URBAN DENSIFICATION AND ENERGY PERFORMANCE OF EXISTING BUILDINGS: A CASE STUDY

C.S. Polo López [1]; F. Frontini [1], S. Bouziri [1]

1: Institute for Applied Sustainability to the Built Environment (ISAAC), SUPSI, University of Applied Sciences and Arts of Southern Switzerland, Trevano, CP 105, CH-6952 Canobbio, Switzerland

ABSTRACT

Urban densification and preservation of soil are a much discussed topics on which there is still little detailed research. In Switzerland these concepts are also acknowledged by visions and regulations at the federal level together with the importance of increasing energy supply by renewable energy sources and reducing the energy demand in-primis of existing building. The scientific community is however well aware of the need to enlarge the scale of analysis and to move to urban planning and design scales, which would better allow to take into account buildings shape, orientation and density and to detect possible cumulative effects limiting both the access to sunlight or solar gains and the possibility of equipping buildings with solar renewable systems. Moreover the impact of solar energy availability on existing buildings (in particular historical buildings) during urban transformation is still not well understood and is a matter of research. High-urban densification plans expect a complex environment, where self-shading and the overshadows of adjacent buildings can dominate solar energy potential and daylight availability, but also the imposition towards greater energetic production of PV for new buildings would compromise the visual perception of existing settlement under transformation. But how do these urban revolutionary changes towards densification appear and impact? What are the implications for existing buildings during the process? What does solar energy mean for new/existing urban areas with protected heritage buildings? The aim of this research is to delve into these questions by analyzing a real case study in the city of Lugano Paradiso (Ticino). The City Centre district is currently undergoing a profound change towards densification of the urban environment with a new urban master plan and new zoning regulations.

Keywords: urban densification, energy efficiency, solar PV potential, protected buildings

INTRODUCTION

From the Aalborg Charter (May 1994), further on the Leipzig Charter and the Toledo Declaration (June 2010), the importance of implementing effective policies in land use and planning was recognized, involving a strategic environmental assessment. The emphasis was put on the opportunities offered by dense urban concentrations to provide public transport services and more efficient energy supply, while at the same time reserving the human dimension of development. In Switzerland urban densification has being supported and emphasized through strategies and regulations at a national and federal level. The need for high quality densification of urban settlements is gaining momentum also in the public opinion, as recently stated by Schweizer Heimatschutz, the Swiss Heritage Society, which agreed for a reasonable and sustainable use of the land [1]. On the other hand, Swiss federal energy policies emphasize the importance of incrementing the supply of energy from renewable resources, while also reducing the energy demand, with specific focus on the construction sector. Furthermore, the future obligation to install at least 10 Watt/m^2 of PV in new buildings, today only voluntary, as reported in the new *"Model for energy* requirements at Swiss Cantonal level" (Swiss Federal Council, Sustainable Development Strategy 2012-2015, January 23, 2012) presumes changes in the visual perception of dense neighbourhoods and in the cities themselves. Furthermore, many European and Swiss research projects also reflect on the cities with substantial and valuable heritage with the aim to overcome the aspect linked to the too rigid protection regulations in urban areas that do not allow even the most needed adaptation of historic buildings and areas to the requirements of recent times by reaffirming the key role of energy efficiency and the integration of renewable solar energy (RES) to propose new solutions and promote new policies for the sustainable renovation of existing cities [2-4]. The effects of urban densification, anyway, are important if new measures are implemented quickly and without a careful study of the boundary conditions that serve to meet with the qualitative and architectural culture of the place, affecting mainly the cultural protected heritage in the area. The interest is also to avoid the opposition of the population towards this transformation.

PURPOSE OF THE WORK

Urban planning determines significantly the possibility to exploit solar irradiation. In densely built-up areas it is important to consider factors such as the buildings' geometry and height, the materials and colours, as well as the distance between the buildings themselves (size and morphology of the roads), as factors that can affect the solar radiation absorption and reflection. In the same way, urban shape also depends on the specific conditions of the local place and the climate. To prevent an arbitrary use of solar energy technology, it is necessary to assess the solar potential in relation with its immediate environment and the constructive and typological features. For this reason SUPSI in 2014 started a research project (VerGE) that focus on a real case study in Ticino with the aim to investigate how urban modifications, in particular urban densification policies, can influence the solar availability but also the impact on the heritage protected and on the energy demand of existing building. Only the first points will be addressed by this paper.

