Case study ‘the Vela Roof – UNIPOL’, Bologna: use of on-site climate and energy resources

A. van Timmeren¹ & M. Turrin²
¹Climate Design, Delft University of Technology, Faculty of Architecture, Building Technology, The Netherlands
²Design Informatics, Delft University of Technology, Faculty of Architecture, Building Technology, The Netherlands

Abstract

The case study presented in this paper focuses on the so-called “Vela roof”. This roof is part of a larger project under construction in Bologna. The focus of the study concerns the use of on-site renewable climate (energy) resources for thermal comfort with special attention given to passive cooling and heating. The very first conceptual design developed by the architectural office is assumed as a starting point for the inclusion of performance criteria at this stage in the process, taking into account a large chain of dependencies that need to be integrated in the design process. Due to extremely low wind speeds on-site, early evaluations pointed out how wind should be caught in order to provide some cooling effect; secondly, side openings at the wrong location on the roof would contribute to a greenhouse effect more than to a passive cooling effect. As a result, in the preliminary design of the roof uncomfortable conditions were highly expected under the whole roof in the summer, with an even higher critical level in the space between the lower buildings’ roof and the Vela. Two main issues of the Vela are therefore highlighted especially related to the improvement of the existing design (configuration and shape). On one hand, in the preliminary design the overheated air was going to be kept at the top enclosed spaces without being passively extracted. On the other hand, the system of side openings could be related better to the local wind behaviour. The latter has been analyzed and digitally simulated and the first results are presented in this paper. Integration of these main issues in larger strategies was also investigated, considering both active solar technologies and passive systems for heating and cooling.

Keywords: on-site renewable energy resources, urban space related comfort.
1 Introduction

By presenting the case study of a roof structure, in this paper we discuss design explorations aimed at integrating strategies for on-site energy use in the early architectural and structural design phase.

The first section briefly introduces the context of the roof and offers an overview of the larger project the Case study object – the “Vela roof” – is a part of. The role of the roof in relation to the use of on-site energy resources for climate comfort is explained, especially referring to passive strategies for thermal reasons. These strategies enable achieving indoor thermal comfort by using on-site renewable energies, and reducing the need for imported energies. Taking advantage of periodic climatic changes enables one to store the solar thermal energy needed for heating the indoor spaces or to disperse excessive heat to the outside. The architectural geometry of the overall shape and the roof details can support this effect and were both investigated. As part of this general context and according with the fundamental role played by the shape in order to design a climate efficient environment, the subsequent sections focus on the relation between the local conditions and the conceptual design of the shape, with a more detailed level of design addressed in the last two sections.

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2 Context and tasks

The “Vela” roof structure is part of a larger active project referred to here as the UNIPOL Project. The latter consists of a high-rise office building, a hotel, a system of lower buildings for shops and services, referred to here as Piastra, and a public square, partially covered by the Vela. The overall area is illustrated in Figure 1, showing the concept developed for the site by the architectural office.

The project is located in Bologna, Italy; the architectural process is lead by Open Project Office; the structural design is lead by Prof. Massimo Majowiecki.
and his office. While the office tower and the building facing it are in an advanced stage of the design and construction process, the low-rise buildings and the public space including the roof are still at a conceptual level. In designing them, one main criterion is the development of a system that joins the specific architectural, functional and climatic requirements. Following this direction, various strategies are being investigated considering both active solar technologies and passive systems for heating and cooling. Reflecting on an expected critical summer overheating, especially the second kind of systems has been analyzed more deeply. With respect to these issues, the roof is expected to play a key role in contributing to the climate control. The structure is thought as a roof opening on the sides. With reference to natural ventilation both for quality air and passive cooling, as well as to evacuation of smoke in case of fire, the openings are a key aspect; relations between their location and shape and the overall geometry of the roof are therefore investigated as well as the potential integration with kinetic systems to open and close some of the modules of the roof (cf Figure 1).

3 Thermal comfort, summer overheating and passive cooling

The general character of the proposed investigation aims at defining the architectural geometry of the roof through an integral approach involving climate comfort performance evaluations across the project scales. Since the covered space is a semi-indoor (or outdoor) space partially surrounded by adjacent indoor spaces, the concept of thermal comfort needs some specification. The determination of the indoor thermal comfort and the evaluations of the best way to achieve this are in fact a complex issue. They have to take into consideration the interaction of a big number of related internal as well external factors and human needs. These are depending on particular specifications, such as the building use type with its occupancy schedules and use profiles, the internal heat gains from lighting, office equipment, machinery and people and so on. However, since the spaces enclosed by the Vela are supposed to be between indoor and outdoor, the demands for the thermal comfort are less strict. On the other hand, uncomfortable conditions of summer overheating have to be avoided and cold winter conditions and too strong daylight have to be mitigated as well. Due to the need of only mitigating the worst thermal conditions, a simplified approach is proposed. As a consequence, the presented suggestions only focus on passive cooling for summer time and passive solar heating for winter conditions. Without aiming at modeling the concept of thermal comfort and all the factors influencing it, these would in any case strongly contribute to achieving the thermal comfort in a passive way.

