Climate Change Impact on Historical Buildings: A Case Study Within the Interreg Ita-Slo Secap Project

Marco Manzan – University of Trieste, Italy – manzan@units.it
Amedeo Pezzi – University of Trieste, Italy – amedeopezzi@hotmail.com

Abstract

Climate change effects on human activities have become more and more evident in the last few decades and human society is looking for new solutions to deal with such consequences. One of the measures that can be developed to tackle this problem is the development of the Sustainable Energy and Climate Action Plans (SECAPs), aiming at reducing the mutual impact between human activities and climate at municipal level. To develop such policies, an extensive study of the building stock, of its current and future performances, and its possible improvements is fundamental. Therefore, an energy analysis for a historical building used as a museum and situated in Trieste, a location included in the Interreg ITA-SLO Secap Project, is carried on in this work. The building represents a challenging task due to its historical nature and architectural features. The current climate for Trieste was represented through a Test Reference Year that was then projected into the future using different climate models. The building was numerically modeled, highlighting its main structural and plant features and usage patterns. Future projections for the climate of Trieste showed a general increase in temperatures for all the studied models, leading to a forecasted decrease in heating gas consumption and an increase in electricity-cooling usage of the base building. Regarding the refurbishment interventions applicable in accordance with the preservation regulations, the results show an obtainable reduction of both gas and electricity consumption for every climatic condition considered. However, the interventions proved not to be economically feasible, showing a too-long simple economic return on the investment.

1. Introduction

In recent years climate change has proved to be an extremely influential parameter for consideration in the development of human society. Nowadays the scientific community has recognized the impact of anthropogenic activities on global warming and climate in general (Cook et al., 2016). This is a mutual influence, since climate evolution is also affecting several sectors of human assets. In literature, many authors focused their studies on global warming effects on the building sector, showing that climate change has significant impacts on the energy consumption of buildings (Cui et al., 2017; Radhi, 2009; Wan et al., 2012). In fact, even if sometimes the projections show a reduced/minor impact of climate change in the short term for many aspects, significant variations are forecasted for long-term scenarios and should be considered within the design procedures. Generally, depending on climate type, a decrease in heating energy consumption and an increase in cooling energy consumption is forecast (Crawley, 2008).

Considering that, worldwide, the building sector accounts for a great part of total energy usage and of Greenhouse Gas emissions, it has become crucial for both mitigation and adaptation purposes to study and to reduce as much as possible the mutual interaction between this sector and climate evolution (Jentsch et al., 2008; Robert et al., 2012).

Many measures have been defined to tackle climate change on different scales, from global to local ones. About the former, the most well-known initiative is the Paris Agreement on Climate, aiming to limit global warming compared to the pre-industrial age to under 2 °C and pursuing efforts to limit it to 1.5 °C. It also aims to improve the capacity of countries and local governments to deal with the inevitable effects of climate change and support them in their efforts (Paris Agreement, 2015). Regarding local measures, one of the main ones is the evolution of the Sustainable Energy Action Plans, i.e., SEAPs, into Sustainable Energy and Climate Action Plans, i.e., SECAPs. These policies are draft-

Part of
Pernigotto, G., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2023. Building simulation applications BSA 2022. bu,press.
https://doi.org/10.13124/9788860461919

