A CitySim Urban Energy Simulation for the Development of Retrofit Scenarios for a Neighborhood in Bolzano, Italy

Fahad Haneef – Free University of Bozen-Bolzano, Italy – fahad.haneef@natec.unibz.it
Federico Battini – Free University of Bozen-Bolzano, Italy – federico.battini@natec.unibz.it
Giovanni Pernigotto – Free University of Bozen-Bolzano, Italy – giovanni.pernigotto@unibz.it
Andrea Gasparella – Free University of Bozen-Bolzano, Italy – andrea.gasparella@unibz.it

Abstract

The urban territory is responsible for a high percentage of natural resources depletion and waste generation. Population increases and cities expand, and thus energy demand climbs. Consequently, an efficient use of energy is becoming more and more crucial in order to promote both local and global sustainability. To achieve such a goal, the reduction of energy demand, the optimization of energy supply sources, and the increase of renewable energy share can facilitate the transition of urban areas into highly efficient and sustainable districts. In this framework, this study assesses to what extent typical building retrofit interventions can reduce energy consumption, enabling a transition towards a nearly Zero Energy District (*nZED*). A state-of-the-art urban simulation was developed with CitySim for part of the city of Bolzano, Italy, to evaluate the annual district energy uses and define possible efficiency measures (e.g., façade and roof insulation and substitution of windows). Achievable energy savings are analyzed and the most significant factors affecting the overall performance identified.

1. Introduction

Communities around the world are entering an age characterized by what some authors have labelled the "Fourth Industrial Revolution" (Rifkin, 2004), as society moves from fossil fuels – used since the "Second Industrial Revolution", towards renewable energy generation and technologies to adopt in sustainable and smart communities. For communities around the world, energy needs are growing year after year, as population increases, cities expand, and energy demand climbs. The challenge of supplying energy for increasing demand, while reducing carbon emissions, calls for more complex and new creative solutions (Clark, 2010).

Furthermore, there has been a rapid population shift from rural to urban areas. According to a recent UN report (UN, 2014), over 54 % of the total world population lives in cities and this is likely to increase to 66 % by 2050. As a result, cities, already responsible for approximately 70 % of the world's fossil fuel emissions (Polly et al., 2016), are drastically expanding. Consequently, urban energy efficiency is crucial for promoting local and global sustainability (Aelenei et al., 2016; De Lieto Vollaro et al., 2014; Marique and Reiter, 2014).

Several case studies in the literature have explored the possibility of improving energy efficiency in buildings (Copiello, 2017). For instance, some authors have used data mining techniques to identify low-efficiency buildings (Zucker et al., 2014), analysed the efficacy of different energy policies (Lee et al., 2015), and discussed the energy saving potential from the renovation into net zero energy buildings (Konstantinou and Knaack, 2013; Luddeni et al., 2018). Other researchers have optimized existing and new building design and features (Afram et al., 2017; Evins, 2013; Gong et al., 2016), and investigated the effectiveness of smart energy management for buildings (Rocha et al., 2015), with different targets of energy consumption and renewable integration at district scale (Guen et al., 2018; Mohajeri et al., 2019). However, energy simulation tools and policies have mainly addressed individual buildings and smart energy systems. Hence, there is a need to expand energy performance assessment and energy efficiency actions from a building scale to urban scale, to help identify inefficient buildings

Part of
Pernigotto, G., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). (2020). Building simulation applications BSA 2019. bu,press. https://doi.org/10.13124/9788860461766

and the impact of the available retrofitting measures. The purpose of this case study is to analyse to what extent a set of energy efficiency measures can reduce the district energy consumption, facilitating the transition towards a nearly zero energy district, nZED. In this framework, a model of part of the city of Bolzano, Italy, was developed according to a state-of-the-art urban simulation. Annual district energy uses are analysed, with the aim of defining targeted energy policies with particular attention to façades, roof and windows renovation. The results allow the estimation of the achievable energy saving and the assessment of the most significant factors affecting the overall performance.

2. Method

2.1 Case Study and Input Data

The case study investigated in this research is located in the city of Bolzano (46° N, 11° E), in the North of Italy. The selected area is made up of 95 dwellings built during the period 1990-1995, all connected to the urban district heating network (Fig. 1).

