Journal of Sustainability Perspectives 4 (2), 2024, 256-269

Journal of Sustainability Perspectives

journal homepage: https://ejournal2.undip.ac.id/index.php/jsp/

The Importance of Energy Management in Public University Campuses

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Article Info

Received:
07 June 2024
Accepted:
18 October 2024
Published:
31 October 2024

DOI:
10.14710/jsp.2024.24806

Presented in the 10th International Workshop on UI GreenMetric World University Rankings (IWGM 2024)

Abstract. Energy consumption has gained great attention in recent years, particularly due to the changes in the geopolitics situation and the difficulty in ensuring security in energy sources supply. Several national and international governments set new and more stringent targets to reduce fossil fuel consumption, also proposing specific short-term and mid-term actions. For instance, the Italian Government emanates the Italian National Plan to Reduce Natural Gas consumption in 2022, particularly focused on residential, commercial and public buildings. University of L'Aquila takes inspiration from this planning, to revise its energy management and promote technical actions and a communication campaign aimed at reducing energy consumption. The short-term actions are related to the HVAC plants management of its building: a) shortening the heating days and reducing the daily hours HVAC switching on; b) slight reduction of the indoor comfort temperature; c) reduction of lighting time and intensity. Moreover, virtuous behavior has been encouraged with a communication campaign addressed to employees and students. Results obtained in only one year are very exciting: the natural gas consumption has been reduced more than 20% in academic year 2022/2023, with respect to average values of previous years, with an estimated GHG emissions avoided close to 140 tCO2 for the specific faculty considered. These results are very positive in the GreenMetric perspective, and they boost the importance also of a quite simple but effective energy management strategy and diffusion of awareness on energy and environmental issues.

Keyword:
Energy management, energy saving, HVAC, CO2 emissions

1. Introduction

In the last years, the awareness on energetic issues has raised in the population around the world, in particular relation to the geopolitics situations and the increasing need for energy in all the economic sectors. Among them, residential and commercial sectors have a great share in the energy consumption (about one third) and related carbon dioxide emissions. They account for nearly 30% of global energy consumption and 28% of total energy-related CO2 emissions, mainly due to across heating, cooling, lighting, and appliances 123.

In the U.S., residential and commercial buildings consume about 40% of the nation's total energy, with heating and cooling systems being the largest energy users 4. Same figure apply to European Union, where buildings account for approximately 40% of total energy consumption. The European Commission has implemented stringent energy efficiency directives to reduce this figure 5. Also in China, the rapid urbanization has led to significant increases in building energy use, which now constitutes about 25% of the country's total energy consumption 6. This claims for a high reduction potential, which is particularly related to buildings energy management and innovative clean technological solutions 7.

The factors that influence the energy consumption of a buildings are mainly related to climatic conditions, building and HVAC characteristics, and occupant behaviour. Climatic conditions can be taken into account with Heating Degree Days (HDD) and Cooling Degree Days (CDD). They are metrics used to estimate the energy required for heating and cooling. Buildings in colder climates have higher HDD, leading to greater heating needs, while those in warmer climates have higher CDD, resulting in increased cooling demands 89. Building characteristics are important: the age, design, and materials of a building significantly affect its energy consumption. Older buildings typically have poorer insulation and less efficient systems compared to newer, more energy-efficient constructions. The use of energy-efficient technologies and materials can drastically reduce energy needs 101112. Occupant behavior and lifestyle choices also influence energy consumption. Studies have shown that energy use can vary widely even among similar buildings due to differences in how occupants use heating, cooling, lighting, and appliances 131415. Definitively, sustainable buildings topic is strictly related to occupant well-being, including correct lighting, thermal comfort, and indoor air quality 1617.

Hence, energy efficiency in buildings must face to all these aspects but reducing energy consumption in order to meet the decarbonization path begun in many countries of the World 1819. In this regard, the idea of “glocalization” is the one that best fit into this topic: every local single action, even the littlest, will produce a benefit on wide scale, and this effect can be amplified if the sustainable action is done by a public entity, which has the power to influence the community and increase social awareness on energy-related environmental issues 20.

Indeed, in this pursuit of sustainability, public university campuses stand as bastions of innovation and social responsibility. Far more than a mere administrative routine, energy management within these institutions holds profound significance, shaping not only economic benefits but also environmental stewardship and education-related issues. Public universities, as microcosms of society, deal with the same energy challenges faced by cities and industries worldwide 2122. From the energy demands of classrooms and research laboratories to the climate control needs of wide residential complexes, the energy requirements are substantial and multifaceted. Effective energy management transcends mere utility management, becoming a fulcrum for sustainable development and responsible citizenship.