ed at municipal level with the aim of reducing the impact of cities on the climate, and adapting them to the inevitable changes likely to happen in the future.
Because the municipalities are usually lacking the knowledge to develop these plans fully, different projects have been set up to support this process. One of these is the Interreg ITA-SLO Secap Project, aiming to stimulate the sustainable development of human activities within the cross-border territory composed of the metropolitan city of Venice, the Friuli Venezia Giulia region and the western part of Slovenia (Interreg, 2018).
The main aim of the project is to provide reliable bases and experiences that could help cities, both directly and indirectly, to reduce their environmental impact and develop suitable adaptation strategies to climate change. One of the main measures to achieve this objective is to reduce energy use in public and private buildings. In fact, in the European Union the building sector accounts for 26-28 % of the total energy usage (Borozan, 2018; Eurostat, 2020), and 19 % of Greenhouse Gas emissions (Eurostat, 2015). In Italy, this feature is even more relevant because of this sector accounting for about 31% of the total national energy consumption (Directorate-General for Energy, 2021). Regarding this, the municipalities developing their SECAPs normally focus their efforts on the building stock of their own property, accounting for a remarkable 46 % of the total of implemented policies (Palermo et al., 2020). In fact, this is the sector where they can intervene through a more systematic approach, having a full knowledge and control of their own buildings and equipment. Therefore, they can directly implement measures and monitor the results accurately.
Because of this situation, one of the main outputs developed in the Interreg ITA-SLO Secap Project and presented in this paper is the energy analysis of a building, representing a case study that municipalities could exploit when developing their SECAPs. The case study includes a dynamic energy simulation of the building-plant system, of its functioning in present and future climatic situations and the evaluation of the effects of its possible refurbishment improvements.
The building analysed for the case study is the Revoltella Museum of Trieste, a location included in the program area of the Project, and managed by the municipality itself. The choice fell on this building for several reasons. First, it is a historical building preserved by the regulations of the fine arts, a very common situation in Italy, where particular attention is required when dealing with refurbishment interventions (De Santoli, 2015). Because of this, the design solutions are limited and therefore it is of interest to highlight the effects of these restrictions on the analysis output. Moreover, the museum is a place of public utility, a category for which the government is allocating funds to improve energy efficiency. Finally, yet importantly, the municipality of Trieste openly stated a willingness to intervene in this particular building to improve its energy performance, therefore this will not be only a theoretical case study, but it will be effectively carried out.

2. Climate Change Modeling

The source data to represent the current climatic situation were detected between 1995 and 2019 by a meteorological station located less than 1 km away from the building analysed. Raw data were treated to assess their quality, fill the gaps and reject the periods having too-low data quality.
The actual climate for Trieste was represented through a Test Reference Year generated using the Finkelstein-Schfer statistic (Finkelstein et al., 1971).
Climate change was modeled through five different Global-Regional circulation model couplings, assessed to be the most reliable for climate projections in the Friuli Venezia Giulia region, where Trieste is located, by the Regional Agency for Environment Protection, ARPA FVG:

- HadGEM2-ES RACMO22E;
- MPI-ESM-LR REMO2009;
- EC-EARTH CCLM4-8-17;
- EC-EARTH RACMO22E;
- EC-EARTH RCA4.

Before using them, the five models were calibrated through the quantile mapping method (Cannon et al., 2015) to better fit their outputs to the historical data detected for Trieste for a period common to both historical recordings and model outputs. This allowed more reliable results for the future climate projections to be obtained. The corrected models were then applied to the RCP8.5 scenario, representing a situation where no relevant climate mitigation measures are implemented, therefore similar to the current global situation. The future timeframes considered in the analysis are 2021-2035 and 2036-2050 to represent climate evolution in the near future. Then, the mathematical morphing procedure (Belcher et al., 2005) was used to project the current TRY into the future considering these two periods.

Fig. 1 displays the Heating (a) and Cooling (b) Degree Days for Trieste for current and projected situations. It can be immediately noted that for all the climatic models considered an increase in temperature is forecast as it can be assessed by the decrease of the HDDs and the increase of CDDs. Moreover, it can be noted that climate warming will happen in both the timeframes considered, though with different magnitudes.

Among the projected situations, the one deriving from the HadGEM2-ES RACMO22E model proved to be the warmest one. This being the configuration that most differs from the actual climate, it was used as the future boundary condition for the building-plant analysis.