Partially achieving the thermal comfort in a passive way would positively affect not only the direct use of the spaces covered by the Vela, but also the indoor thermal behaviour of the surrounding buildings with specific reference to the Piastra. Passively avoiding uncomfortable (coldest and overheated) conditions in this semi-indoor space would relevantly reduce the energy demand for thermal comfort, by improving the energy performance of the system of buildings and is therefore strongly recommended.
According with these specifications, local climate aspects have been evaluated and design aspects have been analyzed. Particularly, in a climate like in Bologna, summer hot temperatures reach critical levels (EERE, 2008), showing uncomfortable temperatures during all the working hours for a relevant period of the year. In addition, the site is quite exposed to direct sunlight. Due to this combined situation affecting south facing enclosed spaces, hot weather during summer time will require not only to limit the incoming of solar heat, but also to cool the indoor spaces. As a consequence, a shadow system to reduce the incoming radiance is strongly recommended, but will not be enough to prevent uncomfortable conditions of overheating in the covered spaces. A strong contribution can be given by passive cooling. In respect to that, rainwater, green roofs, wind and natural ventilation have a key role. Next paragraphs will focus on each of these aspects.

4 Wind and wind driven ventilation for passive cooling

On one hand, the role of the shape of the roof in directing the airflows is an example of the close relationship between aspects affecting the passive thermal behaviour of a build system and its geometrical shape. Bologna is interesting with respect to wind due to the low speeds and the local wind rose shows almost no dominant wind direction. This means average wind is weak and coming almost equally from all sides. However, the climate related data analysis (EERE, 2008) made clear that the summer condition and the winter condition are the most relevant situations regarding the local wind behaviour.

![Analyzed wind directions and summary of EERE dominant wind data.](image)

In wintertime, the calm wind periods equal around 70% of the measured conditions; in case of wind, there is a 30% predominance of West Winds. In summer time, calm wind periods decrease to 35% of measured conditions; the dominant direction is more variable and less identifiable, even if some predominance from East has to be acknowledged especially in daily hours. During night hours calms of wind are more frequent and there is a predominance
of West Winds. During May, July and August no relevant amount of wind is coming from the Northwest.

Winds selected according to these data have been digitally analyzed (Figure 2). Referring to the simulated winds, two main general aspects have emerged as relevant for the Vela (square) design. On one hand, the average wind not only never reaches an uncomfortable speed, but it even needs to be captured in order to provide the desired cooling effect. On the other hand, natural wind shadows are caused on the square by the configuration of the built environment, but some useful draughts are created by the high-rise building. In the latter case, special attention should be given to using the roof to direct the wind in order to provide some cooling effect. More precisely, wind simulation showed that concerning winds from Southeast, due to the hotel, the whole square is within the wind lee. Simulation also showed that trying to redirect the wind from the hotel’s roof does not seem effective. However, when the South-East wind blows, a relevant draught is brought on the square by the high-rise building. This means that when the South-East wind blows the only wind affecting the square comes from the North-East. Wind from the North-East converges on the square under effect of the built environment with specific influences brought by the high-rise building and the hotel. Since these latter drive the wind within the square, in their proximity higher wind velocity is evident. The wind simulation also showed that a similar behaviour is expected by the East wind.

On the basis of the analyzed wind behaviours and with respect to the specific context of a roof such as the Vela, two main possible strategies for passive cooling can be followed, the chimney effect and the wing effect. The first one is based on the natural temperature between the bottom and the top air enclosed by the roof; as result of the consequent convection air drafts, warmer air is extracted through a hole at the top point. The latter is based on the cooling effect provided by incoming colder air drafts that have to be made to blow correctly through the enclosed spaces.

![Figure 3: Schematic examples of some general cooling categories whose behaviours were taken into consideration in the Vela’s case.](image)

Evaluating the early design developed for the roof, both strategies were partially shown in the lengthwise and width wise sections. Longitudinally, the section drives the warm air to the top point, while transversally the section would drive the outdoor winds to pass through the covered spaces. The coexistence of the two approaches is a possible solution with a high potential, but the balance between the two behaviours has to be considered in order to improve their reciprocal principles without negatively interfering with each other.

