncertainty of natural forces. However, atriums or in general common areas within a shopping center can suite the ventilative cooling purpose. In fact, on one hand they present more relaxed ranges of interior conditions respect to retail zones and, on the other hand, they can exploit the airflow driven both by thermal buoyancy and by wind pressure because of the big volumes involved. The use of ventilative cooling strategies can be beneficial in reducing both cooling demand and electricity consumption for ventilation.
The paper investigates the feasibility of ventilative cooling strategies as retrofit opportunities in shopping centers. Ten shopping centers, representing the retail stock among Europe have been analyzed under two aspects. First, we evaluated, according to the climatic cooling potential, the feasibility of natural or hybrid ventilative cooling strategies depending on internal gains; secondly, we identified the most suitable ventilative cooling strategies according to the architectural features of each shopping center. Then combining the results of the two analysis, we identified the most suitable ventilative cooling strategies according to different internal load. As last step, we proved the beneficial effect of the ventilative cooling strategies proposed in one of the reference shopping center. By means of dynamic simulation, we verified their effectiveness in terms of cooling need and ventilation consumption reduction. The results shows a cooling demand reduction between 41% and 49% depending on the lighting gains. The electricity consumption for ventilation is as well, decreased or nullified depending on the ventilative cooling strategies, linked with the lighting internal gains values.

KEYWORDS
Ventilative cooling feasibility, Shopping center, Cooling energy savings, Climate potential,

1 INTRODUCTION

In shopping centers, differently from residential buildings where energy is mainly consumed by heating, cooling, hot water, cooking and appliance (BPIE, 2011), energy is principally used for store lighting and ventilation followed by heating and air conditioning, food refrigeration and other (Schönberger, 2013).This energy consumption distribution depends, however, on the shopping center typology and on the climate location.
Based on these data, energy retrofit solutions should consider actions able to reduce both specific lighting power installed and the energy used for the air-conditioning and ventilation system (HVAC). Lighting power installed always affects the HVAC consumption. In fact, while high internal gains during winter have a beneficial effect in decreasing the heating demand, in summer they cause an increase of the cooling demand. Generally, shopping centers have common areas managed by a unique referent (e.g. owner, energy manager) which is also the one who makes the decisions during a retrofit process. On the other side, in the “leasing” area, each shop is managed by franchising companies, which rule and direct the shop according

to standardized protocols and refer to a distinctive interior and lighting design, restraining the applicability of general retrofit solutions (e.g. installation of a defined lighting technology, centralized HVAC controls). Accordingly, it is easier at a first retrofit step to consider the common area where there is a higher degree of freedom in the solution applicability. Generally, shopping centers are conditioned by means of HVAC systems, without considering the potential of natural ventilation to guarantee the minimum air change rate required by IAQ standards and to reduce cooling demand. Mechanical ventilation systems are also preferred to natural ventilation because more controllable and reliable, since they are not affected by the uncertainty of natural forces. Thereby, within the design process the team never focused neither on opening sizing nor on control strategies definition for ventilative cooling systems (natural or hybrid). So far, shopping mall design has included a small proportion of automated windows, sized for smoke ventilation only. Depending on the external climate conditions, acceptable levels of thermal comfort and IAQ can be reached without or with partial use of the mechanical systems, leading also to operational and maintenance cost savings.

However, atriums or in general common areas within a shopping center can suite the ventilative cooling purpose. In fact, on one hand they present more relaxed ranges of interior conditions respect to selling area and, on the other hand, they can exploit the airflow driven both by thermal buoyancy and by Venturi effect because of the big volumes involved.

Thermal function and role of the atria depend on the ventilation strategy (Moosavi L., 2014): either they can supply outside fresh air or they can drive stagnant air outside, or a combination of both. Atria can be used to enhance stack ventilation taking air in and exhaust air out from vents at the top of the atrium.

The paper investigates the retrofit opportunities to exploit ventilative cooling in shopping centers' common areas (shop galleries and atria) in terms of external climate conditions and architectural features. In particular, the paper analyses the ventilative cooling strategies in ten reference buildings identified within the CommONEnergy EU FP7 project (Bointer,R, 2014) to represent the retail stock among Europe.

Table 1 collects the reference buildings showing the typology they belong to (Bointer,R, 2014), and the climate classification according to the IEA Task 40 definition (Cory S., 2011).