Fig. 1 – Google Map image of the selected district in Bolzano

Considering the way in which the 95 residential dwellings are connected and served by the district heating network, for the sake of simplicity they can be grouped into 11 main multi-zone buildings (named B1, B2, …, B11 in this work).

The geometrical data relating to the district were available thanks to a GIS file containing detailed building footprints (Autonomous Province of Bozen-Bolzano, 2019) and a dataset of roof heights for the selected district developed by the authors. For about 2/3 of the sample of buildings in the district, it was possible to characterize in detail the thermal transmittances of the different building envelope components, by means of the energy certificates provided by the Klimahaus Agency, the local energy agency.

2.2 Modelling Approach

For modelling the buildings' space heating and cooling uses at an urban scale, the simulation code CitySim was selected. CitySim is a command-line integrated solver with a JAVA based graphical user interface, which includes integrated custom modules for modelling microclimatic effects, transient heat flow, plants and equipment, as well as occupants' presence and behaviour (Walter and Kämpf, 2015). In order to prepare the input quantities required by CitySim to run simulations, the approach described in Fig. 2 was implemented. After processing the geometrical data with QGIS, a 3D model was prepared with SketchUp and subdivided into different layers – each one dedicated to an individual category of envelope components such as walls, roofs and floors, and incorporated into the context geometry of surrounding buildings. In order to optimize the computational time needed for the simulation, the 11 multi-zone buildings in the district were aggregated into three groups considering the average thermal transmittances for the different types of components (Table 1).

Table 1 – Average thermal transmittances (W m^{-2} K^{-1}) of building components for the three groups

	Wall	Roof	Floor
Group1	0.60	0.32	0.39
Group2	0.64	0.24	0.46
Group3	0.52	0.35	0.43

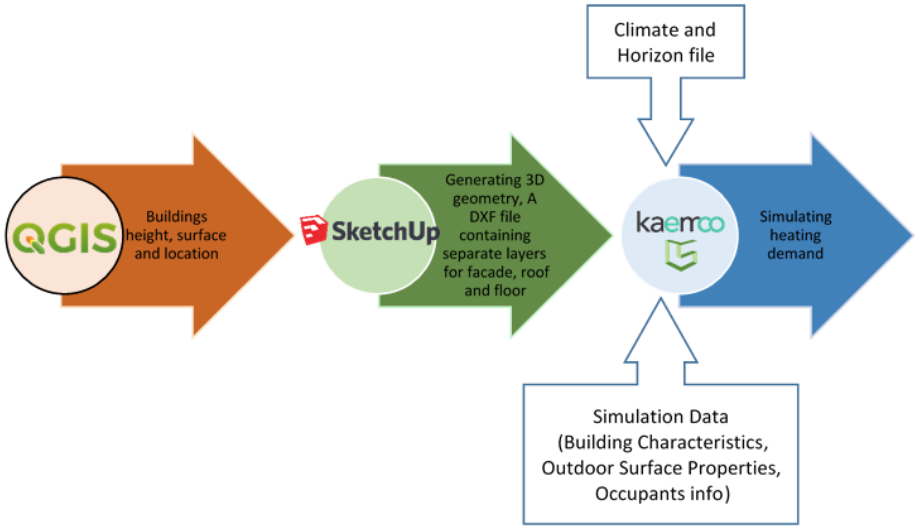

Fig. 2 – Flow chart of the developed methodology

2.3 Model Calibration

An initial CitySim model was developed with the input data collected from the building energy certificates, as well as some CitySim default values (Table 2). In order to check the representativeness of the model, four annual simulations were run using the hourly weather data collected at the meteorological station of Bolzano Hospital for the years 2012-2015, including air temperature and relative humidity, solar irradiation and wind speed data. Results were compared to the corresponding annual final energy uses provided by the Municipality of Bozen-Bolzano for each multi-zone building connected to the district heating network (B1, B2, …, B11).

Since in a previous study (Battini et al., 2019) the same Bolzano district was modelled with the Urban Modelling Interface umi by MIT, and calibrated against the uses for the same period (2012-2015), a second CitySim simulation was run considering the parameters calibrated in umi as inputs.