In building, several technological options are usually introduced to reduce energy consumption: advanced insulation and better enveloping 2324, high-performance windows, energy-efficient illumination, mechanical systems 25 and high-efficiency Heat and

Ventilation Air Conditioning (HVAC) systems 2627. The use of renewable energy plants, like photovoltaic and thermal solar panels, also integrated in buildings an HVAC 28, geothermal heat pumps, or small wind turbine can significantly lower the carbon footprint of a building 2930. More recently, the use of energy modelling, predictions and artificial intelligence is proposed and widely indicated as tools for improve building management efficiency 3132. All these opportunities can achieve good energy saving results, but with an economic effort and an important modification of structures and plants.

In this work, the results related to an efficient energy management of the University of L'Aquila has been reported. The Engineering campus has been considered as case study, with a diverse utilization of area among classroom, offices, and laboratories purposes. The energy management established is started in September 2022 and it is based on two pillars: a) the rising of people (teachers, researchers, technicians, students, etc.) awareness and the promotion of individual sustainable behaviours, and b) the settlement of a series of administrative actions related to the reduction of heating days and hours-per-days in relation to the external weather, as well as a reduction in lighting time switching on. Data were collected form meters of energy carriers used in the University of L'Aquila and classified for the last four academic years. The focus was given to the Engineering Campus, where a significant share of classrooms, offices and laboratories are present, and it could represent a significant average Campus among Italian Universities.

The results obtained are very significant, since more than 20% of natural gas has been saved (normalized per Heating Degree Days, HDD, to consider the external temperature variations during years), and about 140 tons CO_2eq emissions has been reduced, combining electricity and thermal power saved, if compared to the average values of previous years. These results demonstrate that, before more complex and economically significant actions, initiatives on a rational use of energy and individual responsibility can produce important environmental benefits which should anticipate the investment on buildings, HVAC and renewable plants.

2. Methodology

The University of L'Aquila started its major effort in sustainable energy management in 2022, in response to Italian Plan to reduce Natural Gas consumption, particularly directed to the public entities.

University of L'Aquila proposes a strategy of three lines of actions to reduce energy consumption: 1) administrative actions, 2) communication and awareness raising and 3) mid-long term buildings energy efficiency improvements. An *Energy Efficiency Workgroup* has been established to promote actions and monitor the results and the advancement states. The workgroup is composed by researchers, teachers and technicians, with skills on energy, building, engineering, architecture, applied physics, computer engineering, sustainability and management. They work together to develop and implement strategies, policies, and technologies to enhance energy efficiency in the University Campus. It has mainly the role to propose energy monitoring and management activities, efficiency actions and technological improvement. Main focus is on the buildings of the Campus, but also other issues are considered, like indoor air quality and thermo-hygrometric comfort, facilities and maintenance management, energy contracts management, and exploration of renewable energy sources exploitation opportunities. They have three-four meetings per year, where they discuss about buildings and thermal plants management, as well as mid and long-term improvements. So, the support the technical office and the facilities office in relation to the energy topics.

Administrative actions are taken by the governance of the University, according to the Energy Management, in order to guarantee a sustainable use of final energy and a reduction of primary energy consumption. They can be summarized as following:

1) Reduction of internal temperature of rooms of 1°C, moving from 20°C to 19 °C as thermal comfort temperature and incentivizing correct clothing.
2) Reduction of number of heating days:
   a) postponement of the start of the heating period of 15 days;
   b) closing of the university structures for 10 days during Christmas holidays;
   c) reduction of Saturday activities (e.g. MD and BD theses discussion) and their concentration to one building (the most efficient one).
3) Reduction of the heating and cooling time during days
   a) 2 hours daily reduction;
   b) turning off of lighting and heating during weekends and night-time;
   c) institution of «Energy Guardians» to control heating and lighting turning off after lectures and office activities.

Regarding second item, a social media and web campaign has been set, where a kind of guidelines of energy efficient behaviors has been proposed to incentivize the awareness and individual responsibility of each person (students, teachers, researchers, employees, technicians, etc.) in the topic of energy saving. The actions proposed in the campaign are related to the switching off lights, devices, and heating after work time, to the use of energy efficient devices, etc.

Finally, mid- and long-term actions are mainly related to efficiency improvement of buildings (materials, insulations of walls and improved fixtures, smart control of lighting and heating/cooling of rooms, etc.), HVAC and lighting (LED substitution, efficient boilers and thermal components installation, etc.), as well as the exploitation of renewable sources (solar photovoltaic plant, solar cooling unit, etc.).