METHODOLOGY

In order to assess solar access in urban planning it is important to consider the interaction of multiple parameters and factors. The solar energy potential in urban is also a key factor that affects the energy consumption and the behaviour of existing and new buildings.

The starting point of this research is the analysis of a real case study in Ticino (Switzerland), in the Paradiso municipality, part of Lugano's settlement. It is a district that is undergoing a very fast urban densification process, by changing the open urban sprawl towards infill with closed and compact urban fabrics, as defined in the new master plan regulation.

a) b)

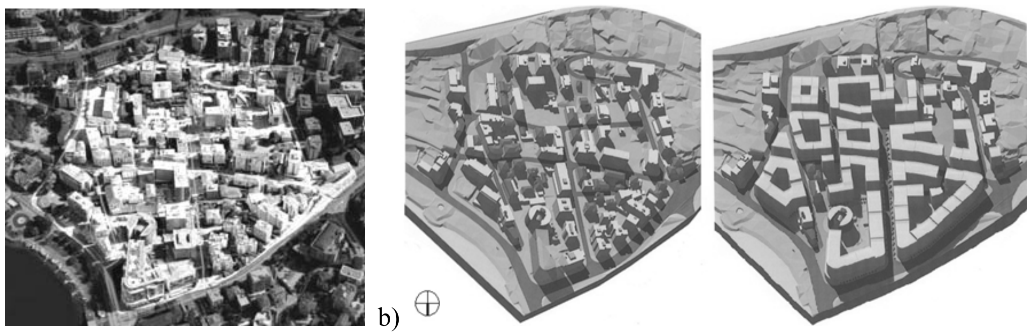

Figure 2: Lugano-Paradiso City Centre district: a) Aerial view (google earth, 2013); b) Spatial urban planning, current and future urban development (new Master Plan).

The study includes the analysis of the current situation and the urban transformations envisaged by the municipality with the entry into force of the new Master Plan. The project workflow presented in Fig. 2, shows three level of analysis from the general aspects (urban level) to particular and detail aspects (building and energy levels). For each level of the analysis some parameters that influence energy aspects and the energy balance of a building (consumption and production) are identified together with the relevant phenomena highly influenced by urban morphology.

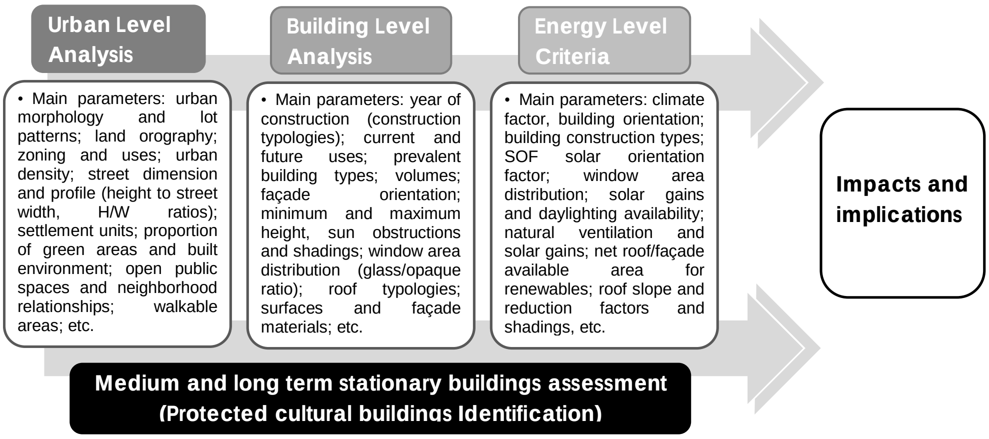

Figure 2: Workflow diagram of VerGE project methodology.

The specific urban planning significantly determines the possibility to harvest solar irradiation in buildings. At the same time, solar energy exploitation on existing buildings could be compromised during urban transformation. To shift the detail at a building level, but always referring to the urban environment, it is necessary to examine the existing and under transformation architectonical situations. This will be done by analysing the distinctive elements of the surroundings according to building techniques, year of construction, materials used, morphology of the buildings and so on. All these aspects will finally complete the assessment at the energy level. All levels have a direct impact on medium and long term stationary buildings (i.e. heritage buildings). Compare the current situation with the future one (when the New Master Plan will be completely implemented) allows to establish the main impacts of densification, such as the solar potential for renewable solar energy installations (RES). The main focus of the methodology proposed is to measure the impact and repercussions of the urban changes on the solar availability and also the effects of these measures in the existing historical buildings and cultural monuments.

ANALYSIS

The analysis has been done with three levels of detail: Urban, building, energy.

