# Ventilative cooling in a single-family active house from design stage to user experience

Christoffer Plesner*[1], Nicolas Dupin[2]

*1 VELUX A/S*
*Ådalsvej 99*
*2970 Hørsholm, Denmark*

*2 VELUX*
*1. rue Paul Cézanne B.P. 20, 91421*
*Morangis Cedex, France*

**Corresponding author:*
*christoffer.plesner@velux.com*

## ABSTRACT

Ventilative cooling through window airing presents a promising potential for low energy houses in order to avoid overheating risks and to reduce energy consumption of air conditioners. This case study aims at describing how ventilative cooling has been taken into account as from the design stage of a low-energy single-family active house located near Paris. Its performance on thermal comfort and air renewal, monitored from both sociological (feedback from a family) and scientific approach, is described and compares these two qualitative and quantitative approaches.
Key learnings from the sociological survey are presented and compared to the data monitored by environment sensors installed inside and outside the house.
Results from a research project carried out on the same house are presenting the accuracy of natural ventilation evaluation for design tools. Simulation tool were used to evaluate the potential of natural ventilation for its contribution to both air change and passive cooling of houses.

## KEYWORDS

Ventilative cooling, active house, design stage, passive cooling, natural ventilation

## 1 INTRODUCTION

Ventilative cooling of indoor spaces, including both natural and mechanical ventilation strategies, shows high energy savings and comfort improvement potential, especially for new and upcoming residential buildings with high standards for the envelope performance – making these subjects to overheating risks.
As a matter of fact, residential buildings such as single-family houses or apartments are originally designed to provide a comfortable, safe and healthy indoor environment to their occupants, whereas energy efficiency recently became an additional requirement to reach environmental and primary resources safeguarding.

One of the biggest drawbacks to the development of ventilative cooling is mainly the complex air flows passing through open windows, which requires detailed models for assessing indoor comfort with sufficient accuracy.
The case study presented here aims at describing how natural ventilation through window openings has been considered in the design process of a low-energy single-family active house - Maison Air et Lumière, part of the Model Home 2020 project - in order to reach simultaneous high targets on energy performance, summer comfort, indoor air quality and visual comfort. Furthermore, Maison Air et Lumière is to be found as 1 of initially 14 cases (5 more to come), in the upcoming IEA EBC Annex 62 “case study brochure” showcasing documented case studies of recent buildings with effective ventilative cooling systems.

In previous articles published for AIVC Conferences 2012 and 2013, Maison Air et Lumière has been presented with different focuses on key learnings of the quantitative monitoring of the house. This paper focuses on the global approach, presented through 3 main stages: the design stage, the occupancy stage (during which a family of 4 lived in the house for one year from September 2012 to August 2013) and the key learnings.

# 2 RESULTS

The results in this section are based on the data and information extracted from the various stages Maison Air et Lumière (MAL) has gone through, from the initial design stage to the occupancy stage. Finally, the key learnings stage is evaluated encompassing the user experience from the occupants (via a sociological survey) and the quantitative monitoring. Each stage serves specific purposes with its corresponding tools and methods, adapted for the needed evaluation.

The 3 main stages are shown below in Figure 1.