In this paper, the results have been reported after 2 years of energy efficiency actions, and, so, they are referred only to administrative ones and sensibilization campaign. No mid- and long-term actions were deployed since they take longer time to be established and to produce significative results.

The results have been referred to the Engineering Campus of the University of L'Aquila. It is composed by three main buildings (called "A", "B" and "C"), with an overall volumetry considered of 66870 m^3 and useful area approximatively equal to 21500 m^2. Figure 1 shows an aerial view of the Engineering Campus, with the main buildings highlighted.

The main purpose of the rooms is for teaching (classrooms) for about 45% of the buildings, a 30% is used as administrative office and common space, and 25% of laboratories can be roughly estimated.

The Heat and Ventilation Air Conditioning (HVAC) system is composed by a central unit and four substations. The substations feed two parallel circuits: 1) hydronic circuit (fan coils in classrooms/offices and radiators in bathrooms); 2) air handling units (AHUs) for primary air supply only, except for three greater classrooms that have supply/return circuits.

The regulation of the substations is done exclusively on the flow rate of the central unit working fluid, using an environmental air temperature probe and a supply fluid temperature sensor. The central unit is composed by basement natural gas boilers with external modulating two-stage burners, for a total installed thermal power of 3.7 MW. Actually, there are no air flow rate or air temperature regulation devices. Hence, the heating of the rooms can only be done on the whole system, without the possibility of controlling each room or floor or get benefits for a thermal comfort feedback.

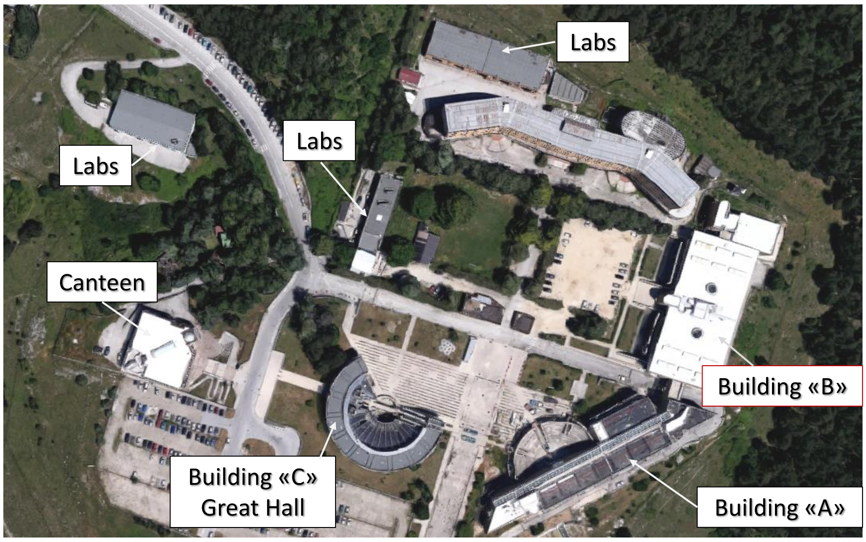

Figure 1: aerial view of the Engineering Campus of the University of L'Aquila

Electricity supply is granted by a grid connection and medium voltage cabin of about 500 kW. The main use of electrical energy is for lighting, but in summer weather conditions, some disperse air conditioning units are used, but their operation is limited to few summer weeks where there are no lectures and only some office rooms are active. Few laboratories have high power instrumentations, which occasionally require peak power supply.

Data have been collected thanks to energy and natural gas meters from main supply lines of each building and aggregated per month. Analyzing historical measured data provides a broad view of energy consumption trends over time. Data for 5 years has been recorded to have a statistical reference, and compared each other to find possible energy saving and also dis-uniformities and hot spots in building management or structures. Several indexes can be proposed to evaluate the savings or increment in energy consumption 3334. They all need the total energy consumption of single building or entire Campus, but this direct value could be affected by several by several external factors: external temperatures and, more in general, environmental conditions, number and type of occupants, room destination (laboratories, classroom, office, etc.), kind of energy supply plant (boilers, heat pump, etc.), size of the building, and surely the management choice. Hence specific indexes should be considered to have a suitable reference base.

In this case study, specific indexes have been considered: the electricity consumption has been referred to the overall area of the campus considered, since it is mainly related to lighting (*kWh/m^2*); on the other hand, thermal energy consumption, and so cubic meters of natural gas in standard conditions (*Sm^3*), is related principally to the external temperatures during each year. These are taken into account in the Heating Degree Days (HDD) on hourly base. Usually, also the number of occupants could be used as parameter, but in the specific case, the control of the heating plant does not consent a regulation that can be feedbacked by internal free apports, which are also related to number of people in the rooms.

