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The Impacts of Covid-19 Pandemic on Energy Use in Various Types of Buildings

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Abstract

The recent SARS-CoV-2 pandemic and the necessity to minimize virus contamination has caused many changes in our lives. One of the impacts of Covid-19 pandemic was the changes in energy consumption of various types of buildings compared to the pre-pandemic period. During the period of the pandemic the energy use in some types of buildings was increased while in others was decreased. Previous research regarding the energy use during the pandemic in several types of buildings in various countries has indicated significant differences in energy consumption compared to the pre-pandemic period. The goal of the current study is the investigation of the changes in the energy use of various types of buildings during the Covid-19 pandemic compared to the pre-pandemic period as well as the identification of the types of buildings with increased and reduced energy consumption. The data presented in several published studies have been compared and analyzed. It was found that the Covid-19 pandemic had diverse impacts in the energy consumption of different types of buildings. The greatest increase has been observed in residential buildings while the higher reduction in school buildings and in academic buildings. Our results indicated that financial subsidies offered in many countries in energy and fuels consumed in residential buildings consisted of an effective policy supporting households who were suffering from the lockdown and the job losses during the painful period of the Covid-19 pandemic.

Keywords: buildings, Covid-19 pandemic, electricity, energy consumption, heat, lockdown,

1. Introduction

Covid-19 crisis has created many changes in the daily life over the world. The measures taken in various countries to restrict virus infections, has changed the energy consumption pattern in various types of buildings compared to the pre-pandemic period. Several studies have been published recently investigating the impact of Covid-19 pandemic on energy consumption in buildings indicating that the pandemic had different impacts on their energy consumption (*Deiss et al, 2021, Huang et al, 2022, Senghong et al, 2022, Gaspar et al, 2022*). These studies are focused in estimating the change in energy consumption in several types of buildings during the Covid-19 pandemic (*Krarti et al, 2021, Hyuna et al, 2021, Corticos et al, 2021*).

The aim of the current work is the evaluation of the changes in the energy consumption in various types of buildings during Covid-19 pandemic, compared to the pre-pandemic period, and the identification of the types of buildings with positive and negative energy use changes.

The current research offers a general picture regarding the energy changes in different types of buildings during the Covid-19 pandemic compared to the pre-pandemic period indicating the types of buildings that increase or decrease of energy consumption has been observed. It contributes in the existing knowledge offering the opportunity to compare the energy behavior of several types of buildings during the Covid-19 pandemic.

The work is structured as follows: After the introduction section the published literature is surveyed and the changes in daily life during the Covid-19 pandemic are mentioned. In the next sections the energy consumption in various types of buildings is stated while the energy use in residential and academic buildings is analyzed. After that the discussion of the findings is presented followed by the conclusions drawn and the citation of the references used.

The study could be useful to public authorities, to policy makers and to private and public power companies who should be aware of the changes in energy consumption in several types of buildings during the Covid-19 pandemic.

2. Literature survey

The literature survey is separated in two sections concerning; a) the change in energy consumption in private buildings, and b) the change in energy consumption in public buildings.

2.1 Energy consumption in private buildings during the Covid-19 pandemic

Hyuna et al, 2021 have studied the changes in energy consumption according to building use type under Covid-19 pandemic in South Korea. The authors stated that on average, in various types of buildings, electricity consumption was decreased by 4.46% while the gas consumption by 10.35%. They also mentioned that only in residential facilities the electricity consumption had been increased up to 2.53% while in non - residential buildings it had been decreased up to 16.29%. The gas consumption in residential buildings had been decreased up to 3.06% while in non-residential buildings up to 35.73%. *Monzon-Chavarrias et al, 2021* have studied the alterations in heating energy consumption in residential buildings in Barcelona, Spain due to changing habits during Covid-19 pandemic. The authors analyzing theoretically the residential building stock in Barcelona estimated that changes in daily life due to virus can increase the heating energy demand in residential buildings in the city by 182%. They proposed that retrofitting the existing old residential building stock in the city will be profitable particularly in periods like in Covid-19 pandemic that daily life completely changes. *Corticós et al, 2021* have investigated the impacts of guidelines changes due to Covid-19 on energy consumption in office buildings in USA. The authors mentioned that Covid-19 pandemic has changed the guidelines concerning health protection in workplaces to avoid virus contamination. New HVAC settings in offices have been imposed resulting in higher flow rates and increased air filtration. With appropriate software tools they studied the energy consumption in office buildings according to the guidelines before and after Covid-19. Estimations were made in various cities located in nine different climate zones in USA including very hot zones to subarctic zone. They stated that the energy intensity changes in office buildings, before and after pandemic, were different in different climate zones. Energy intensity changes varied between +21.72% to -11.92%. *Kawka et al, 2021* investigated the changes in energy consumption during Covid-19 compared with previous years in 225 houses in USA. They studied the changes in non-HVAC loads, in HVAC loads and in the whole home loads. They concluded that:

