A holistic method for energy renovation of buildings: focus on users' involvement

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Abstract

The energy renovation of existing building stock has been widely acknowledged as having a key role to tackle the 20-20-20 European targets (EuroACE, 2014). However, many open challenges characterize the effectiveness of building renovations, for instance, procedural methods that consider the interaction of multiple variables and their influence on a specific building are still inadequate. The aim of the paper is to investigate a holistic method (Eriksen et al., 2013) that, if used during the diagnostic pre-renovation phase, allows for the evaluation and planning of strategic renovations. To achieve the aim, the holistic method was applied on a multi-storey building for social housing that must be renovated. Thus, investigations about economic, architectural, technical, user and legislative aspects were carried out to create an overview of the building's features and needs. Thanks to the holistic diagnosis, the users' involvement and active participation was found to be a challenge. Therefore, TRNSYS simulation software was employed to specifically assess how much users can influence the success of the renovation project. Specifically, the first step was the creation of a baseline model for the existing building. The baseline model calibration was based on the current thermal performance, which was derived from data collected during the holistic method application. Afterwards, two borderline renovation scenarios were developed: on one hand, a model conforming to a pre-feasibility study that does not entail users' habits, and on the other a model that can be representative also of users' behaviour. The rationale behind is to quantify the impact of users in case they are not considered or they are not willing to be part of the project and, hence, they do not modify their habits accordingly.

Research results showed that the holistic method can contribute to optimizing the design that will be used in the renovation as it effectively assesses the multiple effects of the variables and it incorporates the users' perspectives. Users are a crucial component to take into consideration from the beginning of a project. The paper represents other evidence of the importance of using building performance simulations (BPS) early in the design process to both assess the influence of users' habits on the energy consumption and become a system check for subsequent further design phases.

1. Introduction

The European Union (EU) has recognized the retrofit of existing building heritage as a priority since it represents one of the most cost-effective solutions to reduce global warming (EuroACE, 2014). Nevertheless, the available procedural tools are still inadequate (Ma et al., 2012). According to these authors, although there is a wide range of retrofit technologies available on the market, it remains a challenge to identify the most appropriate and cost-effective solution for a specific building because of the great number of variables that can widely change from building to building, e.g., climate, users' behavior, policy, financial limitations, services, maintenance, malfunctions. As a result, a discrepancy exists between the building's targeted energy performance and the real one. For the role of building users, a growing number of empirical studies has shown their crucial impact on the success of an energy retrofit. Tenants have an influence on the building's performance with their presence and activities (Hoes et al., 2009). They directly influence the energy demand when

Part of
Baratieri, M., Corrado, V., Gasparella, A. & Patuzzi, F. (Eds.). 2015.
Building simulation applications BSA 2015. bu,press.
https://doi.org/10.13124/9788860460745

operating windows, blinds and thermostats whereas they have an indirect effect on the energy consumption pattern due to the changes over time of occupancy schedules and usage patterns (Masoso and Grobler, 2010). However, Kashif A. et al. (Kashif et al, 2014) stressed that while great attention has been paid to the building's installations, the understanding of users' behavior has not been sufficiently investigated. Therefore, to optimize the outcome of a renovation, the design approach should integrate the influence of the building's technical aspects together with the users' behavior representation, giving them the same importance. This paper focused on testing the effectiveness of a holistic approach (Eriksen et al., 2013) that aims to provide a standardized evaluation of a building by investigating technical, economic, architectural and social aspects and by giving them the same importance. The application of such a method has allowed us to answer the following research questions:

1. How can a holistic approach contribute to optimizing the renovation of an existing residential building?
2. How does users' involvement influence the effectiveness of a renovation project?

2. Method

The two research questions were addressed by splitting the method in two parts: Part 1 regards the application of the holistic method to answer the first research question, while Part 2 answers the second research question through simulation modeling. The outcomes from Part 1 were used as input for Part 2.