Heating Degree Days (HDD) are a measure of the thermal need of a building, usually used to estimate the energy needed for heating and to design HVAC plant, as well as to evaluate the building performance 8. It reflects the demand for energy to heat a building to a comfortable temperature. It is calculated according to eq. 1. Where T_{SP} is the comfort internal temperature (SP - set point temperature, typically assumed to be 20°C in Italy 35, T_{ext} is the measured external averagely daily temperature, and N is the heating days during a year (when thermal plant is turned on – i.e. $T_{ext}<T_{SP}$). If the average daily temperature is lower than the base temperature, the difference is counted as HDD. If the average is higher, HDD for that day is zero.

$$HDD = \sum_{i=1}^{N} \left(T_{SP} - T_{ext,i}\right) \quad (1)$$

HDD can be summed also over a specific period (week, month, year) to estimate the total heating requirements for that period. They can be retrieved by weather forecast service. In the specific case study, data coming from L'Aquila Weather Station of has been used, in the format of NOAA (National Oceanographic and Atmospheric Administration) report 36.

Therefore, a normalized natural gas consumption (NG_{norm}) has been considered, dividing the raw values per HDD of each single month (eq. 2, in Sm^3/HDD). Data have been elaborated during last academic year (a.y. 2022/2023), which starts in September and closes in August of the following year. Latest data have been compared to the averaged values of the previous 3 academic years. The heating season in L'Aquila starts in October and closes in April.

$$NG_{norm} = \sum_{i} \frac{Sm_i^3}{HDD_i} \quad \forall i = month \quad (2)$$

Overall data has been translate into tons of equivalent oil (toe), in order to homogenize the values of electricity and natural gas consumption, and to find an equivalent primary energy consumption during years. Specific conversion factors have been used (Table 1). Finally, the estimation of equivalent CO_2 emissions from natural gas consumption and electricity has been performed, using the emissions factor presented in Table 1 and Table 2 373839.

Table 1: equivalence and emissions factor used in the evaluation of primary energy consumption (toe) and greenhouse gases emissions (tons of CO_2)

Equivalence factor	**Ref.**
0.836 toe/1000 Sm^3	37
0.187 toe/MWh	37
1.991 tCO2/1000 Sm^3	38

Table 2: CO_2 emission factors considered for electricity supply for Italian grid 39

Emission factor (g CO_2/kWh)	**Academic year**
373	2022/23
341	2021/22
337	2020/21
352	2019/20

3. Results and Discussions

The results have been referred to the Engineering Campus of the University of L'Aquila, and organized in the last four academic years (a.y.). An average value among last three years is considered to be compared to the value of the 2023, in order to have a statistical reference. Figure 2 shows the specific electricity consumption per building area of these years. The average value of the 2019-2022 years has been reported and used as reference value. The specific consumption is reduced of about 6.7% in the last a.y. (2022/23).

It is just important to notice that in academic years 2019/20 and, in particular, in 2020/21 the electricity consumption is really low as consequence of the partial closing of the campus to the students, due to the pandemic Covid-19 emergency. This enforces the significance of the result obtained in last year. In fact, in 2020 the energy consumption was lower than the previous year since, for many months, the buildings were closed, and energy plants turned off or set to a minimum technical operating point. Also lectures were performed online, without the need for classroom lighting and heating. However, the values of a.y. 2019/20 and 2020/21 were included in the average and the a.y. 2022/2023 value was even lower than the average value where the months of 2020 were included. Moreover, after the more critical months of pandemic COVID-19, when the Campus was opened again to students, researchers and teachers, the urgent need to have a better indoor air quality, lead to more frequent air exchange, particularly for classrooms, libraries, and other rooms dedicated to students and teachers. This is realized thanks to HVAC systems, whose switching on time is increased, also when heating/cooling is not necessary 40. Furthermore, the more frequent windows opening increases the thermal losses due to ventilation in rooms. Hence, from 2020 after, the energy consumption related to health guaranteeing is increased. In Figure 2, this swing of electricity consumption is evident from a.y. 2019/20 to a.y. 2021/22. So, the results obtained with the improved management in 2023 are even more significant.