Table 1 List of reference shopping centers

ID	Name of the shopping center	Shopping Center typology	Location	Country	Climate
CS	*City Syd*	Medium Shopping center	Trondheim	NO	HD
ME	*Mercado del Val*	Specialized and Others	Valladolid	ES	H&CD
GE	*Genova Ex-Officine Guglielmetti*	Specialized and Others	Genoa	IT	CD
KA	*Centro Commerciale Katané*	Medium Shopping center/ Hypermarket	Catania	IT	CD
DO	*Donau Zentrum*	Very Large Shopping center	Wien	AT	H&CD
BC	*Brent Cross*	Very Large Shopping center	London	UK	H&CD
ST	*Studlendas*	Small Shopping center	Klaipeda	LT	HD
GB	*Grand Bazar*	Small Shopping center	Sint-Niklaas	BE	H&CD
WA	*Waasland Shopping Center*	Large Shopping center	Antwerp	BE	H&CD
PA	*Pamarys*	Small Shopping center/ Hypermarket	Silute	LT	HD

2 METHODOLOGY

The following paragraphs describe the methodology used to identify the ventilative cooling strategies that better suits each of the ten reference buildings.
The analysis consists of three steps:

1. Ventilative cooling potential analysis used for the identification of the climatic potential in terms of ventilative cooling suitability for a reference gallery/atrium thermal zone;
2. Architectural features analysis with the aim to identify which ventilative solution better suite with the internal layout and space distribution;
3. Ventilative cooling strategies identification; it combines the two previous analysis with the aim of defining the most convenient one for each reference buildings.

2.1 Ventilative cooling potential analysis

Firstly, we evaluated the ventilative cooling potential of each climate location by using the ventilative cooling potential tool (Belleri A., 2015) that is under development by the IEA EBC Annex 62 research project (IEA EBC Annex 62 - Ventilative cooling, 2014-2017).

The tool requires basic information about very simplified building model, its use and the climate. In particular, the method assumes that the heating balance point temperature (T_{0-hbp}) establishes the outdoor air temperature below which heating must be provided to keep the desired indoor temperature at the heating set point (T_{i-hsp}).Therefore, when outdoor dry bulb temperature (T_{o-db}) exceeds the heating balance point temperature, direct ventilation is considered useful to keep indoor conditions within the comfort zone. The comfort zone is determined according to the adaptive thermal comfort model proposed in the EN 15251:2007 standard. When the outdoor dry bulb temperature falls below the heating balance point temperature, ventilative cooling is no longer needed.

The analysis with the tool is based on a single-zone thermal model. The user should provide to the tool the hourly climatic data. Within this analysis, in order to provide for a proper comparison of the ventilative cooling potential of the ten reference buildings, we referred to the same reference zone that is assumed to be representative for a typical atrium or a gallery. Table 2 reports the geometrical specifications.

Table 2 Reference zone geometrical characteristics

Height m	Length m	Width m	Floor Area m^2	Envelope Area m^2	Fenestration Area m^2	Opening hour	Heating set-point temperature
5.1	50	10	500	1112	111	9:00-21:00	16°C

We assumed the opening time of the center as 09:00-21:00 (11 hours per day) and set the heating set point temperature at 16°C as recommended by the standard EN 15251: 2007 for building Category II (new buildings and renovation).
The weather files referred to the reference buildings' locations derive from the historical data series (2000-2009) of the Meteonorm database (Meteonorm, 2009).
Approaching a shopping center retrofit, the most effective and easy-fit retrofit solution is the installation of energy efficient lighting system (Haase M., 2015).Taking this into consideration we decide to assess a parametric analysis by varying the internal lighting power density input and then evaluating the ventilative cooling potential. By doing so we can evaluate possible synergies and restrictions in the application of retrofit solution that consider simultaneously lighting, ventilation and cooling retrofit. The two considered levels are:

- lighting power density of 50 W/m², representing the state-of-the art of lighting installation according to a local retail building design firm (Howlett G., 2011);

- lighting power density of 10 W/m², representing the expected level after retrofit (Haase M., 2015).

General electric equipment power density (10 W/m^2) and internal loads due to occupancy (7 W/m^2) are considered the same in both cases.

A threshold value of 4.5±2.5 ACH as maximum airflows is fixed to prevent too high inlet air velocities which might cause discomfort situations. This value comes from a simple calculation; assuming that 25% of the glazed surface is openable for natural ventilation purposes and keeping air velocity of inlet airflow to be lower than 0.2 m/s as prescribed by standard, we derive the threshold airflows value.