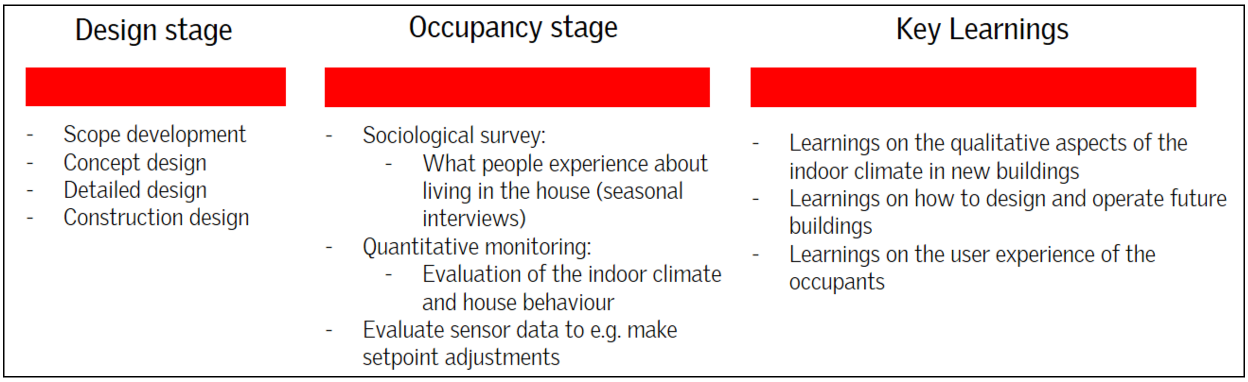


Figure 1 - The 3 main stages of Maison Air et Lumière

## 2.1 Stage 1: Design stage

The design stage consists of 4 sub-stages; Scope development, concept design, detailed design and construction design which all are part of the preliminary building phase as seen in Table 1.

In this design stage, potential overheating issues may become visible through continuous evaluations from simulations and therefore improvements in the design is an important aspect here. These design evaluations are essentially what makes the difference between buildings with good thermal comfort with no or limited overheating issues and buildings with overheating issues. In this case overheating was a focal point in the design stage and this has a significant impact on the positive results achieved from the "occupancy stage" shown in section 2.3.

Table 1 - Description of the design stage

| Stage | Tool | Function |
|---|---|---|
| Scope Development | Perrenoud (RT 2005) | Define building features of materials/systems |
| Concept Design | VELUX Daylight Visualizer | Initial Daylight Check |

| | | |
|---|---|---|
| Detailed Design | BSim (DK) | Thermal Comfort analysis & ACR |
| Construction Design | U21/U22 Perrenoud (RT 2012) | Check compliance with RT 2012 regulation and evaluate future nZEB target level |

At the very start of the scope development sub-stage, meetings were held between the various stakeholders of the upcoming Model Home 2020 project, where one of the homes were to be built in France. The aim was to agree on a set of building requirements for Maison Air et Lumière which would enable the building at that time to comply with first the minimum demands as set in the existing French thermal regulation, RT 2005 and also the future French thermal regulations at that time RT 2012 and nZEB 2020 (Near Zero Energy Building). From the start of this project the bar was set very high, as the target was to end up with a requirement specification that did not only comply with the existing French thermal regulation, RT 2005 - but requirements that were set even higher than the future, RT 2012. The targets for the requirement specification were even set to comply with the future demands, of the upcoming nZEB regulation in 2020.
One of the tasks of this stage was to define building features of materials and systems, and here the choice of the ventilation system is important. This was to see what would work and what wouldn't work regarding building design. One of the tools used was Perrenoud to continuously check if the proposed design would comply with at least the existing regulations, RT 2005 and future nZEB targets. For this, simulations were carried out by French consulting engineers, Cardonnel Ingénierie. The Perrenoud tool continuously enabled the stakeholder group to see what features worked or didn't work according to the design, hence looking at the energy consumption of the building.

Topics such as indoor climate and connection to outside were discussed as being important parameters to make the occupants in the building satisfied. It was important that there would be a balance between the different indoor climate parameters such as ventilation, daylight and connection to the outside. It was especially important to demonstrate a good indoor climate in combination with good energy performance, for good summer comfort. The energy consumption was of course always kept in mind continuously verified using the Perrenoud tool. As the project's target was set to nZEB 2020 foreseen level, one could say this specification was a contributing factor to specifying the later Active House specifications (Active House/).

The final requirement specification ended up satisfying the demands of future nZEB 2020 buildings.

### 2.1.1 Concept design

In the concept design sub-stage, more evaluations were made to e.g. evaluate the preliminary daylight levels in the MAL. This is important to focus on, as daylight is a valuable aspect to the indoor climate, both regarding the visual aspects as well as the free solar gains entering the building. Furthermore, daylight apertures are bringing a connection to the outside.
Daylight levels were evaluated using the software VELUX Daylight Visualizer, to check illuminance levels at specified locations as seen in Figure 2. Daylight simulations and concept design illustrations were carried out by French architects, Nomade Architectes. This stage is important as the initial daylight levels found had an impact on the further building design and structure of MAL, enabling to optimize the daylight levels both on room and building level.