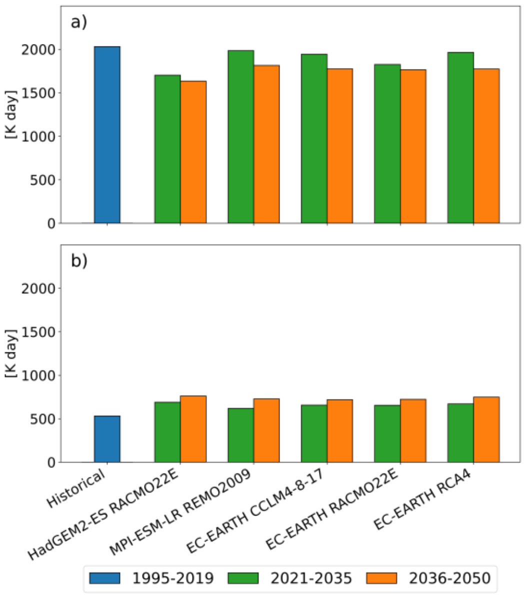

Fig. 1 - Heating (a) and Cooling (b) Degree Days of the historical and projected TRYs for Trieste

3. State-Of-The-Art Modeling

The geometry of the building was modeled using DesignBuilder software, the graphic interface of EnergyPlus calculation engine.

Fig. 2 shows the building within its urban context (a), and its model (b); the presence of the surrounding buildings inserted as elements of solar obstruction for a more accurate analysis can be appreciated in the model.

a)

b)

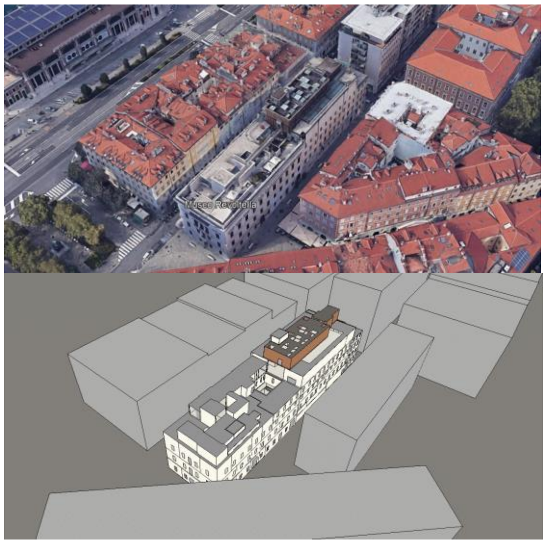

Fig. 2 – Revoltella Museum view (a) and numerical model (b)

To reduce the computational burden, the model was simplified by removing some internal partitions and unifying spaces sharing the same characteristics. Partitions were still considered as internal masses to correctly model the thermal inertia of the system. Fig. 3 presents as an example the spaces modeling for the second-last floor, with the internal masses added to ensure the correct thermal capacity of the building visible in blue.

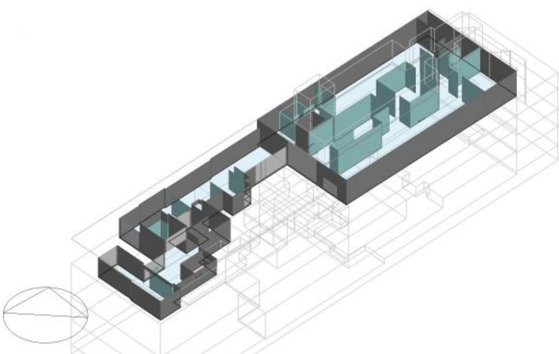

Fig. 3 – Internal spaces modeling for the second-last floor

In total, a building volume of 26,307 m³ was modeled. Envelope element stratigraphy was obtained through site inspections and data gathered from the municipality of Trieste. Table 1 reports the transmittance values for all opaque elements of the building.

Table 1 – Transmittance values of envelope opaque elements

Element	**U** [W/(m² K)]
External walls	0.72
Earth retaining walls	1.20
Ground floor	0.41
Internal floor	1.94
Roof	1.77

Double-glazed windows with air-filled gap and wooden frame having transmittances of 3.21 W/(m² K) are present. The building also presents skylights having a transmittance of 5.59 W/(m² K).

Regarding the characteristics of the internal spaces and their use patterns, three main zones were identified for the typical floors and are reported in Fig. 4. Zone A is the historical residence museum and is architecturally preserved both internally and externally. Zone B hosts a modern art museum while zone C is intended for office use, and both are subject to preservation rules regarding only the façades.