2.1 Setting

The setting is the city of Bolzano, which is in the Autonomous Province of Bolzano (APB), in the north of Italy. According to UNI 10349 of the National Standard, the city's climate is continental. It belongs to zone E and it is characterized by 2791 Heating Degree Days (HDD). The subject of the research is a multi-storey building for social housing belonging to building stock from the 1970s. The targeted renovation's aim is the decrement in the energy needs for heating from the current average value of 100 kWh/m^{2}year to approximately 25-30 kWh/m^{2}year, the highest class of the regional rating system. Before the holistic method application, only data in Table 1 were available.

Table 1 – Building's available information pre-method application

Year built	1978
Shape	5 main bodies, block A′-B′-C′-D′-E′
Orientation	Orientation axis N-E/S-W. Blocks are differently orientated.
Stores number	8 stores for blocks A′-B′- C′- D′ 7 stores for block E′
Area	Useful (walkable) area: 7.835,45 m^2; Gross area: 9.402,54 m^2 Business area= 0 m^2
Apartments	106
Preservation	Not rated as worthy of preservation

2.2 Danish holistic method overview

The holistic method elaborated by Eriksen et al. (Eriksen et al., 2013) has been taken as a starting point for Part 1. The method entails equivalent consideration of energetic, structural, economic, architectural and social aspects. The method was developed within the Danish context, it was applied to two case studies and it is still under finalization. Since its purpose is to provide a standardized and holistic evaluation of buildings to renovate during the prefeasibility study phase, its application on the Italian case study served to test the actual goal achievement. Fig. 1 depicts the method's structure: six constituent elements with the same importance led towards the determination of "focus points". Next to each element are listed the building's main aspects that were assessed. The investigations were carried out by means of available documentation, direct inspections, and by performing questionnaires and interviews with building users. Although the acquisition of data was an ongoing process, the arrows indicate the recommended way to progress. The analysis started with the *Master data collection* and *Economical investigation* to gather preliminary hints regarding both the building potential and the feasibility to perform holistic energy renovation.

Once verified the financial means, the *Architectural, Technical, Social* and *User investigations* were performed to obtain an overview of building defects to renovate. The coherent legislation was consulted across all previous elements to ensure the fulfillment of updated national laws requirements.

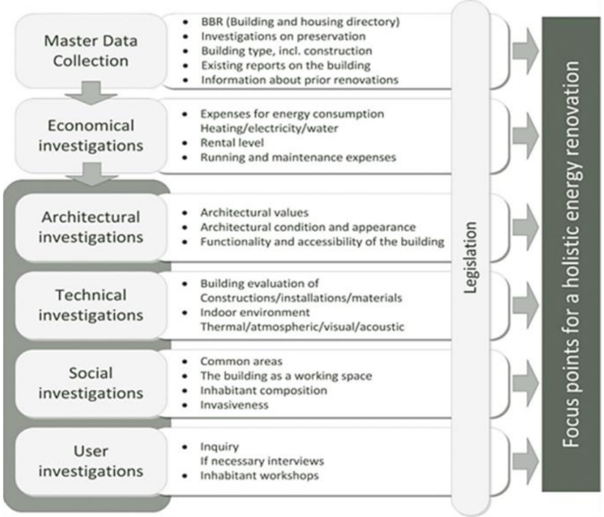

Fig. 1 – Holistic method structure (Eriksen et al., 2013)

2.3 Simulation modeling

Since the holistic method introduces the importance of building users, part 2 investigated their influence on the thermal energy performance once the building is renovated according to the given energy target.