After the assessment of the impact of the different parameters through a sensitivity analysis, a manual calibration was performed focusing on the most impactive inputs, i.e., ventilation rates and HVAC system efficiency; this is similar to the procedure adopted for the development of the umi model (Battini et al., 2019). The ventilation rates were varied in the range between 0.4 and 0.6 ACH, with a 0.05 ACH step, while the system efficiency between 0.82 and 0.88, with a 0.01 step, for a total of 30 combinations. The selection of ventilation rate and system efficiency minimizing the deviation between simulated and actual heating uses was done according to the *k*-fold cross validation method. Specifically, for each multi-zone building the root mean square difference RMSD was calculated over three out of the four available years, and the combination with the lowest RMSD value was selected and then validated against the fourth year. The procedure was repeated for all possible combinations of years and the most frequent pair of values of ventilation rate and system efficiency selected for each multi-zone building.

Table 1 – Citysim simulation initial inputs

T_{min} = 20 °C; T_{max} = 26 °C
Shading device 0
Cut-off irradiance: 1300 W m^{-2}
Windows U-value: 3.2 W m^{-2} K^{-1}
Windows SHGC: 0.75
Windows operable fraction: 100 %
Visible surface reflectance: 40 % roof, 70 % wall
Occupants: typical residential density: 25 m^2/person
Sensible heat: 75 W/person
Radiant part: 60 %
Latent heat: 45 W/person
HVAC system efficiency: 0.85

2.4 Development of the Retrofit Scenarios

As specified above, the energy efficiency measures discussed in this work relate to the building façade, roof or windows. In more detail, these are:

- façade insulation with an external polystyrene layer (thermal conductivity: 0.04 W m^{-1} K^{-1}; density: 40 kg m^{-3}; specific heat capacity: 1470 J kg^{-1} K^{-1}) of 10 cm (minimum insulation) and 15 cm (high insulation);
- roof insulation with an external polystyrene layer of 10 cm (minimum insulation) and 15 cm (high insulation);
- substitution of windows with thermally efficient, double/triple glazing low/high SHGC (respectively, 0.35 or 0.6), with thermal transmittance equal to 1.2 and 0.6 W m^{-2} K^{-1}, respectively.

As a whole, 15 scenarios were simulated, considering the typical year reported in EnergyPlus weather data as input (EnergyPlus, 2019):

- Case 0: current situation;
- Case 1: façade minimum insulation;
- Case 2: façade high insulation;
- Case 3: roof minimum insulation;
- Case 4: roof high insulation;
- Case 5: double glazing with high SHGC;
- Case 6: double glazing with low SHGC;
- Case 7: triple glazing with high SHGC;
- Case 8: triple glazing with low SHGC;
- Case 9: façade / roof minimum insulation;
- Case 10: façade / roof minimum insulation and double glazing with high SHGC;
- Case 11: façade / roof minimum insulation and double glazing with low SHGC;
- Case 12: façade / roof high insulation;
- Case 13: façade / roof high insulation and triple glazing with high SHGC;
- Case 14: façade / roof high insulation and triple glazing with low SHGC.

3. Results

The initial CitySim model provided results generally within 15% of actual measurements and a comparison with the actual annual energy uses for space heating showed these to be underestimates. As can be seen in Fig. 3 for the year 2014 and in Table 3, if calibrated umi parameters are used as input in CitySim, there is still a significant gap between simulated and actual consumption data, suggesting that a dedicated calibration is required for the CitySim model. Indeed, the highest accuracy is found after calibration through the *k*-fold cross validation. Calibrated values of system efficiency and ventilation rates according to the *k*-fold approach are reported in Table 4.