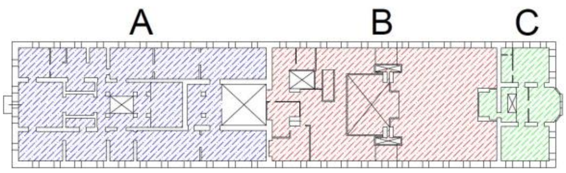

Fig. 4 – Building main zones: A (blue) – historical residence museum, B (red) – modern art museum, C (green) - offices

Because of this situation, internal gains due to illumination, people density and activity, as well as the features of the plant, vary between these three zones. Table 2 reports the principal features for every zone.

Table 2 – Building internal zones features and plant terminals

Parameter \ Zone	**A**	**B**	**C**
People density [people/m²]	0.143	0.143	0.070
Lighting norm. power dens.[W/(m² – 100 lx)]	6	6	4
Illuminance [lx]	200	200	300
Plant terminals [/]	Fan-coils	Fan-coils + CAV units	Radiators + VRF units

People density during the day was modified through a schedule following the typical occupation pattern detected during the opening time of the museum, 9 a.m. – 7 p.m., Tuesday excluded. People density in the office area was instead considered constant during the opening time, as well as lighting for all zones. People metabolic rates were fixed at 140 and 120 W/person for museum and office spaces respectively.

Regarding the plant, various terminals are used in this building, as can be deduced from Table 2; this is due to the different uses and working conditions of the building zones. In particular, only fan-coils are present in Zone A because of the preservation regulations limiting the possibilities in the historical internal spaces. Plant temperature set-points are 20 °C for heating and 25 °C for cooling respectively; humidity control is not present. Heating is available from October 15 to April 15, following the calendar of the Italian Climatic Zone E; cooling is always available. The former is working 14 hours per day, the maximum allowed from 7 a.m. to 9 p.m.; the latter is working during the opening time of the museum. Both are deactivated on Tuesday, the closing day of the museum. As it can also be noted by Table 2, the plant serving the building presents a complex configuration depending on the three main areas. The generators of zones A and B are gas-fired condensing boilers and a water chiller for heating and cooling purposes respectively. These generators serve both the fan-coils and the Air Handling Unit (AHU) for the functioning of the CAV system. Zone C generation is given by a dedicated gas-fired condensing boiler coupled with

VRF units for heating and cooling respectively. Finally, an evaporative cooling tower is present on the roof working with the chiller for summer season cooling.
In the analysis, the existing system was modeled as precisely as possible to determine the energy vectors involved in the most coherent way possible, also by exploiting the technical data sheets available for the boilers and the chiller. In addition to the synthetic data, the chiller performance was properly modeled as a function of the condenser and evaporator water temperatures. Through this, and to take the operation of the system in the different conditions into account, the correction curves for the nominal power and for the Energy Efficiency Ratio (EER) were obtained (UNI, 2018). In the same way, the efficiency and the nominal power of the gas-fired condensing boilers were parameterized according to the load and to the returning water temperature. Regarding the AHU, the cooling tower and the VRF units, their characteristics were hypothesized on the bases of the expected behavior of the whole plant and of historical consumption data. The whole audit process was carried out following what is reported in UNI CEI EN 16247-2 standard (UNI, 2014).