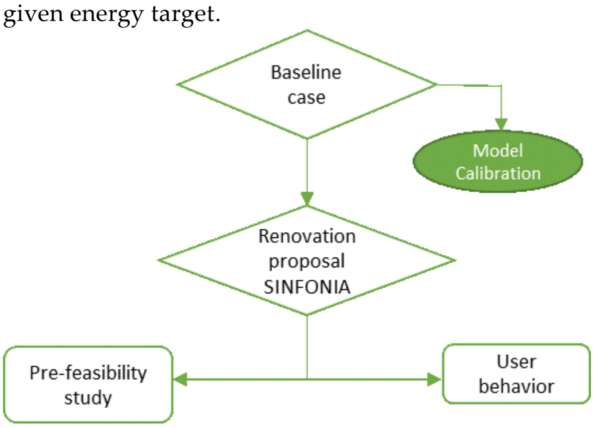

Fig. 2 – Simulation modeling structure

To achieve the goal, a baseline model was created based on the outcomes of the application of the holistic method. After the model creation and input definitions, the model was calibrated to obtain a simulation model's energy consumption for heating as close as possible to the real one, 118 kWh/m²year. This was accomplished by defining the only missing variable: the total air exchange rate, as further explained in 2.3.1.1.

Fig. 2 shows that the baseline-calibrated model was then renovated. Two proposals are presented: the first is explicitly inspired by the pre-feasibility study carried out by project designers; the second one shows one of the worst cases for post-renovation: unchanged users' behavior in terms of window opening compared to pre-retrofit situation.

2.3.1 Baseline case

The modeling framework incorporates a 3-D model of the multi-zone building, realized by means of the SketchUp building geometry design tool, into the TRNSYS 17 simulation model using the TRNSYS3d plug-in. The parameters assigned for the thermal performance evaluation of the existing building are:

Geometrical properties: found out in the *architectural investigations*, these were assumed according to available data and direct inspections, coherently with the UNI 11300 attachment B1.

Table 2 – Geometrical properties: baseline case

Element	Thickness [m]	U-value [W/m²K]
Roof	0.25	1.70
External wall	0.30	0.90
Ground floor	0.36	0.79
Insulated divisions	0.41	0.70
Windows	Single glazed	4.00

Environmental properties: the building orientation was defined in SketchUp by orienting the geometrical model like the real building. The microclimate conditions, i.e. the incident solar radiation and the air temperature and relative humidity, were set up in TRNSYS Simulation Studio respectively by means of solar radiation processor and psychometric type 33. These data were collected from the meteorological radar in Bolzano, on an hourly basis for 2013.

Internal gains: according to results of questionnaires, most of the tenants are more than 60 years old and they occupy their own apartment for more than 18 hours per day. Therefore, it was decided to define a constant internal gain equal to 4 W/m², according to UNI TS 11300 for residential buildings.

Natural ventilation - venting and infiltration: the building's total air exchange rate is the sum of window opening rate, which relies on users' habits, and of structural infiltration rate through the building envelope, which depends on its tightness. Given the complexity to properly define the infiltration rate at the initial stage, a constant value was initially assumed and later calibrated, as explained in Section 2.3.1.1.

Heating system: the building is connected to the district heating (DH) network that works from October 15th until April 15th. A schedule was created to diversify operation hours (6 a.m. – 10 p.m.) from switching off hours. When in operation, the temperature set point was assumed equal to 21 °C according to the questionnaire's results. Outside operating time, a set point temperature of 11°C was defined in order to avoid the heating system onset. Finally, the average efficiency of the system was assumed to be 87.5%, as the multiplication result of the efficiency coefficients of heat exchanger, distribution system and radiators, as indicated in UNI 11300.