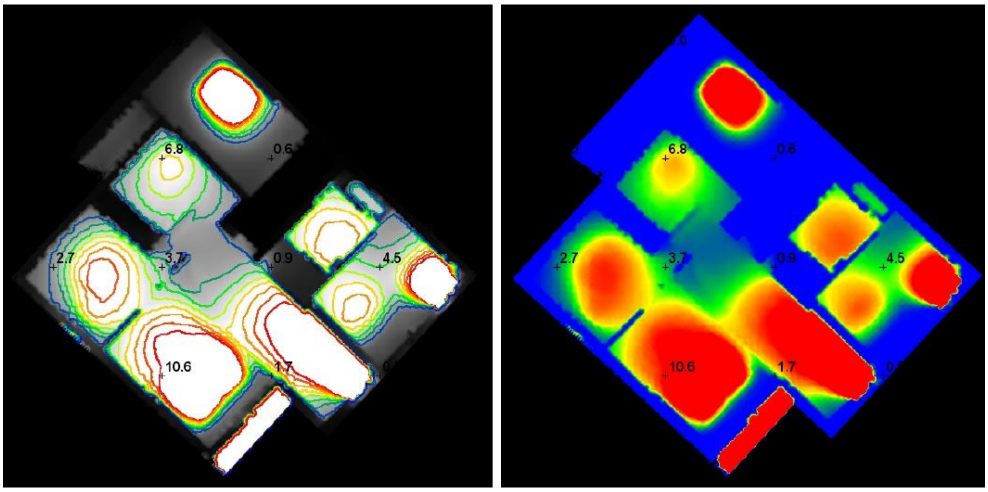


Figure 2 – Daylight factor simulations made in VELUX Daylight Visualizer

### 2.1.2 Detailed design

In the detailed design sub-stage, a thermal comfort and air change rate evaluation was made in order to evaluate the scoped design further, by making more detailed analysis through e.g. computer simulations. The simulations initially checked thermal comfort performance in Maison Air et Lumière. The tool used in this stage is BSim, which is an integrated tool for analysing buildings and installations (Danish building research institute). This simulation was carried out by a Danish consulting engineering firm, Esbensen consulting engineers. The basic BSim model is shown in Figure 3.

The air change rate analysis was also made using BSim as seen in Figure 5 which shows the average air change rates for all non-winter hours, while the lighter column shows the average air change rate of when the operative temperature is above 25 °C.

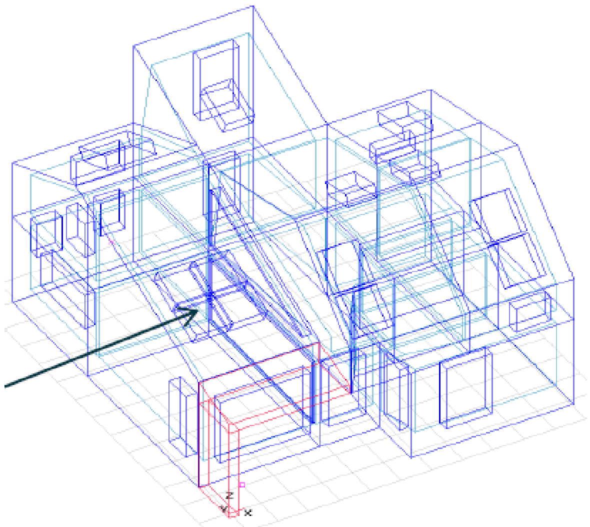

Figure 3 – Simulation model setup in BSim

In Figure 4, the operative temperatures are plotted as a function of the running mean temperature for the Living room of MAL, as e.g. found in the European standard, EN 15251 called the “adaptive comfort model”. This shows that the operative temperature in the living room is within the acceptance range.