Urban Level Analysis

As result of this analysis, the City Centre area (CC) of Paradiso was selected to investigate the main key parameters mentioned above, regarding phases 2 and 3 as stated in the methodology process because an important urban transformation is expected in this area towards densification by increasing the percent of buildable area and the public walkability of the streets, with tallest closed blocks of buildings up to nine floors. The new master plan sets out for a minimum of 40% primary residence and a maximum of 30% on secondary residences, 30% offices. The downtown area of the municipality has an urban setting with "*warped parallel*" roads as street pattern and currently buildings are freely positioned on the plot where façade orientation in this case is less determined by the street layout that are equally divided on North-South and East-West. The geography of the place does not have much slope varying from 16% to 1% next to the lake. It is the most densely built area of the territory of Paradiso. It is the area with the largest number of protected cultural buildings. Currently, the proportion of buildings with respect to open spaces (public and private) is important, near to 40% of buildings and 10% for roads, and 50% of open spaces (mainly private 28%).

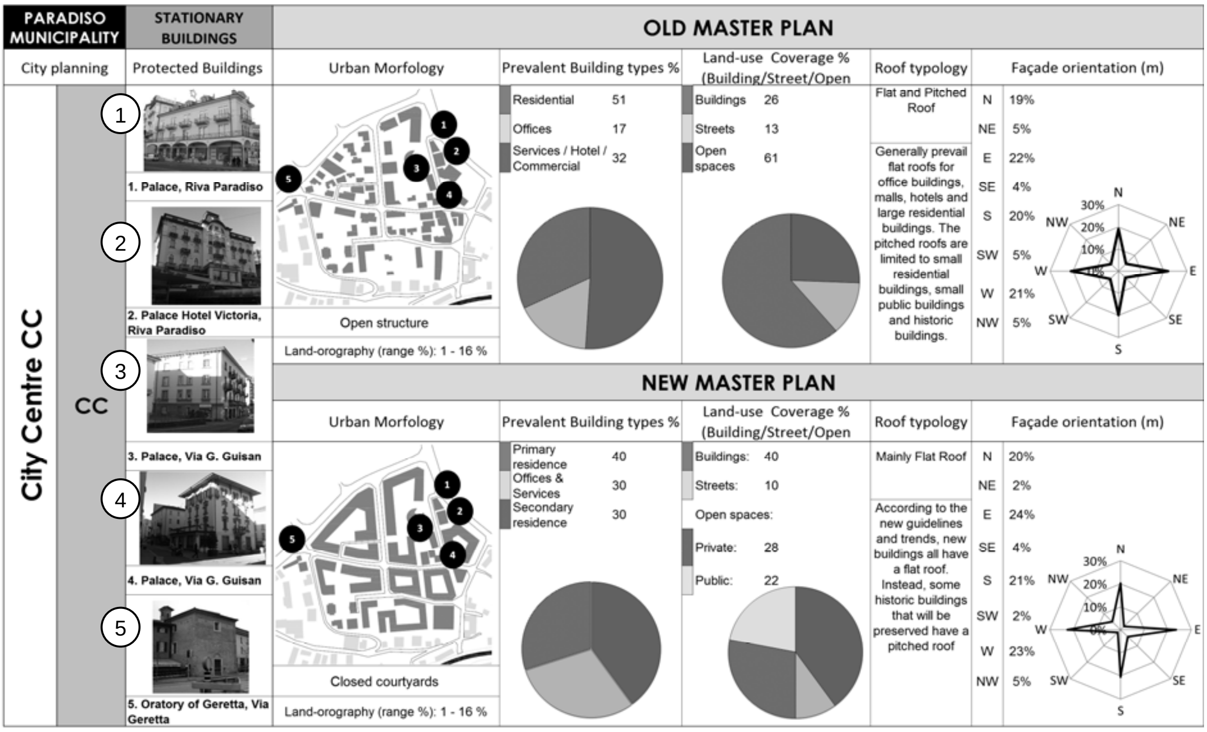

Figure 3: Comparative table of the New Master Plan regulatory status and the current situation status for the whole City Centre area.