The two aspects described in Figure 4 are indeed identified as possible main problem areas. As a result, the warm air is expected to remain under the roof.
The preliminary designed geometry of the roof was expected to cause relevant problems and thus variations were advised, e.g., with respect to the lengthwise section, the absence of a top opening or openable point on the roof could be solved by introducing a hole correctly shaped in correspondence to the top point (chimney like effect). In this context, various curvatures were tested satisfying architectural issues. The chimney effect can be further improved by a small wing located at the top hole. (Figure 5).

![Figure 4: Lengthwise and width wise sections of the Vela.](image)

![Figure 5: One of the proposed alternatives; a different curvature with opening.](image)

With respect to the wing effect of the whole structure, both orientation and dimensions of the analyzed open sides should be reviewed by shaping the curvature of the roof more suitably. This point assumes even more importance since it is also related with a third critical point: the roof in fact runs close to the so-called “Piastra” below (the roof level of the surrounding low rise buildings). On the west sides, outdoor fitness activities as well as the terrace restaurant are located on the first and top levels of the surrounding building volumes. The need for a comfortable area protected both from overheating and from uncontrolled air draughts was found to strongly conflict with the actual geometry of the roof. Even in the case outdoor activities were supposed to stop during summer time, avoiding the actual risk of critical overheating between the Vela and the Piastra’s roof is important in order to reduce the negative effect on the below indoor spaces at the level of the covered square. Therefore air ventilation between the Vela and the Piastra’s roof had to be increased. Also specifically with respect to
the former mentioned, variations on the geometry were suggested here in order to introduce an improved wing effect (cf Figure 6).

Major openings on the sides would both allow easier incoming of cooling winds supporting the whole wing effect of the roof and diminish the heating effect of the radiations from the roof on the fitness and restaurant areas. By combining the explained thermal considerations with these local wind factors, two main suggestions are recommended. On the one hand, opening the roof close to the Hotel on the East side and, even more, close to the high-rise building is quite important. This would in fact allow to catch the South-West, East and North East winds, while openings on the west to the Piastra’s roof have to be increased and shaped differently to achieve a Venturi effect on the West side (cf Figure 6).

Modelling the geometry and the curvature of the roof for this wind effect affects the large-scale definition of the early design concept. However, reducing summer over-heating should be considered an important goal. Discussion with the structural engineers also pointed out undesired structural behaviours in case of anomalous winds and these need to be taken into consideration as well.

5 Heat gain reduction

Different ways of regulating the sun coming in through the roof and the air permeability of the roof with respect to passive cooling are of importance to heat gain reduction. Originally the roof is thought of as a partially transparent system. It is located on the south side of the tower and as an architectural requirement it has to allow the view of the tower from the inside. While natural light has to be used, at the same time, solar thermal energy has to be filtered (esp. in summertime) in order to passively achieve the indoor thermal comfort in the square and to avoid as much as possible summer thermal loads on the surrounding buildings.
As a different option, the combination of different cladding systems can reduce the need for adding extra material in support of the reduction of heat gain. As proposed by Open Office, by combining a translucent, opaque fabric and transparent glass cladding material the heat gain can be lowered by reducing the amount of direct sunlight inside the space. In this case, a high percentage of translucent or opaque cladding system is required in order to reduce the incoming sun. Besides this aspect, the budget does not allow for a complete glazed roof and Teflon or EFTE has been proposed as a possible alternative material.

To achieve heat gain reduction additional options such as the use of rainwater collected from the roof and green roofs on the low surrounding buildings could be realized as well. As stated in the previous section, integrating the thermal behaviour of the Piastra’s roof and the Vela is strongly advised. Particularly, thermal performance evaluations while choosing the materials covering the Piastra’s roof are needed. Green roofs are a good option when dealing with passive thermal comfort. The low-rise buildings would benefit themselves from it due to the insulation capacity of green roofs. However the most relevant aim is avoiding heat reflection toward the higher adjacent buildings as well as cooling the air drafts entering below the roof. Due to this latter aspect, the green part can be mostly concentrated in the areas right outside the roof borderline. Planting of Sedum species should be preferred to grass. This also allows extensive green roof systems that need less water, thin soil layer and minor maintenance labour. (Considering the near highway, Sedum species keep more fine particles (PM10) than grass. While an open water surface could be even more effective than grass and Sedum for cooling, risks of leaking, weight and evaporation are relevant disadvantages.)

Collecting the rainwater strongly contributes to passively achieving the thermal comfort goal, by providing the feeling of a lower temperature concerning the air lying above it. Applying this effect to the whole semi-indoor space under the Vela is impossible due to its dimensions. However, localizing the effect on selected areas where people stay can provide a relevant help. The actual configuration of the Vela offers a surface up to 3.000 square meters, allowing a relevant water collection (approx. 788mms/a).