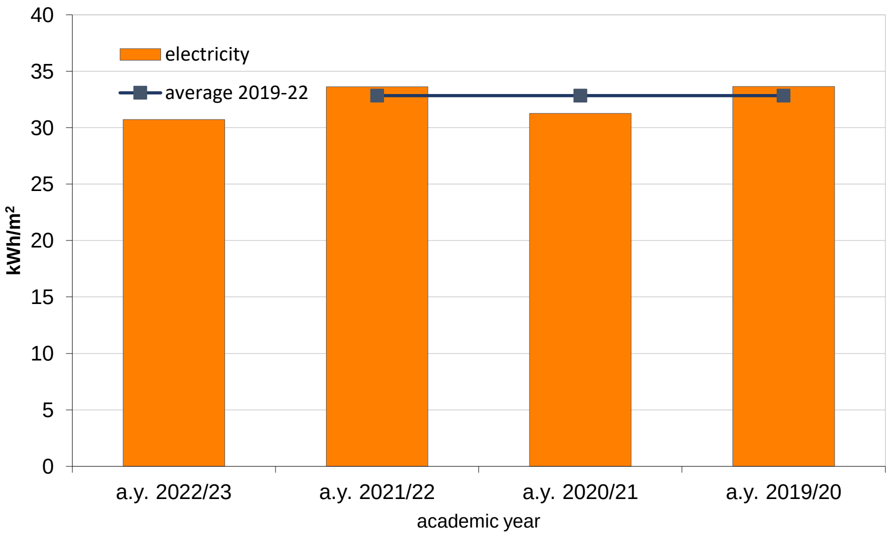

Figure 2: specific electricity consumption for the selected case study

Figure 3 shows the results obtained in the natural gas consumption. In this regard, the energy saved is of higher importance, since the heating management strategy has been quite stringent. A reduction of about 21% of normalized gas consumption, calculated according to eq. 1, in the Engineering Campus has been reported.

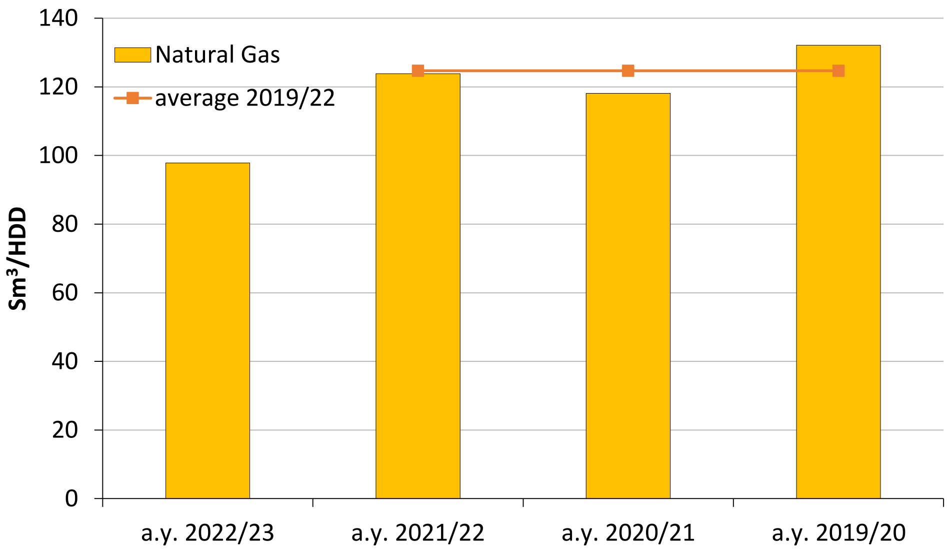

Figure 3: normalized natural gas consumption for the case study

In order to homogenize and put together the data of electricity and natural gas consumption, the tons of equivalent oil (toe) have been calculated and reported in Figure 4 in aggregated form. A reduction of 67.7 toe has been obtained, which corresponds to a 16.7% with respect to the average value of previous 3 academic years.