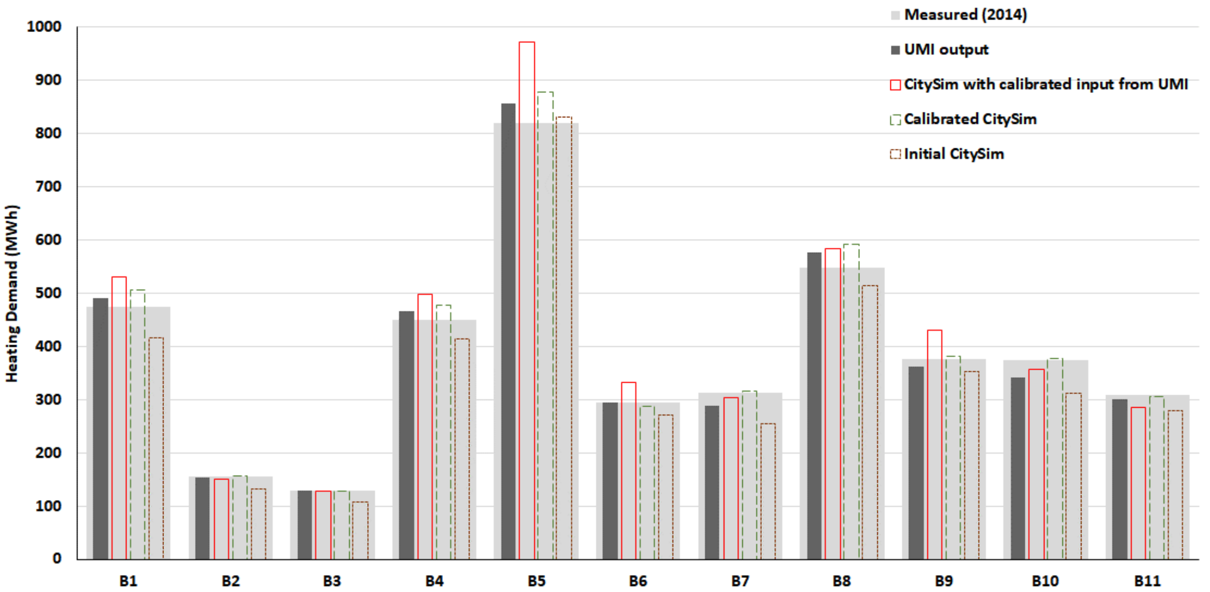

Fig. 3 – Annual energy uses for space heating for the 11 multi-zone buildings for the year 2014: comparison between actual consumption data, umi output, CitySim output using umi calibrated input, using the initial settings and after calibration

Table 3 – Percentage deviations of simulated CitySim annual heating demand using umi inputs or after CitySim calibration according to the *k*-fold approach

	2012		2013		2014		2015	
Building#	**CitySim with umi inputs**	**Calibrated CitySim**	**CitySim with umi inputs**	**Calibrated CitySim**	**CitySim with umi inputs**	**Calibrated CitySim**	**CitySim with umi inputs**	**Calibrated CitySim**
B1	3%	-2%	6%	1%	12%	7%	1%	-3%
B2	-2%	2%	-5%	-1%	-4%	1%	-7%	-2%
B3	3%	2%	5%	4%	-1%	-2%	-4%	-5%
B4	7%	2%	7%	2%	11%	6%	-3%	-7%
B5	14%	2%	14%	3%	18%	7%	3%	-8%
B6	35%	16%	12%	-4%	13%	-3%	3%	-12%
B7	5%	3%	8%	5%	4%	1%	-5%	-7%
B8	1%	9%	8%	17%	0%	8%	-5%	3%
B9	17%	3%	18%	4%	14%	1%	8%	-5%
B10	4%	3%	3%	2%	2%	1%	-4%	-5%
B11	-3%	5%	-7%	0%	-7%	-1%	-13%	-5%

Table 4 – Calibrated system efficiencies and ventilation rates according to the *k*-fold approach

Building #	System Efficiency (%)	Ventilation Rate (ACH)
B1	0.86	0.6
B2	0.88	0.6
B3	0.85	0.55
B4	0.87	0.55
B5	0.86	0.45
B6	0.87	0.45
B7	0.83	0.6
B8	0.85	0.55
B9	0.88	0.5
B10	0.86	0.6
B11	0.87	0.5

The 14 retrofit scenarios under consideration were simulated using the calibrated CitySim model and compared with the base case (Case 0), to assess the annual energy reduction that could be achieved by such refurbishments for each group of buildings. As highlighted by Fig. 4, the Case 13, i.e., high insulation of walls and roof (extra 15 cm insulation layer of polystyrene) and substitution of windows with triple glazing with high SHGC, would bring the largest energy savings, with a reduction of the calculated energy consumption to almost half of the current value. It should be noted that significant improvements could also be achieved in Case 9 and Case 12, i.e. with the insultation of both walls and roof, either if 10 or 15 cm of polystyrene are chosen. Performance could be further enhanced only through interventions on the transparent components, preferring technological solution with high solar gain coefficients.