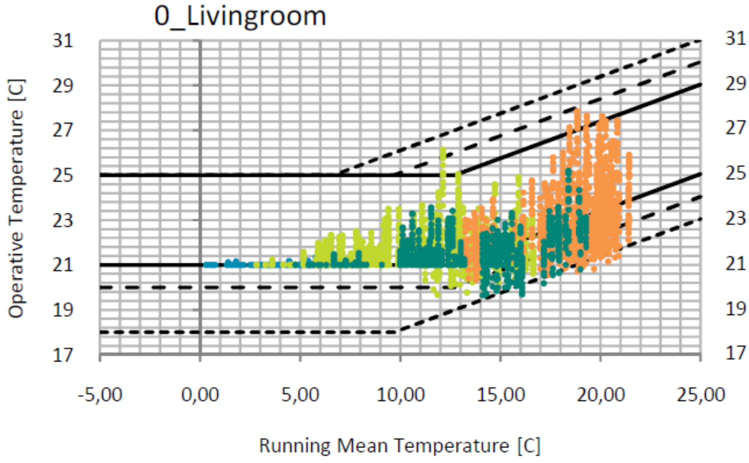


Figure 4 – Overheating evaluation based on EN 15251

In Figure 5 the lighter column is of particular importance as it indicates if there is sufficient natural ventilation in the zone. BSim maximizes the air change rate to cool the zone because the operative temperature is above 25°C. The maximum air change rate is 5 $h^{-1}$. The average air change rate is lower due to days with low wind velocities. However, the closer the average air change is to 5 $h^{-1}$, the better the natural ventilation works, where the bedrooms in MAL seems to perform best as they have the highest air change rates.

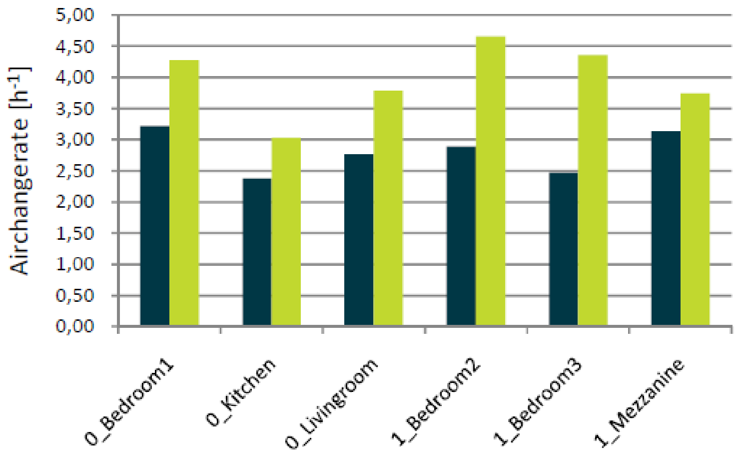


Figure 5 – Air change evaluation from BSim results

### 2.1.3 Construction design

The construction design sub-stage is the final sub-stage of the "design stage" where it is evaluated if the proposed building design complies with the regulation set in the requirement specification. To evaluate the energy performance of MAL, the Perrenoud tool was used to check if the proposed construction design would comply with the future French thermal regulation RT 2012 and nZEB 2020 targets. This stage was also carried out by French consulting engineers, Cardonnel Ingénierie, like in the scope development stage.

Maison Air et Lumière complied with energy performance of the upcoming RT 2012 regulation, showing high energy performance (below 50 $kWh_{PE}/(m^2.yr)$).

## 2.2 Stage 2: Occupancy stage (methodology for monitoring)

As the project was strongly focusing on the occupant's comfort, a double monitoring process was set up to track both scientific and sociologic achievements for the indoor comfort targets. The processes are:

- Sociological survey:
  - A sociologist carried out seasonal interviews with the family to get their feedback on the perceived indoor comfort while living in the house. Specific attention was paid to the summer comfort, indoor air quality and the automation of the natural ventilation system
- Quantitative monitoring:
  - A scientific monitoring was carried out thanks to built-in sensors in each room analysing both the indoor and outdoor environments and monthly reports were released to follow, inter alia, indoor air temperature, relative humidity, $CO_2$ concentration, illuminance, energy consumption, energy production, and outdoor weather conditions incl. solar radiation, wind speed and wind direction

Cross comparisons were carried out between these two monitoring processes to confirm the interpretation of sociological and quantitative results provided by the monitoring systems. Scientific indicators such as thermal comfort were evaluated to establish their relevancy towards end-users' perception. The feedback from the interviews were also used to adapt and adjust the home automation along the way, and increase users' acceptance and satisfaction (e.g. by windows opening frequency, actions on awning blinds, etc.).