- a) The largest percent increase in non-HVAC loads occurred between 10 a.m. - 4 p.m. Peak changes occurred between 11 a.m. and 12 p.m. (lunch time),
- b) The majority of percent increase in whole home energy consumption occurred between 10 a.m. – 1 p.m.,
- c) In HVAC loads the largest increase occurred during April and October while the smallest in September. HVAC energy consumption in general was increased,
- d) The lowest household income group and the highest household income group had the largest percent increases in total daily loads while the middle income had the lowest impact.

Zhang et al, 2021 have examined the impact of Covid-19 on urban energy consumption of the commercial city Macao. The authors stated that the energy consumption in casino hotels, during Covid-19 pandemic, was reduced by around 15% compared to pre-pandemic period. They also mentioned that the energy consumption in residential buildings was increased due to lockdown policy. *Salama et al, 2022* have studied the impacts of Covid-19 pandemic on green hotel management. The study was focused on green hotels in many Arab countries. The authors stated that Covid-19 pandemic has negatively affected all sectors of green hotels. A published report by IEA, 2020 has investigated the impacts of Covid-19 pandemic to the energy consumption in buildings. The report stated that during pandemic various activities were shifted in the residential sector. Residential energy consumption in USA was increased by 6-8% compared to the year before pandemic.

Many non-commercial buildings had to adapt their energy operation schedules from full space to partial space operation. It is also mentioned that the energy impacts on these changes and their future sustainability compared to the pre-pandemic period have yet to be determined. *Wu et al, 2022* have studied the energy-saving operation strategy for hotels in the post-pandemic period. The authors stated that in the post-pandemic era hotels should develop a low-carbon operation combined with prevention of the virus. They also mentioned that hotels can significantly reduce their energy consumption by 16% to 29% and their average carbon emissions by around 33% to 39%. *Syariati et al, 2023* have studied the efficient energy use for achieving better hotel performance during the Covid-19 pandemic. The authors stated that better energy management in hotels results in better performance during the current period of increased socio-economic and health turbulence. *Senghong et al, 2022* have studied the impact of Covid-19 on the energy consumption of commercial buildings in Singapore. The authors analyzed data from 540 buildings including: 93 hotel buildings, 303 office buildings, 106 retail buildings and 38 mixed development buildings. They stated that in 2020 the mean energy use was decreased by 57.77 KWh/m² compared to 2019 while the percentage reduction was at 19.9%. *Tei Mensah et al, 2023* have studied the energy demand during Covid-19 pandemic in Ghana and Ruanta. The authors stated that in both countries electricity consumption in the residential sector was soared while in hotels and industries was decreased. They also mentioned that electricity subsidies in Ghana during the pandemic explain the sharp increase in electricity consumption in the residential sector. *Su et al, 2022* have studied the impacts of Covid-19 lockdown on energy consumption in commercial buildings in China. The authors stated that the specific energy consumption was reduced in 2020 by 55.4% compared to 2019. They also mentioned that the indoor temperature in various commercial buildings was lower during the pandemic compared to the corresponding temperature of the pre-pandemic period. *Deiss et al, 2021* have analyzed the energy consumption in office and residential buildings in New York city before and during the Covid-19 pandemic. The authors comparing the energy consumption in offices, in transportation and in employees' homes stated that remote working conditions consume 39.7% less energy and required less personal expenses compared to in-person working conditions. They also mentioned that a shift to remote working conditions or hybrid operations could be beneficial to businesses and employees alike. *Ali Khalil et al, 2022* have studied the energy consumption in residential buildings in an urban region during the pandemic. The authors stated that in residential buildings in British Columbia, Canada the daily average in-home-activity duration during the pandemic was increased by 80% causing an increase in their energy consumption by 29%. After the pandemic the energy consumption in the residential buildings is expected to be higher at around 12% compared to the pre-pandemic period. *Rana et al, 2022* have studied the energy efficiency in a residential building amid Covid-19 in Canada. The authors stated that during May 2020 the energy use was increased compared to the two previous years. They also mentioned that, according to their simulations, under high occupancy times in the residential building, the annual electricity use was increased by 16.4% while natural gas use was decreased by 7.6%. *Vourdoubas, 2023* has studied the impacts of Covid-19 pandemic on tourism industry in the island of Crete, Greece. The author stated that tourist arrivals in Crete in 2020 have been sharply decreased by 74.98% compared to 2019 while in 2022 they have exceeded by 4.98% the arrivals in 2019. The author also mentioned that the rapid recovery of Cretan tourism industry can be attributed to the brand name of the island as an attractive tourism destination. *Krarti et al, 2021* have investigated the electricity demand in various countries and in USA before and after Covid-19. Collected data concerning electricity consumption were compared. The authors concluded that:

- a) Electricity demand in residential buildings was increased up to 30% during the full 2020 lockdown period,
 - b) Overall electricity demand was lower because the lockdown reduced the energy consumption in commercial and manufacturing buildings, and
 - c) The increase in household electricity demand is due to higher occupancy patterns during daytime hours.
- The reduction of energy consumption in several commercial buildings in Singapore in 2020 compared to 2019 is presented in table 1.

Table 1. Reduction of energy consumption in several commercial buildings in Singapore in 2020 compared to 2019

Type of building	Number of buildings studied	%, reduction in energy consumption in 2020 compared to 2019
Hotel	93	15.8
Office	303	16.0
Retail building	106	25.3
Mixed development building	38	29.0
Average	540	19.9

Source: *Senghong et al, 2022*

The average rate of change in energy consumption by building use type during the Covid-19 pandemic in South Korea is presented in table 2.

Table 2. Average rate of change in energy consumption by building use type during the Covid-19 pandemic in South Korea, [(+) = increase, (-) = decrease]

Type of building	Electricity consumption	Gas consumption
Multi-family residences	(+2.44) – (+3.17)	(+2.53) – (-3.00)
Single-family residences	(+0.16) – (+0.19)	(+1.11) – (-3.66)
Medical facilities	(-2.70) – (-1.20)	(-3.41) – (-4.45)
Offices	(-3.00) – (-1.13)	(+0.09) – (-8.37)
Retail buildings	(-8.18) – (-0.92)	(-11.86) – (-9.42)
Hotels	(-11.03) – (- 6.43)	(-15.66) – (-10.78)
Religious facilities	(-15.19) – (-10.29)	(-17.22) – (-20.32)
Education and research facilities	(-21.56) – (-14.01)	(-40.43) – (-35.22)

Source: *Hyuna et al, 2021*

2.2 Energy consumption in public buildings during the Covid-19 pandemic

Squire et al, 2021 have studied the energy consumption in hospitals due to measures taken to avoid Covid-19 infections using mathematical models (in two hospitals). The authors estimated the impact of negative pressure (NP) rooms and of ultraviolet sterilization equipment in hospital's energy consumption. They stated that the energy consumption increase was less than 5% regarding NP rooms while it was less than 1% in the case of UV sterilization equipment compared with their energy consumption in the pre-Covid-19 era. *Kristofersen et al, 2021* have investigated the energy consumption at St. Olavs hospital, Norway during the pandemic period. They used machine learning algorithms combined with operating data to predict the energy consumption in the hospital. The authors stated that the energy consumption of electricity, heating and cooling was very similar both in 2019 and 2020 for all buildings. They mentioned though that in a hospital's laboratory the energy consumption was 35% lower while humidification of some areas, that currently are not humidified, will require increased energy consumption. *Sinner et al, 2021* have investigated the impact of Covid-19 on the energy consumption in 100 municipal buildings including kindergartens, schools and administrative offices located in a city in North Rhine-Westphalia, Germany. The authors stated that municipal buildings were closed and re-opened with different concept. Comparing heat and electricity demand during 2018-2021 period they mentioned that during Covid-19 crisis heat demand was increased by 5% while the electricity demand by 12%. *Schibuola et al, 2021* have studied the use of energy efficient air ventilators to limit COVID-19 contagion in school environments. The authors implemented computer simulations in typical schools in Italy. They investigated the performance of an energy efficient strong mechanical air ventilator, with thermal recovery, increasing the air circulation and the exchange rate in schools. They stated that the system offers high protection to pupils regarding virus infection while the energy consumption in the new ventilation system was reduced by 60-72%. *Rouleau et al, 2021* have investigated the changes in energy consumption in 40 social houses located in Quebec, Canada. They compared the energy consumption during 4 months of lockdown with the energy consumption before it. They concluded that:

- a) At the beginning of the lockdown electricity use in the middle day increased by 46%,
- b) At the beginning of the lockdown the use of hot water in the middle day increased by 103%,
- c) No major changes in space heating were observed,
- d) Changes occurred through the day instead of the evening,
- e) Changes were more intense during the intensive lockdown measures, and
- f) Some dwellings had significant changes in energy consumption while others did not.

Zhang et al, 2020 have investigated with computer simulation the energy performance of community buildings confronting a shock like Covid-19 pandemic in a district area in Sweden. Existing buildings in the district area included residential buildings, offices, schools and retail shops. Comparing the energy behavior before pandemic with the new conditions after Covid-19 crisis the authors estimated an average increase in electricity consumption by 14.3% -18.7%. Heating demand (including space heating, cooling and hot water production) was decreased though by 7.1% -12% offsetting the increase in electricity demand. Therefore, the overall energy balance was unaffected. *Gaspar et al, 2022* have assessed the impact of Covid-19 lockdown on the energy consumption of university buildings. The authors stated that the energy consumption during the lockdown in 83 academic buildings of Universitat Politecnica de Catalunya, Barcelona Teck was reduced at 4.3 GWh compared to the pre-pandemic period. They also mentioned that these buildings were using around 46.9% less energy during the lockdown compared to their typical energy consumption. *IEA, 2020* has reported on the global new renewable energy market in 2020 and 2021. The report stated that the Covid-19 crisis has hurt the global growth in new renewable energy installations. It is mentioned that the new renewable energy projects in 2020 are expected to decline by 13% compared to 2019 while in 2021 the new investments in renewable energy systems are going to recover at the pre-pandemic level. *Huang et al, 2022* have studied the electricity consumption in 35 public buildings, including libraries, museums, offices, primary schools and secondary schools, during the Covid-19 pandemic in Scotland, UK. The authors stated that electricity consumption reduction was higher in the first year of the pandemic than in the second. They also mentioned that electricity consumption was reduced in all types of public buildings except in office buildings. Secondary schools had the highest electricity consumption reduction while museums the lowest. *Todeschi et al, 2022* have studied the impacts of Covid-19 lockdown on the energy performance of three urban neighborhoods in Geneva, Switzerland. The authors using simulation methods evaluated the space heating and cooling needs in residential buildings. They stated that during the partial lockdown the space heating demand increased by 8% and the cooling demand by 17% while during the full lockdown conditions the space heating demand increased by 13% while space cooling by 28%. *Chihib et al, 2021* have studied the impacts of the Covid-19 pandemic on the energy use at the University of Almeria, Spain. The authors stated that all university buildings had lower electricity consumption in 2020 compared to 2019. The reduction in electricity consumption was in the range at 56% to 98% while the library building had the highest reduction and the research facilities the lowest. *Quarnain et al, 2020* have reviewed the government action plans in various countries to reduce the energy consumption in buildings during the Covid-19 pandemic. The authors stated many policy recommendations for the electricity sector which were adopted in several countries including: a) Acknowledgement of the domestic electricity sector by the government as an emergency sector, b) Uninterrupted and reliable supply of electricity to everybody, and c) At least 15% discount of all domestic electricity bills. *Su et al, 2021* have studied the clean energy transition in a Chinese town with population 140,000 inhabitants during the Covid-19 pandemic. The authors examined the realization of circular economy strategies for achieving clean energy transition. They proposed the recycle of rejected industrial heat for heating buildings and the electrification of the transport sector reusing the vehicles' batteries as electricity storage devices. They mentioned that the proposed policies had at least 7% better results compared to simple energy efficiency improvements. *Chaloeytoy et al, 2022* have studied the electricity consumption in higher education buildings in Thailand during the Covid-19 pandemic. The authors stated that the electricity consumption at Chulalongkorn University buildings in 2019 and 2020 was reduced by 20.92% and 35.50% respectively compared to 2018. They also mentioned that the smallest reduction in electricity consumption was observed in buildings related with research activities while the highest in academic and library buildings. *Strielkowski et al, 2021* have examined the role of ICT solutions in effective energy management during the Covid-19 pandemic. The authors stated that the pandemic has changed the energy consumption pattern and the energy prices causing fundamental changes in energy production and consumption.