2.3.1.1. Model calibration

Once having set up all inputs, the model was calibrated by defining the only missing variable: the total air exchange rate. The procedure consisted in a series of attempts with different values of total air exchange rate until the simulation results came very close to the real building energy consumption (equal to 118 kWh/m²year for 2013, according to the DH provider datasheet). As mentioned in 2.3, the total value of air exchange rate can be split in two components, the window opening, which is the human induced component, and the structural infiltration component. Since the structural infiltration rate was assumed, through the calibration it was possible to settle the component influenced by users' habits: the window opening. The structural infiltration was set in TRNBuild after having assumed it according to (Paiola, 2014): with the Blower Door running and the house pressure at negative 50 Pa, a typical building of 70's can leak at the rate of 2-3 air changes per hour. The value, which is usually expressed as N_{50} = 2-3, is the result of equation (1).

$$N_{50} = \frac{average\ air\ flow\ rate\ of\ infiltration\ at\ 50\ Pa}{Zone\ internal\ volume} \quad (1)$$

From N_{50} it was possible to deduce the correspondent infiltration rate at normal pressure conditions, by means of the program Passive Haus Pojecterungs Paket (PHPP), approximate equal to 0,350 h^{-1}. The total air exchange rate during night hours (10 p.m – 7 a.m) was set equal to the infiltration rate because according to tenants' declarations, windows are open almost always during the day. While, during daytime the missing window opening rate was found through a series of simulations. Table 3 shows the results diversified between day and night.

Table 3 - Total air exchange rate: calibration results:

	Night	Day
Structural infiltration [h^{-1}]	0.350	0.350
Windows opening [h^{-1}]	0.049	0.391
Mechanical ventilation [h^{-1}]	0.000	0.000
TOTAL AIR EXCHANGE RATE [h^{-1}]	**0.399**	**0.741**

Regarding the obtained window opening rates, they are to be considered just as time-averaged values calculated on a yearly basis, because the calibration process did not take into consideration any factor such as gender, age, perceptions of personal control, season, and weather conditions.

2.3.2 Renovation proposal

The calibrated baseline model was adjusted according to project targets. The shown renovation proposals include the following borderline cases:

1. Best case: Renovation conforming to the pre-feasibility study.
2. Worst case: renovation in case of unchanged user's habits (compared to current habits in terms of window opening).

2.3.1.2. Best case scenario

The renovation did not involve a change of environmental and heating system properties, nor of internal gains. Applied changes regarded the thickness of insulation, type of windows, as pointed out in Table 4, and the implementation of a mechanical ventilation system.

Table 4 – Geometrical properties: best case scenario

Element	Thickness [m]	U-value [W/m²K]
Roof	0.27	0.15
External wall	0,50	0.16
Ground floor	0.40	0.47
Insulated divisions	0.41	0.70
Windows	6/12/6/12/6 argon	0.70

In order to achieve the ambitiously targeted performance, it was necessary to adopt highly insulating materials so as to lower as much as possible the thermal transmittance of external elements (e.g., walls, windows, and horizontal divisions), thus incrementing the envelope's air tightness. As a direct consequence, the mechanical ventilation system was necessary in order to deliver the right amount of fresh air for indoor comfort conditions, whilst avoiding useless energy losses. The central ventilation plant was modeled as a heat recover ventilator (HRV) by inserting the type "Heat exchanger with constant effectiveness" in Simulation Studio interface and connecting it to the building type. The balanced air-to-air heat exchanger was sized in order to fulfill the UNI TS 11300 requirements. Thus, it provides a continuous value of 0.30 air changes per hour [ach] and it recovers some of the energy of the air passing through it when T_{in} < 24°C and T_{out} < 12°C. To achieve the last condition, a control was created on the output air flow so as to let it passing through the HRV only in the case of favorable conditions. The annual recovery effectiveness of the mechanical system was assumed equal to 65% to take into account the conditions in which the system is expected to operate (Carbon trust, 2011). In addition, the renovated building was modeled with a new structural air infiltration rate that was approximated based on referential Blower Test n_{50}, which is 0.60 h^{-1} for passive houses. As previously stated, PHPP software was useful to find the air exchange rate under standard pressure conditions, equivalent to 0,105 h^{-1}. Table 5 shows the total air exchange rate and the values per each entry.