An algorithm integrated in the tool splits the total number of hours when the building is occupied into the following groups:

1. **Ventilative Cooling mode [0]**: outdoor temperature is below the heating balance point temperature: no ventilative cooling can be used since heating is needed;
2. **Ventilative Cooling mode [1]**: outdoor temperature exceeds the balance point temperature, yet falls below the lower temperature limit of the (cooling) comfort zone: direct ventilative cooling with minimum required airflow rate for indoor air quality;
3. **Ventilative Cooling mode [2]**: outdoor temperature is within the range of comfort zone temperatures: direct ventilative cooling with increased airflow rate;
4. **Ventilative Cooling mode [3]**: outdoor temperature exceeds the upper temperature limit of the comfort zone: direct ventilative cooling is not useful.

The tool also predicts the hourly airflow rates required to maintain comfort condition when ventilative cooling mode [1] and [2] occur and the number of hours when night ventilative cooling can be activated.

Based on the ventilative cooling potential analysis we defined the feasibility of four possible ventilative cooling strategies:

- Daytime natural ventilative cooling consists in circulating outdoor air through windows and openings during opening hours. It is assumed to be effective when the average value of the air flows during ventilative cooling mode [1] and [2] are lower than the threshold value of 4.5±2.5 ACH;
- Daytime hybrid ventilative cooling consists in circulating outdoor air through windows and opening until the average value of the air flows during ventilative mode [1] and [2] is lower than the threshold value of 4.5±2.5 ACH. When the airflows exceed this value the ventilation is switched to fully mechanical (openings/vents are closed) providing the minimum airflow rates and the mechanical cooling system maintain the temperature into comfort ranges
- Daytime and night-time natural ventilative cooling when the condition for the daytime natural ventilative cooling are satisfied and also the percentage of hours when night ventilative cooling is activated is higher than 5%. Night ventilative cooling consists in circulation of outdoor air through windows and openings during night-time;
- Daytime and night-time hybrid ventilative cooling when the condition for the hybrid ventilative cooling are satisfied and also the night ventilative cooling activation percentage of hours is higher than 5%. Also in this case, night ventilative cooling is meant as driven by natural forces.

Figure 1 shows the decision flow chart with two-option questions to assess the most effective ventilative cooling strategy according to the climate potential. The first question regards the level of internal lighting gains, which determined whether natural ventilation is enough to offset internal gains. High lighting gain correspond to 50 W/m^2 while low refers to 10 W/m^2. The second is about the number of air change rates in ventilative mode [1] and [2], which determines whether cold draught risk might occur using natural ventilation. The last question is about number of hours when night-time ventilative cooling is activated, which determines night cooling feasibility. The flow chart allows defining the best ventilative cooling strategy for each reference shopping center according to the climatic potential.