3.1 Model Calibration

To obtain reliable results, the state-of-the-art model has been calibrated through a comparison between its results and the historical recordings of gas and electricity consumption. Historical gas consumption data were available as an average for the years 2010-2012 and on a yearly basis for 2019 and 2020. The latter was characterized by the effects of the COVID-19 pandemic and therefore is not representative of the normal behaviour of the building. Year 2019 instead was not usable for the calibration due to the scarcity of climatic data detected by the meteorological station of Trieste, not allowing the execution of a yearly calibration simulation. Therefore, the mean gas consumption value for years 2010-2012 was used for the calibration. Regarding electricity, monthly consumption values for the years 2017-2020 were available. Year 2018 was chosen to calibrate the model because of the local meteorological station having good data quality for that period. To perform the calibration, a special climatic file containing the 2010-2012 values for the winter season and 2018 values for the summer one was created. The calibration process led to some modifications regarding the envelope elements' transmittance, the internal gains due to people and lighting and the characteristics of the hypothesized elements of the plant. Because of these adjustments, the calibrated model achieved remarkable precision in reproducing the historical consumption recordings, as can be noted through Table 3. The calibrated model was the base to run the energy simulation with the different climatic conditions defined in Section 2 and to assess the effects of the refurbishment interventions described in the next section.

Table 3 – Model calibration results

Energy vectors consumption	Historical	Model	Model Error [%]
Gas [m^3]	56 056	52 458	-6.86
Electricity [kWh]	313 020	319 371	+2.03

4. Refurbishment Interventions

Given the preservation restrictions described in Section 3, the room for improvements to increase the energy performance of the building is very narrow. All the façades, windowed elements included, cannot be modified, and therefore it is not possible to massively intervene on the envelope. Moreover, zone A of the building is also internally protected, limiting the possibilities even further. Regarding the plant, most of its components are still pretty new, therefore solutions concerning this are not considered in this work. Because of this situation, three improvements were hypothesized for the analysed building:

- **A:** Internal insulation of walls pertaining to the modern art museum;
- **B:** Substitution of the existing skylights with new ones featuring solar control window panes;
- **C:** A combination of the previous two.

The internal insulation of the modern art museum walls was carried out through the insertion of 10 cm of rock wool having a conductivity of 0.038 W/(m K), a density of 35 kg/m^3 and specific heat of 840 J/(kg K), coupled with 2cm of plaster.

The skylights used in the second solution were composed of a PVC frame, of an external coated glass layer, 6 mm thick, having a reduced solar transmission value, 0.3622, a 16mm thick Argon-filled cavity and a standard clear glass layer 4 mm thick. This structure presented a transmittance of 1.554 W/(m^2 K) and the coated external layer aim was to reduce the solar heat gains during the summer season, therefore trying to reduce electricity consumption for cooling.

All three solutions were evaluated regarding their energy and economic aspects. The latter was considered in a simplified way by computing the simple return of the economic investment. Intervention costs were computed using the prices reported in the public regional administration price list “Prezzario Regionale dei Lavori Pubblici” (FVG Region, 2021). By using the reported prices of rock wool per square meter comprehensive of materials and manpower costs, applied to the surface to insulate, a cost of 409,264 € was computed for solution A. The same was done for skylight substitution, in this case considering the price per element and the number of elements to install, and a cost of 67,783 € was computed for solution B. The third solution cost is simply given by summing up the previous two, equal to 477,047 €.

5. Analysis Results

The energy dynamic analysis was first carried out for the state-of-the-art building using the current and the two future TRYs. The results, reported in Table 4, highlight a remarkable reduction of heating gas consumption, and an increase in electricity used for cooling and lighting. The variations compared to the current situation proved to be much more marked in the period 2021-2035 and then to slow down in 2036-2050.

This behavior is in line with the climatic projections, which foresee a slowdown of temperature rise in the second period, as can also

Table 4 – State-of-the-art simulation results

TRY	Gas use [m^3]	Electr. use [kWh]	Var. Gas [%]	Var. Electr. [%]
1995-2019	52,931	289,193	\	\
2021-2035	43,961	318,398	-16.95	+10.10
2036-2050	42,654	325,025	-19.42	+12.39

be noted by looking at the Degree Days reported in Fig. 1. It is then evident that the cooling component will become more influential in the energy consumption composition of this building.

Regarding the effects of the refurbishment interventions, reported in Table 5, the analysis highlighted a beneficial effect on both gas and electricity consumption.