Building Level Analysis

Different aspects have been analysed from the urban level to the building level for each of the sectors of the selected area (the Master Plan divides the City Centre core in different building areas, named from A to G), which are: Aspects regarding urban morphology: *street patterns and street profiles, settlement unit, the height to street width ratio (H:W) and the urban density (%)*; Aspects regarding building configuration and design: *prevalent building types (uses and construction typologies, year of construction, etc.), orientation, building heights*; Aspects regarding building shape and façade materials: *roof and façade typologies and building envelop features.*

As outcome of this analysis it has been found that street profiles significantly change in the new configuration of the Master Plan with building heights reaching up to 29,5 meters from the level of the street. Due to the relationship between the heights of buildings in the area on each side of the streets, for all cases the H:W, height to street width ratio, is quite high, which mean, a poor balance in solar access terms with shading effects on surrounding buildings. This situation is significantly accentuated in the case of the new plan with building heights up to nine plants with H:W ratios up to 2,5 in some cases. There will be a reduction on the potential use of solar passive strategies and will limit the use of façade surfaces for integrated solar photovoltaic systems. Besides, air circulation in the urban area could be reduced significantly due to the configuration of these urban canyons. Building orientation remains predominantly oriented along N-S or E-W axis which means that well-oriented façades are proportionally equal to those not well-oriented. It would be necessary to adequately differentiate openings in the different orientations to maximize passive energy gains minimizing energy losses at the same time.

Energy Level Analysis

At this level, a first estimation of the total energy balance in the area was performed considering a full exploitation of the solar potential for renewable systems (solar photovoltaics). This PV potential, in the present status, assumes the use of all the roofs surface available in the area while in the future scenario it has been necessary to consider also the facade surfaces well exposed to solar radiation (to comply with the obligation of 10 Watt/m^2 of PV), due to the high densification. The scope of this analysis is to verify whether it is possible to reach the objectives suggested by future Swiss policies in a high dense urban area, while at the same time, to know the impacts also in terms of visibility and changes of the urban perception when these technologies are in proximity to buildings protected.

The total thermal energy consumption (thermal/DHW) of the buildings has been roughly estimated in the current state and future state based on statistical information collected and developed at SUPSI [5] by applying average coefficients [kWh/m^2yr] of thermal consumption indices as a function of year of construction for new and existing buildings. In the study, the annual heat requirement [MWh/m^2yr] of each sector it has been calculated building by building, considering the category of the building and use relative to each (i.e. residential, commercial, offices, schools, etc.), type of building based on the year of construction (more than 50 years; from 20 to 50 years; max. 20 years; new or renovated buildings) and the energy reference surface [m^2]. In case of future buildings, to quantify an equivalent electrical amount of energy, the heating and cooling energy demand has been converted in an equivalent electric load. Considering the hypothesis that these new buildings will be more efficient, it has been supposed the generalized use of heat pumps for thermal conditioning (equivalent coefficient of performance, COP equivalent equal to 3). The total electrical energy consumption [MWh/m^2yr], i.e. annual electricity needs in the area, sector by sector for the current state and the future one, has been estimated also by applying the Swiss regulation SIA 380/1:2009 and the SIA 380/4:2006. The solar irradiation estimation and solar potential analysis for renewable solar systems (RES) has being conducted by using the solar Cadastre of Ticino provided by OASIS platform (http://www.oasi.ti.ch/) for the current situation and also by using simulation tools like PVSOL for the new (*considering PV modules of multicrystalline technology with Nominal Power of 270 Wp and module efficiency η_m 16.5%, for simulations).

		CURRENT SITUATION (ACTUAL URBAN PLAN)						FUTURE SITUATION (NEW URBAN PLAN)					
Sectors		GROSS FLOOR AREA [m^2]	THERMAL DEMAND [MWh/yr]	ELECTRICAL DEMAND [MWh/yr]	ESTIMATED ANNUAL PV PRODUCTION [MWh/yr]	(1) PV ELECTRICAL CONTRIBUTION [%]	(2) PV ELECTRICAL CONTRIBUTION [%]	GROSS FLOOR AREA [m^2]	PRIMARY THERMAL DEMAND [MWh/yr]	ELECTRICAL DEMAND [MWh/yr]	ESTIMATED ANNUAL PV PRODUCTION [MWh/yr]	(1) PV ELECTRICAL CONTRIBUTION [%]	(2) PV ELECTRICAL CONTRIBUTION [%]
Paradiso Municipality - City Center Area (PRG CC)	A	20'437.0	1'696.5	544.7	257.0	47%	11%	70'822.0	1'010.5	2'051.6	683.5	33%	22%
	B	48'366.0	3'364.1	1'170.1	324.0	28%	7%	77'461.0	1'119.3	2'271.6	627.3	28%	18%
	C	14'624.0	1'158.8	401.9	100.0	25%	6%	33'171.0	491.8	976.8	285.4	29%	19%
	D	3'199.0	188.0	87.8	53.0	60%	19%	2'947.0	52.6	84.7	24.3	29%	18%
	E	15'730.0	1'522.9	432.5	112.0	26%	6%	40'302.0	549.1	1'169.3	400.0	34%	23%
	F	21'162.0	1'900.1	602.4	202.0	34%	8%	41'175.0	561.0	1'194.6	391.1	33%	22%
	G	42'336.0	2'612.2	1'176.0	192.0	16%	5%	64'997.0	934.5	2'145.4	580.6	27%	19%
Total urban area		165'854.0	12'442.7	4'415.5	1'240.0	28%	7%	330'875.0	4'718.8	9'894.1	2'992.2	30%	20%