Table 5 – Total air exchange rate: best-case scenario

	Night	Day
Structural infiltration [h^{-1}]	0.105	0.105
Windows opening [h^{-1}]	0.000	0.000
Mechanical ventilation [h^{-1}]	0.300	0.300
TOTAL AIR EXCHANGE RATE [h^{-1}]	**0.405**	**0.405**

2.3.1.3. Worst case scenario

The worst-case scenario seeks to show a prospective negative impact of users' behaviour on the renovated building's energy performance. In particular, it was simulated the case in which users keep on opening their windows at the same rate that was found through the baseline model calibration, section 2.3.1.1. The rationale of this specific choice descends from the empirical factor according to which if occupants do not receive any information on the proper way to use mechanical ventilation, they will likely keep on acting as they do currently. Therefore, all input parameters of the best-case scenario were kept constant, except for the total air exchange rate. The simulation ran with a total air exchange rate equal to the sum of the value provided by the mechanical ventilation, the value depending on the structural infiltration and the value of windows opening found through model calibration, as shown in Table 6.

Table 6 – Total air exchange rate: worst-case scenario

	Night	Day
Structural infiltration [h^{-1}]	0.105	0.105
Windows opening [h^{-1}]	0.049	0.391
Mechanical ventilation [h^{-1}]	0.300	0.300
TOTAL AIR EXCHANGE RATE [h^{-1}]	**0.454**	**0.796**

3. Results and Discussion analysis

To answer the first research question, the application of the holistic method allowed us to verify that it can effectively contribute to optimizing the renovation of existing residential buildings as it assesses the effects of multiple variables, it facilitates multi-professional and multi-disciplinary collaboration, and it incorporates the user perspective. Therefore, the holistic method was demonstrated to work properly as a development tool also under different settings. In particular, it allowed us to identify the most important renovation focus points and it contributed to creating a broader perspective in the initial design stage that may be beneficial for further steps. When many stakeholders (consumers, policy makers, product manufactures, regulators, technology developers, investors, designers) use it, an extensive wider perspective can be created about a building to renovate. In particular, the method could avoid the misunderstanding about complete freedom of choice and experimentation that designers have had so far, and consequent repercussion on inhabitants that, on the contrary, have not had the possibility to express opinions based on their experience, culture, origin and needs (Civiero, 2012). However, some barriers limit the possible accomplishment of the holistic approach:

1. The widespread lack of information about both building parts and installations results in a prolonged time required to gather all information.
2. The multidisciplinary approach that can maximize the method's effect struggles to become established in the Italian public sphere as well as in academic research (Civiero, 2012).
3. The tenants' willingness to take an active role was found to be a challenge, which in itself reduces the potential benefits of the method.

In addition, the thesis has shown that the method has some deficiencies:

1. The method does not indicate the importance of using the building performance simulation (BPS) as a support to evaluate the multitude of parameters (Ratti et al., 2005). For instance, it lacks a real representation of users' behavior. It is restricted to the evaluation of users by means of questionnaires and interviews but it does not suggest putting into practice the acquired knowledge through modeling/ simulation.
2. The Danish method considers the building as a self-confined entity, neglecting the importance of the interaction with the urban surroundings (NRDC, 2014), which would allow us to broaden the virtual boundaries of holistic method (Okeil, 2010). The resulting focus points would change accordingly (Ratti et al., 2005; Xu et al., 2012) and they could be even as useful for the local surroundings (the neighborhood) contributing to finding solutions that, although conducted at the building level, have a positive influence on the surrounding urban area (Ferrante, Semprini, 2011).

To answer the second research question, in this study user involvement was found to be a challenge, which in itself reduces the potential benefits of the Holistic Method. However, when users were involved, it was possible to identify both hidden problems of the building and the effect of user behavior on performance of energy conservation measures. The results of the users and social investigations, and of the energy simulations, suggest that user involvement can influence the energy renovation of the building in two ways:

1. Users' opinions can help identify some "unspoken" problems correlated to their building that otherwise may be impossible to address, i.e. too many expenses for night garden lighting, or the malfunctioning of elevators that they often experience.
2. Users' behavior affects building energy performance, beyond efficiencies that can be gained through building renovation. In detail, training users can help to achieve larger energy savings.