Table 5 – Refurbishment effects for every climatic set

ID	Gas use [m^3]	Electr. use [kWh]	Var. Gas [%]	Var. Electr. [%]	Simple Return [years]
1995-2019 TRY					
SOTA	52,931	305,032	\	\	\
A	44,794	304,034	-15.37	-0.33	41
B	50,454	298,267	-4.68	-2.22	17
C	41,699	294,746	-21.22	-3.37	32
2021-2035 TRY					
SOTA	43,961	318,398	\	\	\
A	36,875	317,161	-16.12	-0.39	47
B	41,840	311,235	-4.82	-2.25	19
C	34,395	307,362	-21.76	-3.47	36
2036-2050 TRY					
SOTA	42,654	325,025	\	\	\
A	35,768	323,689	-16.14	-0.41	48
B	40,618	317,525	-4.77	-2.31	19
C	33,345	313,582	-21.82	-3.52	37

As can be seen in Table 5, the obtainable gas consumption reduction varies between 4 and 21 % compared with the state-of-the-art for every climatic set considered. The obtainable electricity consumption reduction is instead much smaller, between 0.3 and 3.5 %, mainly due to the reduced surface treated with the insertion of the new skylights. In general, the best reduction in energy consumption comes from solution C.

However, the economic analysis of these interventions highlighted that they are not economically convenient, showing too-long return times on investment, for every climatic set.

Therefore, coupling these actions with interventions on the plant should be considered. Considering that the generators were replaced a few years ago, and are therefore still functioning well, major interventions could rather focus on the distribution and emission parts of the plant, these being older and less efficient.

6. Conclusions

An energy audit was carried out for the Revoltella museum of Trieste. Great attention was placed on information gathering, this being a historical building featuring particular characteristics.

An evaluation of climate change effects has been carried out for the state-of-the-art building. The present climate was represented through a TRY that was then projected into the future by using different climate models applied to the RCP8.5 scenario. The results showed a steady increase in temperature for the near future, to year 2050, for every climatic model considered. By using the model giving the greatest rise in temperature, climate change effects were evaluated for the museum. Results showed that climate evolution will greatly influence the energy consumption of this building, leading to a decrease in gas consumption, up to 19 %, and an increase in electricity consumption , up to 12 %. Therefore, the municipality of Trieste, owner of the building, should start considering interventions on the building to adapt it to the incoming new working conditions.

In order to provide the municipality with a starting base for this purpose, some refurbishment interventions were modeled for the building for both the current and future climates. By considering the preservation restrictions to which the building is subject, internal insulation of walls and substitution of skylights were considered as feasible interventions. The analysis results showed that a good gas consumption decrease, between 4 and 21 %, would be obtainable for every climatic condition considered. Regarding electricity on the other hand, the beneficial effects would be much less evident, featuring a reduction of between 0.3 and 3.5 % of consumption. This minor effect on electricity is due to the possibility of intervening only on the skylights to reduce solar heat gains during the summer season, the windows on the façades not being replaceable due to the preservation rules. Regarding the economic aspect of the interventions, these did not prove to be economical, showing a too-long return time on investment for every climatic set considered.

Considering all the aspects that emerged from this work, it is strongly recommended for the municipality of Trieste to start designing adaptation measures to address the incoming changes in climate conditions. Results in fact highlighted that in the immediate future the focus of the building performance should be shifted gradually from heating to cooling functioning. That said, internal envelope insulation and skylight substitution proved to be good solutions for heating consumption reduction, but not so much for the cooling solution for every climatic set considered in this work. Therefore, these interventions should be coupled with others mainly pertaining to the plant, mainly focusing on distribution and emission components, given the relative novelty of the generators.

Acknowledgement

The authors wish to thank the municipality of Trieste for providing the valuable information used in this study and for giving access to the building analysed to carry out on-site inspections.