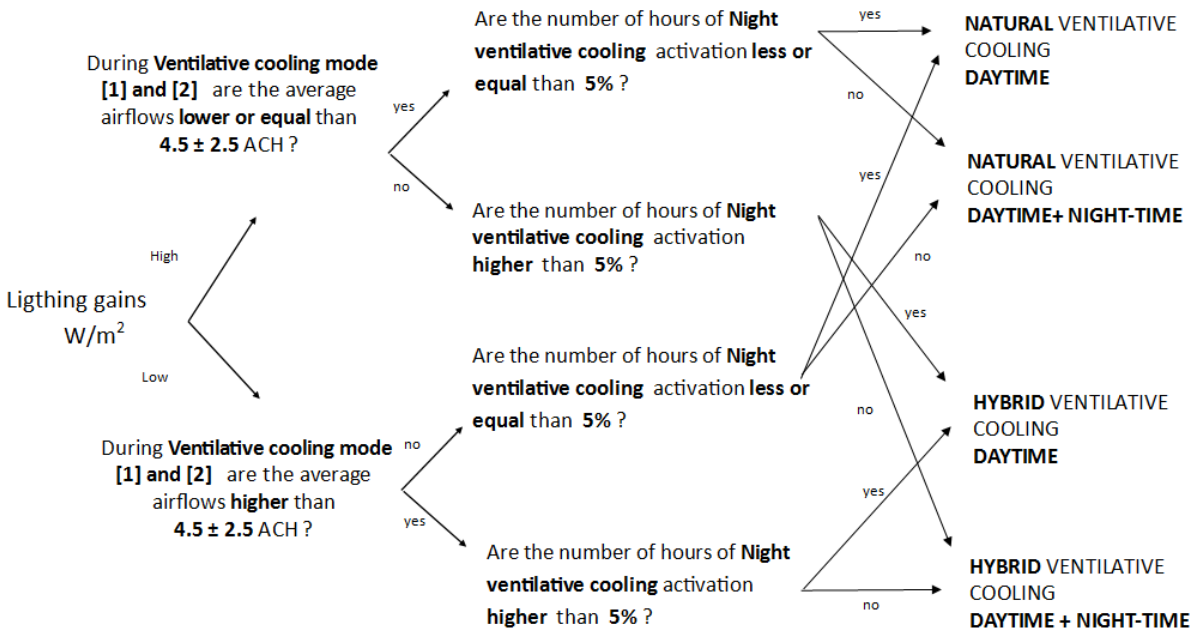

Figure 1 Ventilative cooling strategy decision chart according to climatic potential.

2.2 Architectural features analysis

A ventilative cooling strategy involves the whole building envelope as vents and openings can be located both on façade and roof to exploit buoyancy due to temperature difference between shops and central spaces and along the atrium height. Therefore, it is strictly dependent on building design and indoor spaces layout.

We analyzed the internal layout of each reference building taking into account the following features:

- Interconnected galleries and atria;
- Building shape, number of levels and ceiling height;
- Location of parking areas.

Considering shopping mall features, we identify feasible ventilative cooling systems among the followings:

- *Wind-induced ventilation* uses the wind pressure to force air through the building. Examples of technologies that use this effect are wind scoops, wind catchers and Venturi ventilators;
- *Solar assisted ventilation* exploits the effect of solar radiation to enhance hydrostatic buoyancy of air being warmer than its surroundings. Example of technologies that use this effect are solar chimney, double skin façades and ventilated walls;
- *Wind-buoyancy ventilation* is where air is driven through the building by vertical pressure differences developed by thermal buoyancy;
- *Wind-driven ventilation* exploits the pressure distribution generated by the wind on the building envelope to drive air through the building (i.e. vents and openings located on opposite sides of the building);
- *Fan assisted ventilation* relies on mechanical systems (i.e. fan) to enhance wind and/or buoyancy effects;
- *Mechanically-driven ventilation* uses a system of fans and ducts to circulate air within the building.

Figure 2 shows the ventilative cooling strategy decision chart according to the architectural features. The decision chart is based on three main questions. The first question is about the presence of galleries and atria, which determines the possibility to use ventilative cooling strategies in common areas. The second question investigates the possibility of taking air at roof level depending on its quality and the last one asks for the building shape and in particular the number of levels, which determines the possibility of exploiting air temperature and pressure at different heights (buoyancy effect). Following this chart, we were able to define the best ventilative cooling strategy for the ten reference shopping centers according to the architectural features.
In general, dealing with ventilative cooling as energy retrofit solution, other important design constraints should be considered, such as building regulations and standards (indoor air quality, fire safety), local outdoor environment (air pollution, noise), HVAC system configuration and management and tenants' needs (i.e. food stores with fresh filtered air).
However, the preliminary analyses here reported present at a lower level of detail due to the lack of available information about the design constraints related building energy management and local regulations.

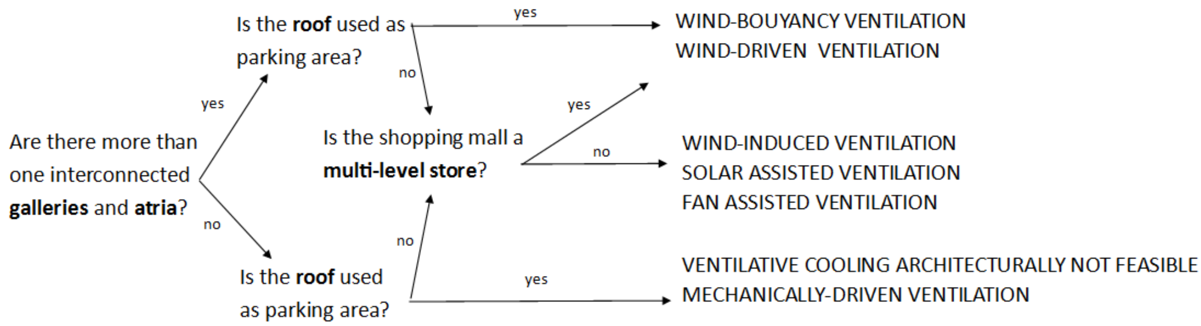

Figure 2 Ventilative cooling strategy decision chart according to architecture

3 VENTILATIVE COOLING FEASIBILITY

The following paragraphs show the results of both the ventilative cooling potential analysis and the architectural features for the ten reference buildings.