## 2.3 Stage 3: Learnings of operation stage

The operation stage has shown good results regarding summer thermal comfort, with a good correlation between measurements and perceived comfort.

From the sociological survey one key feedback given by the family was the perception of indoor temperature during a heat wave in the summer period: "When we were arriving inside the house, the heatwave still was present and the exterior air was above 30°C, and the temperature was 24 to 25°C inside the house without any other cooling system than natural cooling" (Quote from inhabitant of Maison Air et Lumière ).
This statement was supported by the quantitative monitoring via the measurements carried out during both the unoccupied and occupied period (as shown in Figure 6).

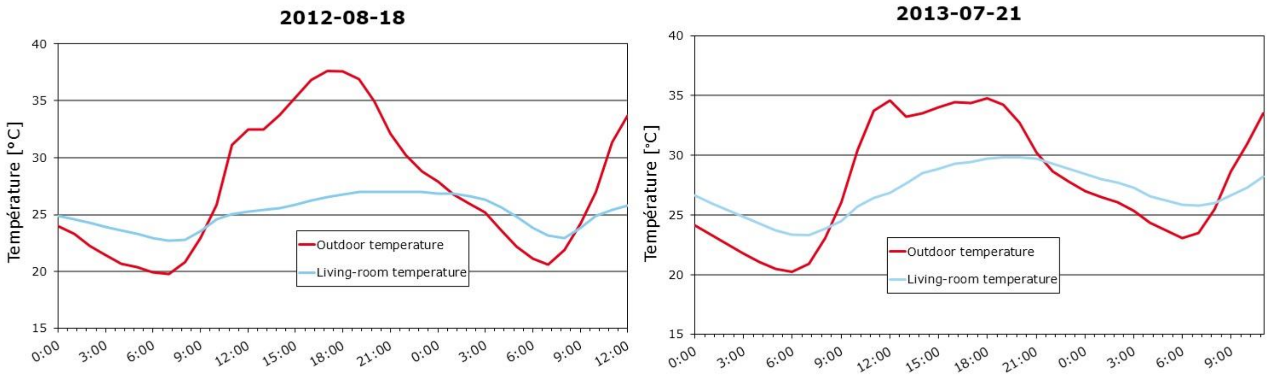


Figure 6 - Comparison of ventilative cooling benefits during a heat wave in unoccupied (left) and occupied periods (right). Blue: indoor temperature. Red: outdoor temperature

Another key learning from the operation stage was the acceptance of the home automation system inside the house, especially the system in charge of managing the motorized windows and blinds.

The family was indeed disturbed during the beginning of the experience by the frequent movements of the solar shadings and windows, which were automated and sensor controlled.
After a short period, and as the family had the possibility to shut down the automation in the different rooms, interviews have shown that they were often switching the system into manual mode, due to the systems swift reaction to the temperature sensors making it complex to be understood.
After a short period, the decision was taken to change the automation principle by adapting the ventilative cooling algorithm to the family's daily and weekly habits instead. An hourly-based schedule was then implemented to be aligned with the family's presence and sleeping hours.

The results shown on Figure 6 during the occupancy period have been monitored with the hourly-based schedule.

Furthermore, from the quantitative monitoring an assessment showing the accuracy of the air flow rate passing through windows based on both laboratory measurements, simulated values using CONTAM software and from actual tracer gas measurements performed in the house, for in this case the Living room in Maison Air et Lumiére. This generally shows a close correlation between the different methods.

Below in Table 2 the aeraulic and thermal performance of ventilative cooling for the living room comparing actual tracer gas measurements and simulated values using CONTAM software for the Living room. As seen in Table 2 a good correlation is shown between actual measurements compared with the simulations, e.g. for the morning case.
Furthermore, the table shows that high air change rates up to 14 ACH could be achieved in the living room with even limited wind velocities (< 3 m/s) and low temperature difference between outside and inside (< 3°C), showing the high potential of ventilative cooling via elevated air change rates for cooling (K. Duer et al., 2013).