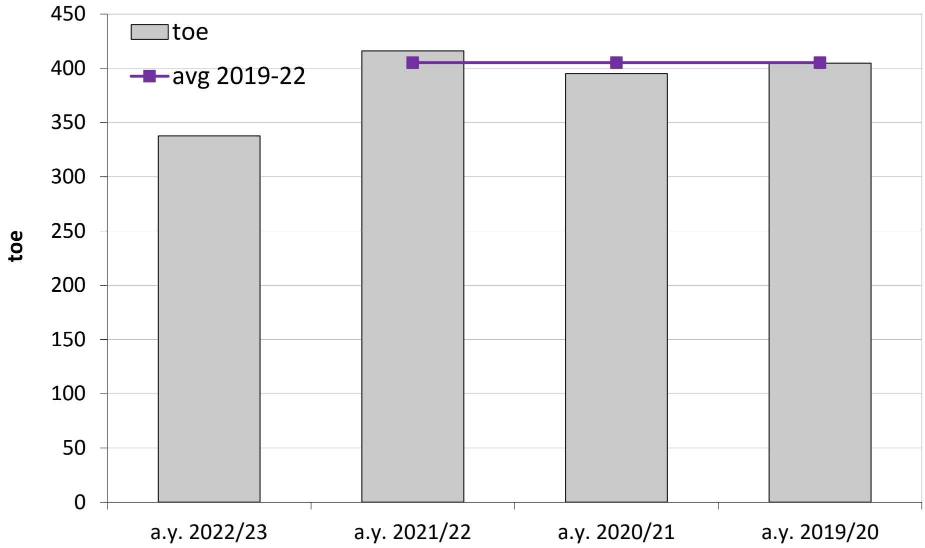

Figure 4: tons of equivalent oil (toe) calculated for the case study

Finally, an evaluation of the greenhouse effect of the sustainable management has been performed. For each year, specific emissions factors have been used for Italian electricity and natural gas supply. Although, these values (specifically for electricity grid) are increasing in last two years (Table 2), the reduction in tons of equivalent CO_2 is still significant: about 142 tCO_2 and -16% of GHG emissions are achieved with the average value of the previous three years (Figure 5).

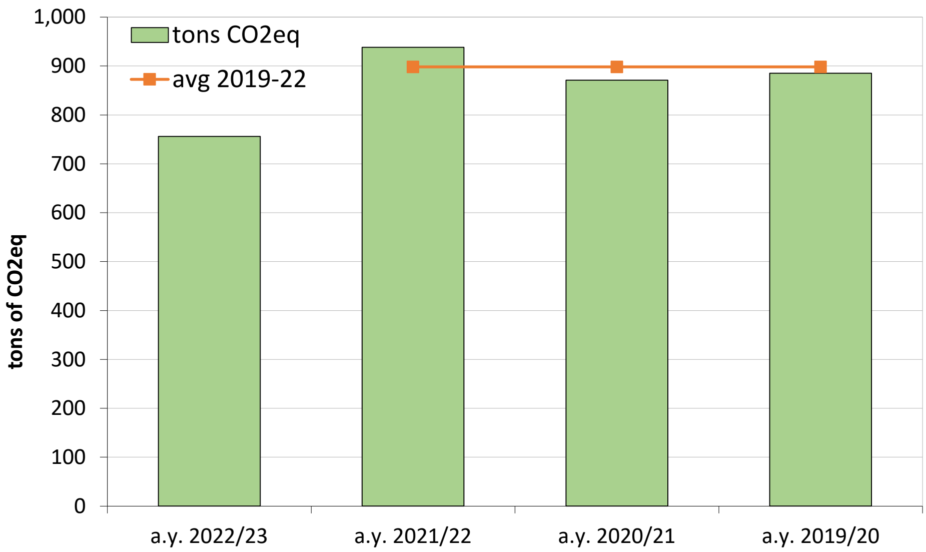

Figure 5: tons of equivalent CO_2 emitted per year for the case study, related to natural gas and electricity consumption

Finally, Table 3 summarized the main results obtained from the improved management and the awareness sensibilization activities performed by the management of the University of L'Aquila. Normalized natural gas consumption, referred to HDD, in a.y. 2022/23 is reduced of about 21.6 % with respect to the average value of the previous three academic years. This is the very huge results which is more strictly related to the thermal management of the buildings, in term of HVAC systems turning on during heating season. At the same time, the electricity consumption is reduced of 6.7%, but, in this case, the energy management benefits are slightly reduced due to the necessity to increase the ventilation for health reason, after the pandemic disease in 2020. These two figures bring to an overall primary energy reduction in a.y. 2022/23, which is approximatively 16.7% lower than the average value of the previous three academic years. The final results are related to the CO2 emissions, which is reduced of about 15.8%, having considered proper emissions factor for each year.

Table 3: summary of the main savings obtained with energy management at University of L'Aquila

	average reference year	**a.y. 2022/2023**	**saving**
Natural gas consumption [Sm^3/HDD]	124.7	97.8	-21.6%
Electricity consumption [kWh/m^2]	32.9	30.7	-6.7%
Primary energy consumption [toe]	405.3	337.6	-16.7%
Energy related CO_2 emissions [tons]	898.2	756.3	-15.8%

4. Conclusions and Future Perspectives

The University of L'Aquila, in last academic year, set a number of initiatives to increase the awareness and individual responsibility on the topic of energy consumption reduction, which is particularly weak in public buildings. Moreover, a novel energy management has been established in order to reduce the energy consumption thanks to administrative actions, which do not require economic effort or plants and buildings modifications. These are based on occupants' behaviour changing and adaptation.

In particular, the days of heating have been reduced, according to a specific seasonal planning; the number of daily hours heating has been reduced as well, in accordance with the occupancy of the rooms; the lighting has also been reduced, and, finally, the comfort temperature has been reduced, when it is possible. Also, several initiatives on people sensibilization have been done, regarding seminars, lectures, social media and web campaign, etc.