4. Discussion and Conclusion

In this work we modelled a neighborhood of the city of Bolzano, Italy, served by the local district heating network, in order to discuss the potential of urban building simulation for the definition of energy re-furbishment strategies towards the transition into nearly zero energy districts nZEDs. Specifically, a CitySim model was developed and calibrated against a four-year set of annual energy consumptions for space heating. Calibration was performed first considering using calibrated inputs from a different urban simulation tool, umi, and then by means of a *k*-fold approach. Finally, 14 different intervention scenarios relating to the renovation of the building envelope (i.e., façades, roofs and windows) were analyzed and compared.

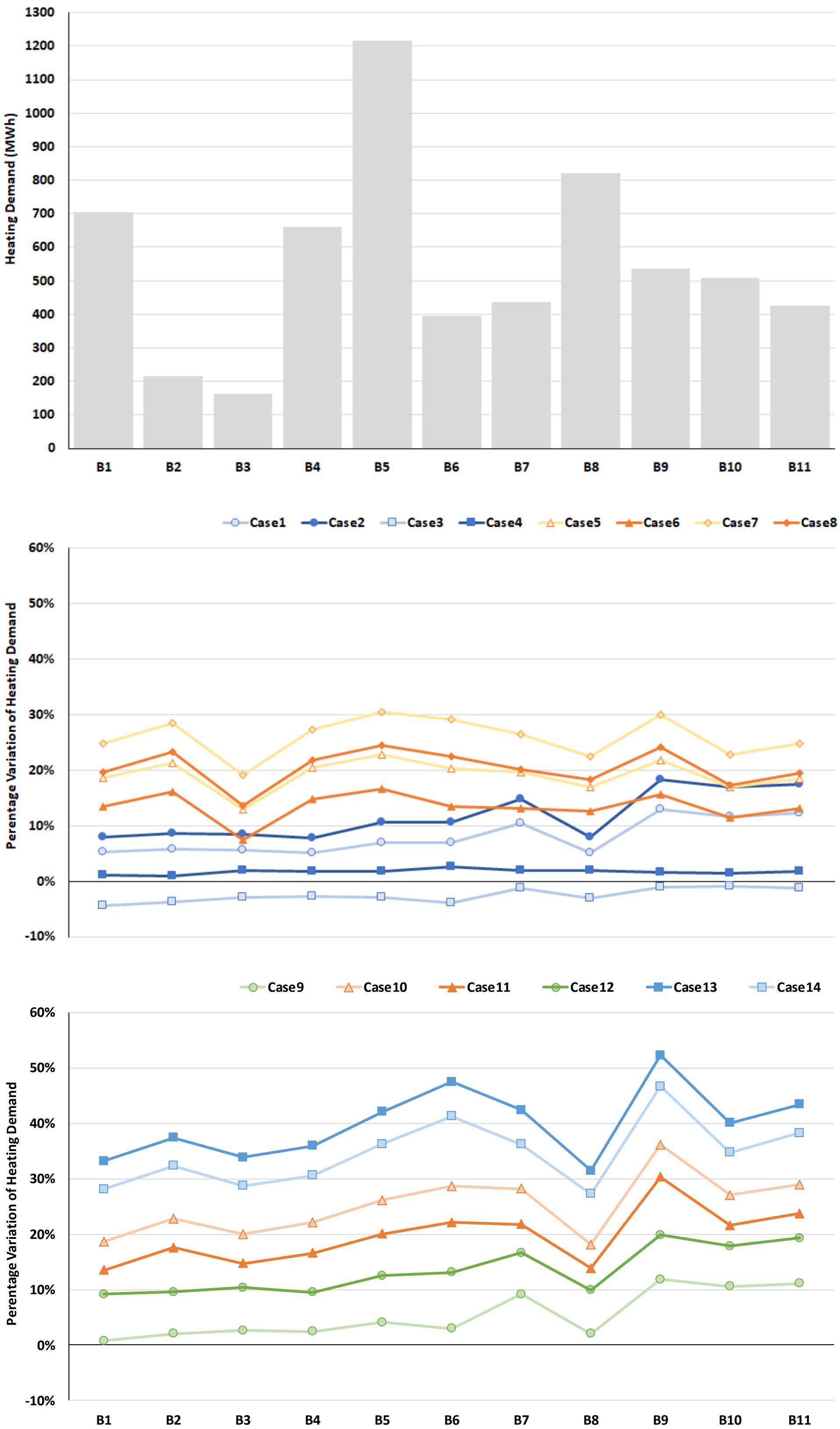

Fig. 4 – Annual space heating uses in the Case 0 (top) and percentage variations in the 14 retrofit scenarios (middle and bottom charts)

It was observed that the calibration of the urban model is not an easy task. In particular, it was noted that calibrated inputs from another tool, umi in this case, are not directly applicable to another, i.e. CitySim in this case. Furthermore, the application of average input values is also not sufficient to properly match the actual energy consumption data and it is necessary, at least, to work with aggregated groups of buildings. Finally, as observed in previous studies (Battini et al., 2019), the *k*-fold approach can be a useful method to apply when only a limited number of annual actual consumption data are available.

Regarding the retrofitting scenarios, since the district is made up of buildings constructed in the same period with similar technologies, no significant differences were found for the different groups and for all of them the largest saving potential is encountered when coupling the insultation of vertical walls and roofs with high performance glazing with high SHGC.