3.1 Ventilative cooling potential

The graph in Figure 3 shows the percentage of hours within a year when direct ventilative cooling can potentially assure thermal comfort during opening hours. In general, considering a high level of lighting power density, direct ventilative cooling with minimum and increased airflows is required for a 25% extra time compared to the case with low level of lighting power density. The values of airflows needed to offset the internal gains are also higher than those ones required with low lighting power as shown in Table 3. According to the analysis, when lighting power density is set to 50 W/m², ventilative cooling can be potentially exploited over 80% of the time in Catania and London while for almost all the time in Genoa.

When direct ventilative cooling is not useful during the day (VC mode [3]) because the outdoor temperatures are above the upper temperature limit of the comfort zone, the night-time ventilation potential during the following night is investigated. Table 3 shows for each reference building the average airflows during ventilative cooling mode [1] and [2] and the percentage of hour of night cooling activation. Both values are then used to determine the suitable ventilative cooling strategies according to the decision flow chart in Figure 1.
Night-time ventilation is activated for more than 10% only in Catania, due to the hot climate.

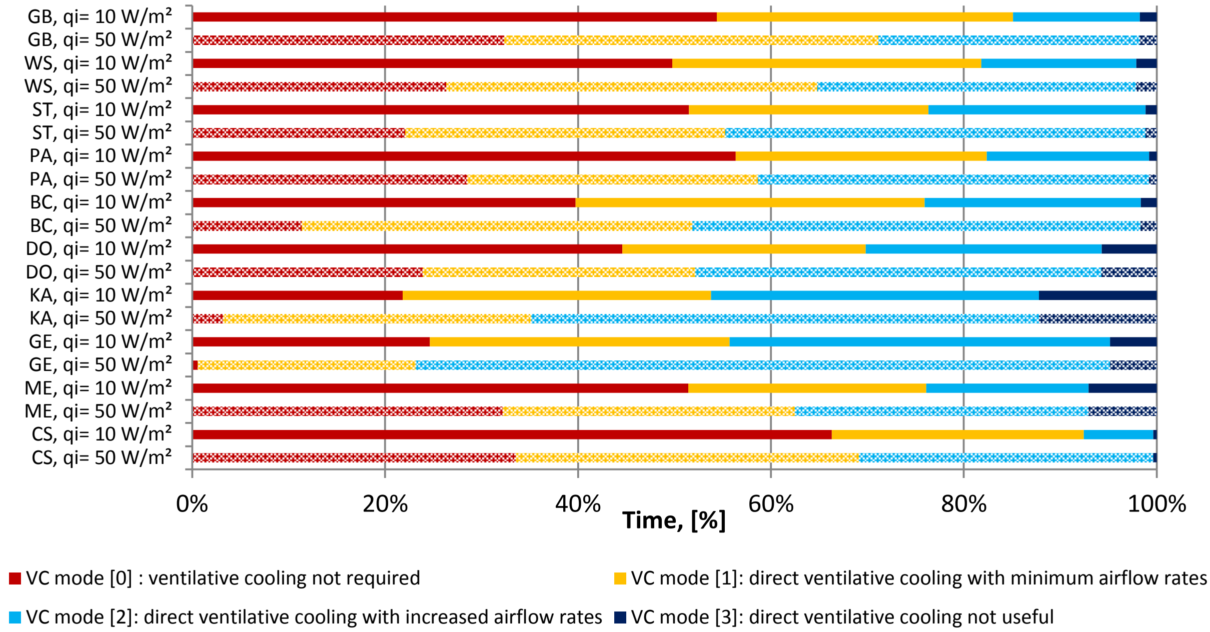

Figure 3 Percentage of hours within a year when direct ventilative cooling is required, useful or not useful in the ten reference building climates considering different values of internal gains.