References

Belcher, S., J. Hacker, and D. Powell. 2005. "Constructing design weather data for future climates". *Building Services Engineering Research and Technology* 26: 49-61. doi: https://doi.org/10.1191/0143624405bt112oa

Borozan, D. 2018. "Decomposing the changes in European final energy consumption". *Energy Strategy Reviews* 22: 26-36. doi: https://doi.org/10.1016/j.esr.2018.08.002

Cannon, A. J., S. R. Sobie, T. Q. Murdock. 2015. "Bias Correction of GCM Precipitation by Quantile Mapping: How Well Do Methods Preserve Changes in Quantiles and Extremes?". *Journal of Climate* 28: 6938-6959. doi: https://doi.org/10.1175/JCLI-D-14-00754.1

Cook, J., N. Oreskes, P. T. Doran, W. R. L. Anderegg, B. Verheggen, E. W. Maibach, J. Stuart Carlton, et al. 2016. "Consensus on consensus: A synthesis of consensus estimates on human-caused global warming". *Environmental Research Letters* 11. doi: http://dx.doi.org/10.1088/1748-9326/11/4/048002

Crawley, D. B. 2008. "Estimating the impacts of climate change and urbanization on building performance". *Journal of Building Performance Simulation* 1: 91-115. doi: https://doi.org/10.1080/19401490802182079

Cui, Y., D. Yan, T. Hong, C. Xiao, X. Luo, and Q. Zhang. 2017. "Comparison of typical year and multiyear building simulations using a 55-year actual weather data set from China". *Applied Energy* 195: 890-904. doi: https://doi.org/10.1016/j.apenergy.2017.03.113

De Santoli, L. 2015. "Guidelines on energy efficiency of cultural heritage". *Energy and Buildings* 86: 534-540. doi: https://doi.org/10.1016/j.enbuild.2014.10.050

Directorate-General for Energy. 2021. *EU energy in figures - Statistical pocketbook 2021*. doi: https://doi.org/10.2833/975418

Eurostat. 2020. *Energy data - 2020 edition*. https://doi.org/10.2785/68334

Eurostat. 2015. *Eurostat Manual for air emission accounts - 2015 edition*. doi: https://doi.org/10.2785/527552

Finkelstein, J.M., and R.E. Schafer. 1971. "Improved goodness of fit tests". *Biometrika* 58: 641-645. doi: https://doi.org/10.1093/biomet/58.3.641

Friuli-Venezia Giulia Region. 2021. "Prezzario Regionale dei Lavori Pubblici", 2021. https://www.regione.fvg.it/rafvg/cms/RAFVG/infrastrutture-lavori-pubblici/lavori-pubblici/FOGLIA7/

Interreg ITA-SLO Secap Project 2018. Accessed March 20, 2022. https://www.ita-slo.eu/en/secap

Jentsch, M. F., A. S. Bahaj, and P. A.B. James. 2008. "Climate change future proofing of buildings - Generation and assessment of building simulation weather files". *Energy and Buildings* 40: 2148-2168. doi: https://doi.org/10.1016/j.enbuild.2008.06.005

Palermo, V., P. Bertoldi, M. Apostolou, A. Kona, and S. Rivas. 2020. "Assessment of climate change mitigation policies in 315 cities in the Covenant of Mayors initiative". *Sustainable Cities and Society* 60. doi: https://doi.org/10.1016/j.scs.2020.102258

Paris Agreement 2015. Accessed March 17 2022. https://ec.europa.eu/clima/policies/international/negotiations/paris_en

Radhi, H. 2009. "Evaluating the potential impact of global warming on the UAE residential buildings - A contribution to reduce the CO_2 emissions". *Building and Environment* 44: 2451-2462. doi: https://doi.org/10.1016/j.buildenv.2009.04.006

Robert, A., and M. Kummert. 2012. "Designing net-zero energy buildings for the future climate, not for the past". *Building and Environment* 55: 150-158. doi: https://doi.org/10.1016/j.buildenv.2011.12.014

UNI. 2014. *EN 16247-2: Energy audits – Part 2: Buildings*.

UNI. 2018. *EN 14825: Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance*.

Wan, K. K.W., D. H.W. Li, W. Pan, and J. C. Lam. 2012. "Impact of climate change on building energy use in different climate zones and mitigation and adaptation implications". *Applied Energy* 97: 274-282. doi: https://doi.org/10.1016/j.apenergy.2011.11.048