They also mentioned that ICT solutions are appropriate for better management of the smart grids with high penetration of renewable energies. *Geraldi et al, 2021* have studied the impacts of Covid-19 on energy use in municipal buildings in Florianopolis, Brazil. The authors evaluated the impact of Covid-19 on energy consumption in various types of buildings including municipal buildings, health centers, administrative buildings, elementary schools and secondary schools. They mentioned that the reduction in energy consumption in municipal buildings during the pandemic was very low while the energy consumption in health centers was reduced by 11.1%, in administrative buildings by 38.6%, in elementary schools by 50.3% and in secondary schools by 50.4%. *A report related with the opportunities facilitating the green energy transition due to Covid-19 pandemic has been published, 2021.* The report stated that due to pandemic new technologies have been appeared which are going to be used in the post-pandemic period. These technologies might increase the energy consumption, particularly the electricity consumption. It is proposed that in the post-pandemic period the electricity should be green while the energy efficiency should be increased. The impact of Covid-19 on electricity consumption in municipal buildings in Florianopolis, Brazil is presented in table 3 while the impact of Covid-19 on energy use in several types of buildings in table 4.

Table 3. Impact of Covid-19 on electricity consumption in municipal buildings in Florianopolis, Brazil

Type of building	Decrease in electricity consumption (%)
Health centers	11.1
Administrative buildings	38.6
Elementary schools	50.3
Nursery schools	50.4

Source: *Geraldi et al, 2021*

Table 4. Impact of Covid-19 on energy use in several types of buildings

Authors, year	Country	Type of building	Energy use	Change during the pandemic (%)
Stinner et al, 2021	Germany	Municipal buildings	Heat Electricity	+5 +12
Monzon-Chavarrias et al, 2021	Spain, Barcelona	Residential buildings	Heat	+182
Corticos et al, 2021	USA	Offices	Energy	(+21.72) – (-11.92)
Zhang et al, 2020	Sweden	Community buildings	Electricity Hot water	(+14.3)-(+18.7) (-7.1) - (-12.0)
Krarti et al, 2021	Various countries, USA	Residential buildings	Electricity	Up to +30%
Zhang et al, 2021	Macao, China	Casino-hotel	Energy	- 15%
Garpar et al, 2022	Spain, Barcelona	University	Energy	- 46.9
International Energy Agency	USA	Residential buildings	Energy	(+6) – (+8)
Senghong et al, 2022	Singapore	Various types	Energy	-19.9
Su et al, 2022	China	Commercial	Energy	-55.4
Todeschi et al, 2022	Switzerland	Neighborhood	Heat cooling	(+8) – (+15) (+17) - (+28)
Chihib et al, 2021	Spain, Almeria	University	Electricity	(-56) – (-98)
Ali Khalil et al, 2022	Canada, British Columbia	Residential buildings	Energy	+29
Chaloeytoy et al,	Thailand	University	Electricity	(-20.92) – (-35.50)

2022				
Rana et al 2022	Canada	Residential buildings	Electricity Gas	+16.4 -7.6
Geraldi et al, 2021	Brazil	Municipal buildings	Energy	(-11.1) – (-50.4)

Source: Various authors

3. The Covid-19 pandemic and the changes in daily life

The Covid-19 pandemic has caused great changes in the typical daily routines of million people worldwide. It has led to an increase in the time people spent inside their homes. Many countries established very restrictive measures of lockdown for a certain time during 2020 and 2021, and, subsequently, it has been recommended to stay at home teleworking to avoid the virus contamination. The pandemic has brought into sharper focus our buildings. The home has been the focal point of daily life for millions all over the world and a safe place to avoid contamination. As an office for those teleworking, a nursery or classroom for children and pupils, and a hub for online shopping, communicating with friends and relatives or downloading entertainment for many. The time people spend in the office, schools, travelling and leisure has been largely replaced by spending time into homes. Social life has been replaced with communication via the web. The Covid-19 crisis has significantly affected all aspects of our life, such as global economy, social connection, work and communication, environment, and energy demand and supply. The result was that homes became offices, classrooms, restaurants and entertainment centers. These changes in daily life caused by Covid-19 pandemic have brought changes in the energy consumption in various types of buildings.