Table 3 Average airflows during ventilative cooling mode [1] and [2] and % of hours of night ventilative cooling activation

		Reference buildings									
		CS	**ME**	**GE**	**KA**	**DO**	**BC**	**ST**	**GB**	**WA**	**PA**
Average airflow during ventilative cooling mode [1] and [2] [ACH]	q_i= 50 W/m^2	4.2 ± 1.9	6.9 ± 2.9	6.0 ± 3.3	6.8 ± 3.4	6.3 ± 3.2	5.6 ± 2.9	3.8 ± 2.1	6.6 ± 2.9	6.4 ± 2.8	3.7 ± 2
	q_i= 10 W/m^2	2.2 ± 0.9	3.6 ± 1.2	3.3 ± 1.3	3.9 ± 1.6	3.1 ± 1.3	2.2 ± 1	1.7 ± 0.9	3 ± 1	2.8 ± 0.9	2.1 ± 1
% of hours when ventilative cooling is activate during night	q_i= 50 W/m^2	1%	8%	6%	15%	7%	3%	2%	3%	3%	1%
	q_i= 10 W/m^2	0%	6%	6%	14%	7%	2%	2%	2%	1%	1%

3.2 Architectural analysis

The internal layout analysis showed that almost all the shopping centers have interconnected galleries and atria, and with our considerations on the architectural aspects, we found that in all the reference shopping centers there are the conditions to exploit ventilative cooling.

A common strategy is the exploitation of wind-buoyancy ventilation, natural or hybrid, since the shopping centers have usually two or more levels (Table 4).

Pamarys shopping centers is the only single-level store thus a ventilative cooling strategy exploiting air movement by means of buoyancy effect cannot suite for the purpose. In this case, indeed exploitation of wind-induced ventilation by means of devices such as wind scoops and wind catcher or fan-assisted ventilator seems the only feasible solution.

Catania and Genoa have roof portions used as parking area. In that case, because of the multilevel geometry the buoyancy effect can still be applied using openings on the lateral façade as airflow guide for the exhausted air.

3.3 Ventilative cooling strategies

Figure 4 merges the outcomes of the ventilative cooling potential and the ventilative cooling strategies. From the climatic potential point of view, we observed that:

- In heating dominated (HD) climates (Trondheim, Silute and Klaipeda) natural ventilative cooling is enough to offset the internal gains, both low and high level;
- In cooling dominated (CD) and heating&cooling dominated (H&CD) climates, with high lighting gains hybrid ventilative cooling is the selected solution, while with low internal lighting gain natural ventilative cooling is sufficient to guarantee an acceptable comfort level.

Night-time ventilative cooling is useful for the climates of Valladolid, Genoa, Catania and Wien. Because of the very common multiple level layout among the reference buildings that helps in creating temperature stratification a ventilation approach that relies on buoyancy effect seems to be the best solution.

The results suggest that, when facing a retrofit, the ventilative strategies chosen have to be in line with the level of lighting power density retrofitted in order to avoid an over-design of the airflows. Overlooking this interdependency could lead to discomfort condition due to the high air volume inside the building and to extra investment costs for windows´ and openings´ actuators, which might not be necessary.

4 POTENTIAL ENERGY SAVINGS

Among the ten reference buildings, we analysed the Donau Zentrum to verify the effectiveness of the ventilative cooling solutions proposed in terms of cooling need reduction. According to the climatic potential outcomes we tested a hybrid ventilative cooling strategy when internal lighting power density is equal to 50 W/m^2 while a natural one when lighting power density decrease down to the value of 10 W/m^2.

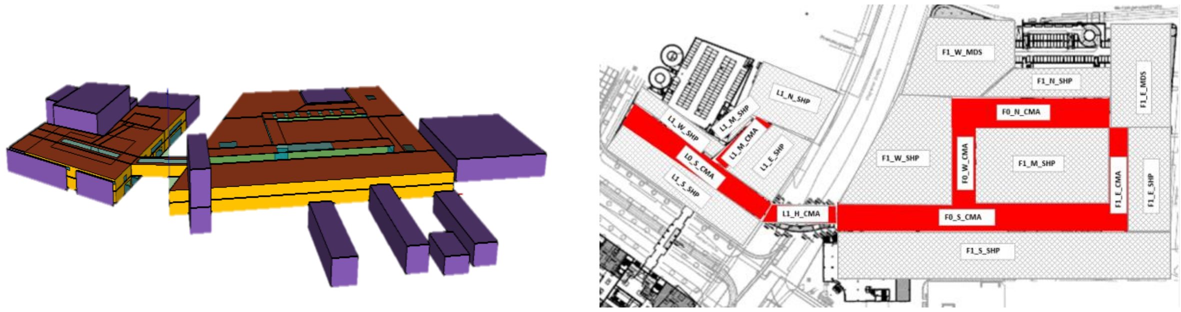

Figure 4 Donau Zentrum sketchup model south view (left) and galleries and atria highlighted in red (right), common area of the mall

We modelled the building within the Trnsys environment applying the ventilative cooling strategies to the galleries and atria highlighted in Figure 4**)**.