Focusing on thermal performances, an optimal condition would require the collected water to lie within the covered spaces during the daytime and outside during night time. This can be achieved by moving the collected water between two connected pools or two parts of the same pool, one located under the roof, the other one outside. Moving the water from inside to outside and vice versa provides benefits; however, a balance needs to be found between the need of providing evaporation for thermal comfort and the quantity of available rain water, due to the relevant but not abundant average summer rain. Integrating the rainwater with filtered and cleaned water from the surrounding buildings was analyzed to be an option.

In both options, a pool for rain water collection is to be included. The pool could best be located at the ground base of the roof and it is recommended to be large enough to avoid dispersion of water falling from the curved surface. Apart
from possibilities for collection and reuse it also introduces adiabatic cooling possibilities and interesting reflection of the roof shape near the entrance. If desired, water could be reused for cooling purposes of covered spaces (as a form of ‘adiabatic cooling’). In this case, it could best be distributed as soon as possible once collected below the floor in order to avoid outdoor evaporation and in this way improve availability of harvested water for cooling purposes (among other) (cf Figure 7). Additionally, if the water is distributed below the floor, then it could be used also for green trees’ irrigation under the roof. The system could refer to ancient Moorish techniques of irrigation and combined cooling of outdoor areas.

Figure 7: One of the proposed alternatives; rainwater collection and reuse.

6 Passive heating and active solar gain

During wintertime, cold weather will require to keep the solar gain inside. More detailed calculations still have to be made in order to verify whether there can be winter sunny days when the solar gain is too high, leading to overheating. Except for that, the main aim in wintertime is to avoid the dissipation of the solar heat and, possibly, gaining as much as possible thermal load. The latter aspect is directly related to the choice that will be made about the shading system. Both aspects at the moment concern work in progress and will not be addressed to in detail in this paper. In case the shading system will be a separate layer of the roof, it can be either adjustable or studied in order to optimize the lamellas’ inclination to protect from the summer sun radiation and to allow the winter solar rays entering the roof. On the other hand, avoiding the dissipation of the solar gain can be effectively supported by closing the top as well as the west side openings of the roof. Closing the top openings would avoid the chimney effect. While west openings in summertime play a key role in driving the cooling winds under the roof, in winter time closing them has high potential in limiting the air circulation. Particularly for the west side openings, e.g. by using a space frame structure, a deployable bar systems can be effectively used to achieve the desired adjustability. In the case of using tensile structure, adaptability can be achieved by adjustable tensile properties. In the case of dividing the roof into smaller roofs, rotating elements can differently address wind behaviour.

Also the integration of active solar systems is advisable. However, its benefits have to be combined with a passive suitable behaviour of the roof. The passive
behaviour has to be developed and later on further supported by the introduction of active technologies like, for example, photovoltaic cells. Differently, active systems simply become a way to mitigate negative effects not avoided or, even worst, created by the built environment. Once a suitable passive behaviour is defined, very interesting options can be introduced in relation to energy production, optimized on the specific conditions.

7 Conclusion

As a result of the stated work in progress on passive heating, active solar gain and improved design alternatives on the basis of climate design and parametric modelling, final conclusions still cannot be made. The focus will be on introducing a way for the extraction of overheated air with as little adjustment of the geometrical shape as possible. Dimension and exact positions of the openings therefore need to be calculated, while the shape could easily follow the existing proposed structure. They are expected to be efficient if located where the shape starts its curvature. There could be either three openings, distributed along the structure, or one bigger, centred. To improve the effect of passive extraction of heated air and avoiding incoming rainwater, it is important to add a small elevated sub-roof which is aerodynamically shaped to increase wind speeds and in that way improve the thermal stack effect (‘chimney effect’). The effect would be improved if the overall shape is reviewed in order to make the location of the openings higher in order to favour warm air flow extraction and to avoid annoying air draughts at the height of the ground floor surface in the covered area. Making the top openings closable would be best, in order to be able of regulating the extraction of heated air with respect to the indoor comfort (i.e. wintertime / summertime). The mentioned regulation capacity would be strongly improved by making closable also the openings along the sides of the roof in order to regulate both incoming airflows and the extraction of air. Specifically this airflow regulation requires switching the roof between a closed (barrier like) to an open (filter like) condition and at the moment related kinetic components are studied with respect to two possible approaches. The first is based on large-scale kinematism of the overall shape. The second is based on the repetition of openable modules, integrated in the structural morphology.

References