4. Changes in energy consumption in buildings during the Covid-19 pandemic

As a result of these substantial changes in lifestyle, the Covid-19 pandemic has significant impacts on how energy is consumed. During this situation, where most people spend the most time inside their dwellings, the total energy consumption of buildings was influenced mostly by energy consumption of residential buildings. The increase in household energy demand is due to higher occupancy patterns during daytime hours, resulting in increased use of energy intensive systems such as heating, air conditioning, lighting, and appliances. Coupled with the rise in telework for many white-collar jobs, this sudden change in behavior has impacted the energy consumption patterns that drive electricity demand in buildings, either residential or commercial. A recent analysis of the electricity consumed by several countries since the Covid-19-related lockdown orders reveals a significant reduction in electricity demand (Krarti et al, 2021). It seems that lockdowns did not just have an effect on electricity demand, but also on the power mix. Renewable energies seemed to consolidate their position in the power mix to meet the reduced electricity demand. In USA, China and Europe renewable energies have increased their dominance in the electricity mix (Krarti et al, 2021). The Covid-19 pandemic also had a significant impact on the operation of all types of commercial buildings and their energy consumption. Many studies have demonstrated a significant reduction in commercial activity during the pandemic, resulting in lower energy consumption in commercial buildings (Senghong et al, 2022). During the lockdown, the energy use of administrative buildings, elementary schools and nursery schools has been also significantly reduced (Geraldi et al, 2021). The change in energy consumption in various types of buildings during the Covid-19 pandemic is presented in table 5.

Table 5. Change in energy consumption in various types of buildings during the Covid-19 pandemic

Type of building	Change in energy consumption
Residential building	+6% to +182%
Medical facilities	-1.20% to -11.10%
Offices	-16% to +21.72%
Retail buildings	-0.92% to -25.3%
Hotels	-6.43% to -15.8%
Academic buildings	-14.01% to -98%
Schools	-50.4%

Source: various authors

5. Changes in energy consumption in residential buildings

During the pandemic, the daily average in-home-activity duration (IHD) has increased. The time people spend in the office, schools, and leisure time has been largely replaced by spending time into homes. During this situation, where most people spend the most time inside their dwellings, the total energy consumption of various types of buildings is influenced mostly by energy consumption of residential buildings. (*Monzon-Chavarrias et al, 2021*). The results of the electricity demand analysis have clearly shown that energy use, and thus the cost for households, is higher because of significant changes in living and occupancy patterns. Studies have indicated that the daily average in-home-activity duration has increased by approximately 80%, causing the energy consumption to increase by around 29% (*Ali Khalil et al, 2022*). The magnitude of the increase in home energy use depends on the size of the households, climatic conditions, and location. However, weather normalized time series data for energy demand have clearly indicated that fully enforced lockdowns and stay home orders have increased the residential sector energy demand by a range from 11% to 32% for several countries with available metered data. The higher electricity consumption is mainly driven by HVAC and the use of electric appliances during daytime hours (*Krarti et al, 2021*). The changes in energy consumption in residential buildings during the Covid-19 pandemic are presented in table 6.

Table 6. Changes in energy consumption in residential buildings during the Covid-19 pandemic

Authors, year	Country	Energy used	Change during the pandemic
Rana et al, 2022	Canada	Electricity Heat	+16.4% -7.6%
Ali Khalil et al, 2022	Canada, British Columbia	Energy	+29%
International Energy Agency, 2020	USA	Energy	+6% to +8%
Krarti et al, 2021	Various countries, USA	Electricity	+11% to +32%
Monzon-Chavarrias et al, 2021	Spain, Barcelona	Heat	+182%
Hyuna et al, 2021	South Korea	Electricity Gas	+0.16% to +3.17% -3.66% to +2.53%