From simulation results, the obtained energy needs for heating in the best case scenario corresponds to 16.03 kWh/m^{2}year. The result is 30% lower than the expectations targeted for the project (25 kWh/m^{2}year). Accordingly, the energy saved by renovating the building consistent with the pre-feasibility study corresponds to 102 kWh/m^{2}year, thus obtaining a difference of 86.5%. The amount of saved CO_2 can be approximated to 354 tons (or 150 TEP), calculated using the National conversion factor of 0.44 tons of CO2 (and 0.187 TEP) per MWh. Table 7 shows the prices of thermal energy (SEL, 2014), the thermal energy consumed and the relative annual expenses in both pre-renovation and post-renovation cases.

Table 7 - Annual heating costs: comparison

	Thermal energy price [€/kWh]	Thermal energy consumed [kWh]	Annual heating costs [€]
Baseline case	0.0651	930066.3	60547
Best case renovation	0.0651	146266.9	9521

From the listed values the annual economic saving in favor of tenants can be calculated, which comes to €51,000 per year.

However, in the worst-case scenario of unchanged users' behavior in terms of window opening, the building energy needs for heating is 291,700 kWh/year, which corresponds to 37.25 kWh/m^{2}year. The result is 49% higher than the threshold needed to fulfill the project purposes, and the energy savings compared to the baseline case amount just to 81 kWh/m^{2}year.

Fig. 3 depicts graphically the comparison in terms of annual energy needs for heating between the baseline model at the existing conditions (number 1) and the two renovated cases: best-case scenario (number 2) and worst one (number 3)

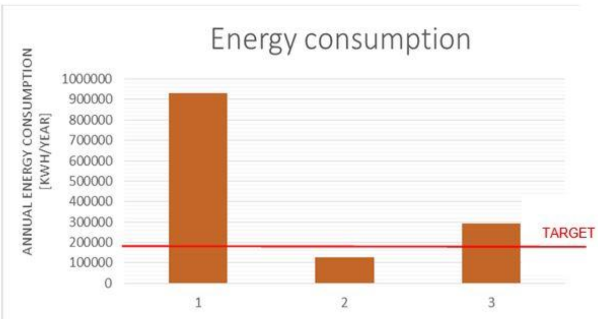

Fig. 3 – Energy needs for heating

4. Conclusion

In conclusion, the holistic method is a valid tool to start a holistic energy renovation, even though it could be further improved by also considering the urban context. The resulting outcome has been an extensive knowledge of building needs, problems and restrictions that, together, can form a solid baseline for further renovation stages. In particular, the main innovation of the method, i.e., the users' involvement, has been crucial to point out what their main habits and concerns can be (e.g., malfunctioning of the elevators), as well as their low level of knowledge about energy topics and low sense of ownership. On the other hand, the model design at the early stage of renovation project was an important part of preliminary documentation that, together with focus points, would become a system check for further design phases. The simulation energy modeling has been crucial to assess the building performance based on the investigations of the holistic method. The simulations showed that the building energy consumption can be reduced even more than the target if there is correct user behavior. They also allowed us to quantify the users' influence on the renovated building energy performance, showing that there exists a difference of 131% between the best and the worst scenarios. It was demonstrated, therefore, that the success of the renovation depends significantly on whether occupants accept the changes and modify their habits accordingly. To accomplish that, the suggestion is to take into consideration all highlighted issues, thus considering the building as a set of services at the users' disposal. In the case that interventions focus only on reducing the energy consumption, but do not contemplate elevators or garden lighting system, the refurbishment could be just partially successful because tenants will keep on complaining. In addition, if they do not take an active role in the renovation project and are not accurately informed about changes, they do not have the opportunity to know how to vary their own lifestyle and they can even lead to the project failure. Based on the results, it is possible to conclude that a recommended way to proceed regards not just a renovation of building parts but also a revision of occupants' habits.