Referring to the Engineering Campus, the results obtained are very interesting: more than 21.6% of natural gas (normalized per HDD) and 6.7% of specific electricity (per square meter) has been reduced with respect to the values of the previous three academic years, which lead to a reduction of about 142 tons of CO2eq emissions. These data demonstrated the utmost importance of an efficient energy management strategy, which should be done before any other more invasive actions on building envelope and renewable energy plants, in order to maximize the benefits associated. The actual social campaign will be maintained and increased, in order to keep high the focus on the energetic and environmental issues and to confirm the positive data obtained with respect to the past years, where no energy management actions were actuated.

In conclusion, the experience of the University of L'Aquila would be useful also other Campus to assess the figure of the potential benefits that could be related only to the better energy management and the social awareness raising. This is surely the starting point, in addition to an insightful energy monitoring, from which introduce more important intervention on buildings, HVAC plants and renewable energy sources exploitation, applying the principle of Energy Efficiency First.

References

1. IEA. Buildings overview. 2022. https://www.iea.org/energy-system/buildings#overview accessed on 10 February 2024

2. International Energy Agency. Energy Technology Perspectives 2020. Paris: IEA. 2020. Retrieved from https://www.iea.org/reports/energy-technology-perspectives-2020.

3. World Green Building Council. Bringing embodied carbon upfront. 2019 Sep.

4. U.S. Energy Information Administration. Annual Energy Outlook 2019. Washington, D.C.: EIA. 2019. Retrieved from https://www.eia.gov/outlooks/aeo/.

5. European Commission. Energy performance of buildings directive - EPBD. Brussels: European Commission. 2020. Retrieved from https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en.

6. Liu H and Zheng L. China Energy Outlook 2020. Beijing: China National Petroleum Corporation (CNPC) Economics & Technology Research Institute. 2020. Retrieved from http://www.cnpc.com.cn/en/cnpcnews/2020.

7. De Rubeis T, Giacchetti L, Paoletti D, and Ambrosini D. Building energy performance analysis at urban scale: A supporting tool for energy strategies and urban building energy rating identification. Sustainable Cities and Society. 2021 Nov;74:1-14.

8. U.S. Energy Information Administration (EIA). Heating and cooling degree days. 2019. https://www.eia.gov/energyexplained/units-and-calculators/heating-and-cooling-degree-days.php.

9. Li H, Wang S, Hou L, Xu X, and Yang L. Research on influence of climate change on future building energy consumption in China's typical climate regions. Taiyangneng Xuebao/Acta Energiae Solaris Sinica. 2020;41 (9):147 – 154.

10. Pérez-Lombard L, Ortiz J, and Pout C. A review on buildings energy consumption information. Energy and Buildings. 2008;40(3):394-398.

11. U.S. Department of Energy. Building Technologies Office: Energy-efficient building design. 2021. https://www.energy.gov/eere/buildings/energy-efficient-building-design.

12. Al-Shargabi AA, Almhafdy A, Ibrahim DM, Alghieth M, Chiclana F. Buildings energy consumption prediction models based on buildings' characteristics: Research trends, taxonomy, and performance measures. Journal of Building Engineering. 2022 August;54:104577.

13. Gram-Hanssen K. Residential heat comfort practices: understanding users. Building Research & Information. 2010 Feb;38(2):175-186.

14. Santin OG, Itard L, and Visscher H. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and Buildings. 2009 Nov;41(11):1223-1232.

15. Fathi AS and O'Brien W. Considering diverse occupant profiles in building design decisions. Building and Environment. 2024 Sep;263:1-16.

16. Iwaro J, Mwasha A, Williams RG, and Wilson W. An integrated approach for sustainable design and assessment of residential building envelope: Part I. International Journal of Low-Carbon Technologies. 2015 Sep;10(3):268 – 274.

17. Liu X. Building Integrated Design Practice under the Concept of Sustainable Development. IOP Conference Series: Earth and Environmental Science. 2018;128(1):1-5.

18. EU directive on “Green Homes Buildings”, Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings

19. Şakar AY. The financial incentives in financing of energy efficiency in buildings: A comparison between Turkey and European Union. Current Perspectives in Public Finance. 2019:181 – 206.

20. di Battista D, Barchiesi C, di Paolo L, Abbate S, Sorvillo S, Cinocca A, Carapellucci R, Ciamponi D, Cardone D, Corroppolo S, and Cipollone R. The Reporting of Sustainable Energy Action Plans of Mu-nicipalities: Methodology and Results of Case Studies from the Abruzzo Region. Energies. 2021 Sep;14(18):1-17.