The baseline is ventilated by a fully mechanical system that supply minimum airflows of 2 ach during opening hour with heat recovery (60% efficiency). The effectiveness of ventilative cooling is tested by setting the airflow rates equal to ones calculated by the ventilative cooling potential tool. When the conditions for ventilative cooling mode [3] occur during the opening hours, the mechanical ventilation (or the natural ventilation) provide the minimum airflow and the cooling system is switched to maintain the indoor temperature within the comfort zone.

The exploitation of the ventilative cooling lead to a decrease of cooling demand and electricity consumption for ventilation (calculated assuming a Specific Fan power (SFP) of 1 Wh/m^2) in both lighting power density cases (Table 5). However, the use of ventilative cooling seems to be not completely beneficial since heating demand increases its values by 30% in case of high lighting power density.

Table 4 Matrix of ventilation approach and ventilative cooling solutions based on different specific lighting internal gains for reference building

ID	Architectural archetype	Internal layout	Lighting power density	Ventilative solution	
CS	compact, purpose built, 2 floors,	Circular gallery in the middle connected with outside	qi= 50 W/m^2	Daytime Natural	Wind-buoyancy ventilation Wind-driven ventilation
			qi= 10 W/m^2	Daytime Natural	
ME	Steel and glass structure, open space with market stands, reconceptualised	Central gallery, big volume over two floor	qi= 50 W/m^2	Daytime and Night-time Natural	
			qi= 10 W/m^2	Daytime and Night-time Natural	
GE	1 floor on extended area, reconceptualised	One semi-circular gallery connected with three entrance from the outside. Part of the roof is used as parking area	qi= 50 W/m^2	Daytime and Night-time Hybrid	
			qi= 10 W/m^2	Daytime and Night-time Natural	
KA	2 floors, purpose built	Main big gallery which extremity end into two atria equipped with glazed surfaces. Part of the roof is used as parking area	qi= 50 W/m^2	Daytime and Night-time Hybrid	
			qi= 10 W/m^2	Daytime and Night-time Natural	
DO	2 floors, compact, purpose built	In total six galleries interconnected; two big atria	qi= 50 W/m^2	Daytime and Night-time Hybrid	
			qi= 10 W/m^2	Daytime and Night-time Natural	
BC	2 floors, compact, purpose built, construction on several years	Main gallery between the shops connected at six small galleries. The gallery roof is glazed	qi= 50 W/m^2	Daytime Hybrid	
			qi= 10 W/m^2	Daytime Natural	
ST	2 floors, compact	Main atrium extended on two floor with escalator in the middle; small galleries between shops connected with the atrium. Glazed surface on both atrium and galleries(at 2nd floor)	qi= 50 W/m^2	Daytime Natural	
			qi= 10 W/m^2	Daytime Natural	
GB	Multilevel, compact	Two circular atria in the middle of the mall. The atria roof is equipped with glazed modules	qi= 50 W/m^2	Daytime Hybrid	
			qi= 10 W/m^2	Daytime Natural	
WS	2 floors, extended	Two big galleries interconnected in three-point Circular glazed atrium with possible operable windows. Glazed surfaces on the 2nd floor	qi= 50 W/m^2	Daytime Hybrid	
			qi= 10 W/m^2	Daytime Natural	
PA	1 floor, extended, purpose built	Simple layout with one gallery facing shop one side and the outside on the other	qi= 50 W/m^2	Daytime Natural	Wind-driven ventilation
			qi= 10 W/m^2	Daytime Natural	

This percentage is restrained to only 5% with low lighting gain. In this last case, because of the consistent energy saving in cooling demand (about 50%), the heating demand increase can be tolerated. The heating demand increase is caused by a drop of the indoor temperature during mid-season because of too high airflow. High airflows create a sort of "sub-cooling" of the building, resulting in an increased heating demand. A possible solution to limit the increase of heating demand is to use smart control systems on windows opening, especially during mid-season. Smart control strategies and system can avoid the temperature drop.