Source: various authors

6. Changes in energy consumption in academic buildings

Higher education is a sector that the global Covid-19 pandemic caused a huge disruption as the rapid outbreak created uncertainty regarding restrictions on campus activities. The pandemic forced higher education institutions to switch to online learning for most of 2020 and 2021 for the safety of their students and staff, which significantly impacted campus resource consumption. To ensure that the operations proceeded smoothly and efficiently while maintaining the safety and well-being of students and staff, universities announced the temporary closure of offices with guidelines for teaching, learning, and working during the pandemic, with consideration given to the options of shifting or overlapping days or times of operation to avoid having people gathering in large groups in one location. Universities around the world were temporarily shut down, and the education of million academic students was disrupted (*Chaloeytoy et al, 2022*). The various types of buildings in an academic Institution were differently affected by the pandemic. It has been indicated in several studies that the research category was the least influenced by the outbreak situation (*Chihib et al, 2021*). The library was one of the categories most impacted by closing down during the outbreak, and this was due to the operating nature of this facility. The buildings related with teaching activities had a significant drop in energy consumption amid the outbreak. The changes in energy consumption in academic buildings during the Covid-19 pandemic are presented in table 7.

Table 7. Changes in energy consumption in academic buildings during the Covid-19 pandemic

Authors, year	Country	Energy used	Change during the pandemic
Chaloeitoy et al, 2022	Thailand	Electricity	-20.92% to - 35.50%
Chihib et al, 2021	Spain, Almeria	Electricity	- 56% to - 98%
Garpar et al, 2022	Spain, Barcelona	Energy	- 46.9
Hyuna et al, 2021	South Korea	Electricity Gas	-21.56% to -14.01% -40.43% to -35.22%

Source: various authors

7. Discussion

The findings of the current study indicate that Covid-19 pandemic has differently impacted on energy consumption of various types of buildings. Depending on the type of building the specific energy consumption was either increased, like in residential buildings, or decreased, like in schools, hotels, academic buildings et cetera. Tables 5 indicates that the highest energy reduction during the Covid-19 pandemic is observed in schools and in academic buildings. The changes in the energy use patterns were caused by the lockdown and the limitations imposed regarding the work, transportation and living habits worldwide in order to avoid the virus contagion. People were obliged to stay at home the most of the day consuming more electricity, heating and cooling energy compared to the pre-pandemic period. On the other hand, primary, secondary and tertiary schools were closed, according to the guidelines for social distancing, causing decrease in the energy consumption of their buildings. The increased energy consumption in residential buildings during the pandemic indicates that their green energy transition is desirable replacing the use of fossil fuels with benign carbon-free energy sources. Their green energy transition will reduce their energy consumption and their carbon emissions contributing in the mitigation of climate change. The limitations of the current research are related with the number and the credibility of the data used. There is limited number of published research on this issue and the study of a larger sample would offer a better picture regarding the energy consumption in several types of buildings during the pandemic. However, the general picture regarding the increase or decrease of energy use in them during the pandemic will be more or less the same. Further research should be focused on examining the energy performance of various types of buildings in different climate zones in the era of Covid-19.

8. Conclusions

Covid-19 pandemic has changed the way that we live, work, communicate, travel and entertain. The lockdowns imposed in various countries for minimizing virus infections has affected the energy consumption in various types of buildings including private and public buildings. The impacts of Covid-19 pandemic on the energy consumption in various types of buildings have been investigated in the current study. It is important to examine their energy behavior during extreme, unexpected and undesired events like the global Covid-19 pandemic. It was expected that the energy consumption in various types of buildings would be different during periods of lockdowns and under the requirements of social distancing. The most important findings of the current research are:

- a) The energy consumption in residential buildings has been increased in all studies reviewed in various countries. The increase reported in several studies varies in a remarkable range,
- b) The energy consumption in hospitals has been slightly increased,
- c) The energy consumption in schools has been significantly reduced,
- d) The energy consumption in academic buildings has been significantly reduced,
- e) The energy consumption in retail buildings has been reduced,
- f) The energy consumption in hotels has been reduced,
- g) Both heat and electricity consumption in public municipal buildings have been increased, and
- h) The energy consumption in offices has been increased or decreased depending on the climate zone that the offices are located.

Therefore, the Covid-19 pandemic had different impacts in the energy consumption of different types of buildings. The greatest increase has been observed in residential buildings while the higher reduction in schools and in academic buildings. The green energy transition of residential buildings promotes the mitigation of climate change and could also increase their resilience in future unwanted extreme events like a new global pandemic or major catastrophes due to climate crisis.

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