21. Schenone C, Delponte I, Pittaluga I. The preparation of the Sustainable Energy Action Plan as a city-level tool for sustainability: The case of Genoa. Journal of Renewable and Sustainable Energy. 2015 June;7:1-22.

22. di Paolo L, di Martino A, di Battista D., Carapellucci R, and Cipollone R. The potential of energy planning at Municipality scale: Sustainable Energy and Climate Action Plans (SECAP) and local Energy Communities to meet the energy demand variability. Journal of Physics: Conference Series. 2023 Sep;2648 (1):1-16.

23. Alghamdi AA, Alqarni AM, and AlZahrani AA. Numerical Investigation of Effects of Camlock System on Thermal Conductivity of Structural Insulated Panels. Buildings. 2023 Feb;13(2):1-14.

24. AlZahrani AA, Alghamdi AA, and Basalah AA. Computational Optimization of 3D-Printed Concrete Walls for Improved Building Thermal Performance. Buildings. 2022 Dec;12(12):1-16.

25. Zhang N, Guo Y, Yuan W, and Lin Y. Energy-Saving Design and Energy Consumption Analysis of a New Vacuum Refrigerator. Buildings. 2022 Feb;12(2):1-17.

26. Monteiro SA, Monteiro FP, Tostes MEL, and Carvalho CM. Methodology for Energy Efficiency on Lighting and Air Conditioning Systems in Buildings Using a Multi-Objective Optimization Algorithm. Energies. 2020 June;13(13):1-25.

27. Song J, Oh S-D, and Song SJ. Effect of increased building-integrated renewable energy on building energy portfolio and energy flows in an urban district of Korea. Energy. 2019 Dec;189:1-15.

28. Lin Y, Bu Z, Yang W, Zhang H, Francis V, and Li C-Q. A Review on the Research and Development of Solar-Assisted Heat Pump for Buildings in China. Buildings. 2022 Sep;12(9):1-33.

29. Verma N and Jain A. Optimized Automatic Lighting Control in a Hotel Building for Energy Efficien-cy. 2018 International Conference on Power Energy, Environment and Intelligent Control, PEEIC. 2018 April:168 – 172.

30. Alfonso-Solar D, Vargas-Salgado C, Sánchez-Díaz C, and Hurtado-Pérez E. 2020. Small-Scale Hybrid Photovoltaic-Biomass Systems Feasibility Analysis for Higher Education Buildings. Sustainability. 2020 Nov;12(21):1-14.

31. Lin Y, Liu J, Gabriel K, Yang W and Li C. Data-Driven Based Prediction of the Energy Consumption of Residential Buildings in Oshawa. Buildings. 2022 Nov;12(11):1-15.

32. de Rubeis T, Smarra F, Gentile N, D'innocenzo A, Ambrosini D, and Paoletti D. Learning lighting models for optimal control of lighting system via experimental and numerical approach. Science and Technology for the Built Environment. 2020 Nov;27(8):1018–1030.

33. Zhao L, Zhang J, Ma J. The application of building energy consumption index in campus energy efficiency management platform. International Journal of Smart Home. 2015;9(7):103 – 112.

34. Zhao L, Liang R, Zhang J, Ma L, and Zhao T. A new method for building energy consumption statistics evaluation, ratio of real energy consumption expense to energy consumption. Energy Systems. 2014;5(4):627-642.

35. Technical regulation UNI TS 11300-1:2014. Energy performance of buildings - Determination of thermal energy demand for air conditioning in winter and summer

36. Stazione Meteo L'Aquila – Dati Storici :-). (n.d.). CETEMPS. http://meteorema.aquila.infn.it/tempaq/dati_noaa.html (accessed on 2 August 2024).

37. Italian Ministry of Economic Development - MiSE Circular of 18 December 2014 point 13. https://www.mimit.gov.it/images/stories/normativa/Circolare_Energy_Manager_18_dic_2014_rev.pdf (accessed 07 May 2024).

38. ISPRA. CO2 emissions coefficients used in the UNFCCC Italian national inventory. https://www.mase.gov.it/sites/default/files/archivio/allegati/emission_trading/tabella_coefficienti_standard_nazionali_11022019.pdf (accessed 07 May 2024)

39. Carbon Intensity of Electricity Generation. Our Worl in Data. 2023 Dec. https://ourworldindata.org/grapher/carbon-intensity-electricity (accessed on 02 May 2024)

40. Lin Y, Wang J, Yang W, Tian L, and Candido C. A systematic review on COVID-19 related research in HVAC system and indoor environment. Energy and Built Environment. 2024 Dec;5(6):970-983.