(1) Considering only the electrical demand
(2) Considering electrical demand plus thermal demand

(1) Considering only the electrical demand
(2) Considering electrical demand plus thermal demand

Table 1: Energy demand, PV solar potential and global energy balance. The table shows the PV percentage contribution to meet the objectives of a Net-zero Energy settlement.

RESULTS AND CONCLUSION

The paper shows the impacts of urban densification and solar RES implementation policies in a case-study (Lugano-Paradiso). The simulated scenarios consider solar photovoltaic systems fully integrated in the City Centre (CC) district area, where there are several protected buildings. The results highlighted that the estimated PV percentage for electrical supply is almost equal for the current and the future situations when the new urban Master Plan will be completed (28% and 30%, respectively). The main differences in the two scenarios are that a high PV density (Wp/m^2) in the second case impacts on PV system visibility while transforming the complete urban area appearance. In the hypothesis of covering also the thermal buildings demand, the future situation is better if considering a high-efficient built stock (future average thermal energy density index of 14 kWh/m^{2}yr compared with 77 kWh/m^{2}yr calculated for the present status). These results show how important is the proper integration of PV technologies in future buildings, especially in dense urban areas through the use of BIPV (Building integrated Photovoltaics) products. The proposed methodology foresees that the energy impacts of the densification policies, must to be quantified to enable new approaches for urban planning alternatives. Further aspects affecting solar access in dense urban areas will be developed within the project and presented in future.

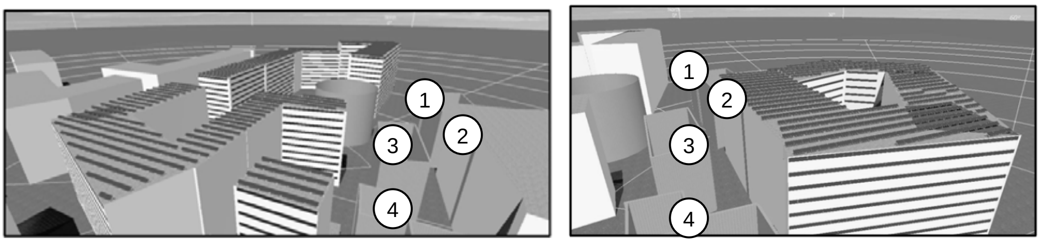

Figure 4: PV in the future scenario, B-C sectors (numbers are protected buildings).

ACKNOWLEDGEMENTS

This project was funded by the Stiftung zur Förderung der Denkmalpflege (Foundation for the Promotion of the Conservation of Historical Monuments). We are also grateful to Lugano-Paradiso Municipality and Planidea SA which provided the 2D/3D drawings of the new urban development planning. Moreover we thank also the colleagues from ISAAC-SUSPI and other contributors (in particular, Pampuri Luca and Sala Mariaemma).

REFERENCES

1. Swiss Heritage Society position paper: L'aménagement du territoire face à de grands défis / Raumplanung vor grossen Herausforderungen. Densificare con qualità (2010).
2. URBACT III European Territorial Cooperation programme (2014-2020). http://urbact.eu/
3. EnSURE Project: Energy Savings in Urban Quarters through Rehabilitation and New Ways of Energy Supply. INTERREG IV B Central Europe (2007-2013).
4. Polo López C. et al.: ENBAU, Energie und Baudenkmal. Energy Conservation Practices on the Historic Heritage Buildings. Proc. of the BRENET Status-Seminar, Zürich, 2012.
5. Bianchi P., Pampuri L., Crivelli G., Cellina F., Mobiglia, M.: Quanto calore consumano gli edifici residenziali in Ticino? Aggiornamento della metodologia di stima dell'indice energetico per il fabbisogno termico. Dati - Statistiche e società, A. XIV, n. 2, pp 81-85, 2014.