Table 5 Potential energy saving because of the ventilative cooling solutions use

	q_i=50 W/m^2			q_i=10 W/m^2		
	Baseline	Hybrid ventilative cooling	Percentage savings %	Baseline	Natural Ventilative cooling	Percentage savings %
Cooling demand [kWh/(m^2 y)]	105	62	-41%	59	30.1	-49%
Electricity consumption for ventilation [kWh/(m^2 y)]]	202	52	-74%	202	0	-100%
Heating demand [kWh/(m^2 y)]]	105	150	+30%	175	184	+5%

5 CONCLUSION

The paper investigates the retrofit opportunities to exploit ventilative cooling in shopping centers' common areas (shop galleries and atria) in terms of external climate conditions and architectural features. Ventilative cooling climatic potential has been assessed for ten reference buildings considering two different levels of lighting power density. The results shows a linear dependence between the level of lighting power density and the percentage of hours of direct ventilative cooling use. This suggest that when facing a retrofit this synergy cannot be overlooked otherwise it could cause discomfort situations inside the building and to extra non-necessary investment costs for windows´ and openings´ actuators. With low internal gains, natural ventilative cooling is able guarantee thermal comfort condition for all the reference climates. On the other hand, with high lighting gains, hybrid ventilative cooling seems the most suitable strategy except for cooling dominated climates (Trondheim, Silute and Klaipeda) where the natural one is once again able to assure acceptable comfort conditions. The night ventilative cooling is predicted to be useful in the climates of Valladolid, Genoa, Catania and Wien.

In terms of architectural features, almost all the reference shopping centers are multilevel, they have galleries and atrium and only for two of them part of the roof is used as parking areas. All the features make feasible the exploitation of buoyancy ventilation by means of dedicated openings and windows located at different height.

The validation of the effectiveness of the ventilative cooling solution proposed for the Donau Zentrum shopping center, has shown a cooling demand reduction between 41% and 49% depending on the lighting gains. The electricity consumption for ventilation is as well, decreased or nullified depending on the ventilative cooling strategies, linked with the lighting internal gains values.

The analysis presented in this paper can be considered as a first step towards the detailed definition of ventilative cooling retrofit solutions, since we did not considering important design constraints (e.g building regulation and standards, HVAC system configuration and management and tenants' needs) due to the lack of available information,. Starting from this preliminary analysis, in further developments we will investigate computational fluid dynamics simulation (CFD) methodologies, able to predict the detailed air movement inside and outside the building, and to provide detailed thermal comfort analysis.

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7 REFERENCES

Belleri A., P. T. (2015). Evaluation tool of climate potential for ventilative cooling. *36th AIVC- 5th TightVent- 3rd venticool.* Madrid.

Bointer,R. (2014). *D21,Shopping mall features in EU-28 + Norway,CommONEnergy project (FP7-2013 grant agreement no 608678).* Obtido de http://www.commonenergyproject.eu/

BPIE. (2011). *Europe´s buildings under the microscope, A country-by-country review of the energy perfomance of buildings .*

Cory S. (2011). Formulating a building climate classification method. *roceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association.* Sydney.

Emmerich S. J., P. B. (2011). Impact of adaptive thermal comfort on climatic suitability of natural ventilation in office buildings. *Energy and Buildings, 43*(2101-2107).

Haase M. (2015). *D25-Main drivers for deep retrofitting of shopping malls, CommONEnergy project (FP7-2013 grant agreement no 608678).*

Hamlyn D., A. P. (2012). Ventilation approaches for shopping malls - An examination of natural and hybrid strategies. *ASHRAE transactions vol. 118. Part 1*, 575-585.

Howlett G. (2011). *Survey of Retail Lighting-Market Trasformation Programme, Developing evidence for Government and business on energy using products.* Building Research Establishment.

IEA EBC Annex 62 - Ventilative cooling. (2014-2017). http://venticool.eu/annex-62-home/.

Liddament M. (1996). *A guide to energy efficient ventilation.* AIVC.

Meteonorm. (2009). Obtido de http://meteonorm.com/

Moosavi L. (2014). Thermal performance of atria: An overview of natural ventilation effective design. *Renewable and Sustainable Energy Reviews*, 654-570.

Moosavi, L., Mahyudding, N., N, A. G., & M.A., I. (s.d.).

Schönberger, H. (2013). *Best Environmental Management Practice in the Retail Trade Sector, European Commmission, Joint Research Centre-Institute for Prospective Technological Studies, Pubblications Office of the European Union, Scientific and Technical Research Series- ISSN 1831.* Luxemburg.