As a conclusion, although this example focused on only one portion of the city, it has been shown that it is possible to recognize the potential of urban modelling for defining targeted energy efficiency measures, enabling the identification of homogeneous groups and the optimization for each of the energy renovation solutions, maximizing in such a way the efficacy of the energy renovation strategy.

Acknowledgement

This study has been funded by the project "Klimahouse and Energy Production" in the framework of the programmatic-financial agreement with the Autonomous Province of Bozen-Bolzano of Research Capacity Building.

The Authors would also like to thank the KlimaHaus Agency for providing access to the building energy certificates and to the Municipality of Bozen-Bolzano for the building energy consumption data.

References

Aelenei, L., A. Ferreira, C.S. Monteiro, R. Gomes, H. Gonçalves, S. Camelo, and C. Silva. 2016. "Smart City: A Systematic Approach towards a Sustainable Urban Transformation." *Energy Procedia* 91:970–79. https://doi.org/10.1016/j.egypro.2016.06.264

Afram, A., F. Janabi-Sharifi, A.S. Fung, and K. Raahemifar. 2017. "Artificial Neural Network (ANN) Based Model Predictive Control (MPC) and Optimization of HVAC Systems: A State of the Art Review and Case Study of a Residential HVAC System." *Energy and Buildings* 141:96–113. https://doi.org/10.1016/j.enbuild.2017.02.012

Autonomous Province of Bozen-Bolzano. 2019. "Maps and WebGIS | Autonomous Province of Bolzano - South Tyrol." Accessed September 9, 2019. http://geoportale.retecivica.bz.it/maps-webgis-geobrowser.asp

Battini, F., G. Pernigotto, and A. Gasparella. 2019. "Calibration of a UMI simulation model for a neighborhood in Bolzano, Italy". *Proceedings of Building Simulation Applications BSA 2019*, Bolzano, Italy: bu,press.

Clark, W.W., ed. 2010. *Sustainable Communities*. New York, U.S.: Springer.