Table 2 - Aeraulic and thermal performance of ventilative cooling for the Living room

| | **Representative air flows in ACH [$h^{-1}$]** | | **Representative average temperature difference ($T_{int} – T_{ext}$)** | | |
|---|---|---|---|---|---|
| | Morning | Afternoon | No ventilation | Full-time ventilation | Control ventilation |
| Simulation value | 14 ACH | 13,2 ACH | 6 °C | 1,5 °C | 0 °C |
| Measurement value | 13,4 ACH | 10,6 ACH | 4,8 °C | 0,2 °C | -0,3 °C |

The close correlations between measured and simulated values support the global evaluation of natural ventilation performance by using simulation tools to evaluate the air flow rate when dimensioning windows. Thereafter the performance of the natural ventilation and ventilative cooling may be sufficiently known, in order to successfully make a ventilative cooling strategy that may work for the whole house, as shown in Maison Air et Lumière.

# 3 CONCLUSIONS

## 3.1 Characterization of natural ventilation through windows

Distinct laboratory measurements carried out for the project has shown that aeraulic features of windows available in the literature are giving relevant characterization for air flow evaluation (N. Dupin et al., 2014).
These aeraulic features can be used for evaluating air flow rates passing through windows thanks to natural ventilation with a good accuracy.

## 3.2 Evaluation of natural ventilation performance on a single family house (air flow rates and air change per hour)

Generally, it is thought that natural ventilation only works in very favourable conditions with high temperature difference (e.g. during night) and with high wind speeds. Though, this has been refuted here, thanks to this project showing that ventilative cooling also works during very reasonable weather conditions.
An analysis carried out by French research institute, Armines - Mines ParisTech has shown that even with limited wind velocities (< 3 m/s) and low temperature difference between outside and inside (< 3°C), elevated air change rates for cooling up to 14 ACH in the Living room, could be achieved during summer, showing the high potential of ventilative cooling.

## 3.3 Temperature reduction potential of ventilative cooling in a single family house

Thanks to the accuracy of the numerical simulations – which were confirmed by on-site measurements – the potential for temperature reduction inside MAL using natural ventilation has been evaluated by comparing indoor air temperatures with and without ventilative cooling.
These results show that natural ventilation using ventilative cooling has a cooling potential of around 5°C with reasonable weather conditions, to which the benefits of solar shadings should be added.

## 3.4 Explain the overall ventilation strategy in Maison air et Lumière

It was found throughout the process of designing, occupying and evaluating the active house, Maison air et Lumiére that the prescribed ventilation system, namely the hybrid ventilation system installed in the house combining the best of both worlds, from energy neutral ventilation during summer using ventilative cooling, to the mechanical ventilation with heat recovery used during colder periods worked well, proven in the both the sociological and quantitative monitoring. Especially the open rooms and floor plans in MAL combined with many well placed windows helped to utilize the stack effect in MAL, thereby increasing the potential air change rates to finally enable a good indoor air quality and thermal comfort. This is in good correlation with the actual found elevated air change rates found from the tracer gas measurements.

# 4 ACKNOWLEDGEMENTS

Armines – Mines ParisTech, France (www.armines.net)

# 5 REFERENCES

B. Peuportier, B. Favre, E. Vorger, N. Dupin (2012), *Towards the aeraulic characterization of roof windows*, 33rd AIVC Conference (Copenhagen, Denmark, 2012)

K. Duer, B. Peuportier, C. Plesner, N. Dupin (2013), *Evaluation of ventilative cooling in a single family house*, Proceedings of AIVC conference (Athens, Greece, 2013)

N. Dupin, B. Peuportier, M. Cohen, B. Favre, E. Vorger (2014), *Evaluation of ventilative cooling in a single family house - Characterization and modelling of natural ventilation*, World Sustainable Buildings Conference (Barcelona, Spain, 2014)

Danish building research institute, *BSim (Building simulation) computer tool*, Dr. Neergaards Vej 15, DK-2970 Hørsholm, http://sbi.dk/bsim/Pages/Start.aspx

Active House, https://www.activehouse.info/

Quote from inhabitant of Maison Air et Lumière (2013), (L’habitat de demain: au-delà des expériences. Retour sur l’expérience Maison Air et Lumière VELUX MODEL HOME 2020, Final conference, December 2013)