5. Acknowledgement

The material of this paper was the subject of the master thesis entitled "Holistic method for energy retrofitting of buildings: application and analysis" written in collaboration between DTU – Technical University of Denmark and EURAC – European academy of Bozen. The research was carried out in the framework of EU FP7 Smart cities and communities projects: SINFONIA.

References

Carbon Trust, 2011. "Heat recovery: A guide to key systems and applications", Accessed November 4, 2014. http://www.carbontrust.com/media/31715/ctg057_heat_recovery.pdf

Civiero P. 2012. "Approccio sostenibile al recupero dell'edilizia residenziale." *Hortus*. ISSN 2038-6095.

Eriksen M. S., Rode C. 2013. "Method for Developing and Assessing Holistic Energy Renovation of Multi-storey Buildings." *In proc. Sustainable building, Munich, Germany, 2013*.

EuroACE, 2014. "Renovate Europe - Energy Efficiency in Buildings." Accessed November 3, 2014.
http://www.euroace.org/LinkClick.aspx?fileticket=ecoJ1VlCGzg%3D&tabid=40

Ferrante A., Semprini G. 2011. "Building energy retrofitting in urban areas". *In proc. International Conference on Green Buildings and Sustainable Cities, Bologna, Italy, 2011*.

Hoes P., Hensen J.L.M., Loomans M.G., Vries B., Bourgeois D. 2009. "User behaviour in whole building simulation." *Energy and Buildings* Volume 41, Issue3: 295-302. doi:10.1016/j.enbuild.2008.09.008.

Kashif A., Le X.H.B., Dugdale J., Ploix S., Bourgeois D. 2014. "Agent based framework to simulate inhabitants' behaviour in domestic settings for energy management." *In Proceedings of the 3rd International Conference on Agents and Artificial Intelligence, pages 190-199*
doi: 10.5220/0003150301900199

Ma Z., Cooper P., Daly D., Ledo L. 2012. "Existing building retrofits: Methodology and state-of-the-art." E*nergy and Buildings* Volume 55: 889-902, doi:10.1016/j.enbuild.2012.08.018

Masoso, O.T., Grobler L.J. 2010. "The dark side of occupants' behaviour on building energy use." *Energy and Buildings* Volume 42, Issue 2: 173-177 doi:10.1016/j.enbuild.2009.08.009

NRDC - Natural Resources Defense Council, 2014. "LEED for Neighborhood Development", Accessed October 6. http://www.nrdc.org/cities/smartgrowth/leed.asp

Okeil A. 2010. "A holistic approach to energy efficient building forms." *Energy and Buildings* Volume 42, Issue 9: 1437-1444. doi:10.1016/j.enbuild.2010.03.013.

Paiola L. 2014. "Blower door test". Accessed November 7.
http://www.ledenergy.it/pdf/121022-2313-Appuntamenti%20costruire%20qualit%C3%A0.pdf

Ratti C., Baker N., Steemers K. 2005. "Energy consumption and urban texture." *Energy and Buildings* Volume 37, issue 7: 762-776. doi:10.1016/j.enbuild.2004.10.010.

SEL. 2014. "Tariffe Teleriscaldamento Bolzano – District heating tarifs Bolzano." Accessed July 11.
http://www.sel.bz.it/it/clienti/calore/teleriscaldamento-bolzano/tariffe.html

Xu X., Taylor J.E., Pisello A.L., Culligan P. 2012. "The impact of place-affiliation networks on energy conservation: A holistic model that integrates the influence of buildings, residents and the neighborhood context." *Energy and Buildings* 55 (2012): 637-646. http://dx.doi.org/10.1016/j.enbuild.2012.09.013