Copiello, S. 2017. "Building Energy Efficiency: A Research Branch Made of Paradoxes." *Renewable and Sustainable Energy Reviews* 69:1064–76. https://doi.org/10.1016/j.rser.2016.09.094

De Lieto Vollaro, R., L. Evangelisti, E. Carnielo, G. Battista, P. Gori, C. Guattari, and A. Fanchiotti. 2014. "An Integrated Approach for an Historical Buildings Energy Analysis in a Smart Cities Perspective." *Energy Procedia* 45:372–78. https://doi.org/10.1016/j.egypro.2014.01.040

EnergyPlus. 2019. EnergyPlus Weather Data. Accessed in May, 2019. https://energyplus.net/weather

Evins, R. 2013. "A Review of Computational Optimisation Methods Applied to Sustainable Building Design." *Renewable and Sustainable Energy Reviews* 22:230–45. https://doi.org/10.1016/j.rser.2013.02.004

Gong, J., A. Kostro, A. Motamed, and A. Schueler. 2016. "Potential Advantages of a Multifunctional Complex Fenestration System with Embedded Micro-Mirrors in Daylighting." *Solar Energy* 139:412–25. https://doi.org/10.1016/j.solener.2016.10.012

Konstantinou, T, and U. Knaack. 2013. "An Approach to Integrate Energy Efficiency Upgrade into Refurbishment Design Process, Applied in Two Case-Study Buildings in Northern European Climate." *Energy and Buildings* 59:301–9. https://doi.org/10.1016/j.enbuild.2012.12.023

Le Guen, M., L. Mosca, A.T.D. Perera, S. Coccolo, N. Mohajeri, and J.-L. Scartezzini. 2018. "Improving the Energy Sustainability of a Swiss Village through Building Renovation and Renewable Energy Integration." *Energy and Buildings* 158:906–23. https://doi.org/10.1016/j.enbuild.2017.10.057

Lee, S., Y. Kim, and W.K. Chong. 2015. "A Statistical Analysis of Effectiveness of Energy Policy in the United States: Incentives vs. Regulations." *Procedia Engineering* 118:1282–87. https://doi.org/10.1016/j.proeng.2015.08.483

Luddeni, G, M. Krarti, G. Pernigotto, and A. Gasparella. 2018. "An Analysis Methodology for Large-Scale Deep Energy Retrofits of Existing Building Stocks: Case Study of the Italian Office Building." *Sustainable Cities and Society* 41:296–311. https://doi.org/10.1016/j.scs.2018.05.038

Marique, A.-F., and S. Reiter. 2014. "A Simplified Framework to Assess the Feasibility of Zero-Energy at the Neighbourhood/Community Scale." *Energy and Buildings* 82:114–22. https://doi.org/10.1016/j.enbuild.2014.07.006

Mohajeri, N., A.T.D. Perera, S. Coccolo, L. Mosca, M. Le Guen, and J.-L. Scartezzini. 2019. "Integrating Urban Form and Distributed Energy Systems: Assessment of Sustainable Development Scenarios for a Swiss Village to 2050." *Renewable Energy* 143:810–26. https://doi.org/10.1016/j.renene.2019.05.033

Polly, B., C. Kutscher, D. Macumber, M. Schott, S. Pless, B. Livingood, and O. Van Geet. 2016. "From Zero Energy Buildings to Zero Energy Districts." *American Council for an Energy Efficient Economy- 2016 Buildings Summer Study*.

Rifkin, J. 2004. *The European Dream*. Oxford, U.K.: Polity.

Rocha, P., A. Siddiqui, and M. Stadler. 2015. "Improving Energy Efficiency via Smart Building Energy Management Systems: A Comparison with Policy Measures." *Energy and Buildings* 88:203–13. https://doi.org/10.1016/j.enbuild.2014.11.077

Walter, E., and J.H. Kämpf. 2015. "A Verification of CitySim Results Using the BESTEST and Monitored Consumption Values." *Proceedings of the 2nd Building Simulation Applications Conference BSA 2015*, 215–22. Bolzano, Italy: bu,press.

Zucker, G., J. Malinao, U: Habib, T. Leber, A. Preisler, and F. Judex. 2014. "Improving Energy Efficiency of Buildings Using Data Mining Technologies." In *23rd International Symposium on Industrial Electronics (ISIE)*, 2664–69. Istanbul, Turkey: IEEE. https://doi.org/10.1109/ISIE.2014.6865041