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Impact of COVID-19 restrictions on building energy consumption using Phase Change Materials (PCM) and insulation: A case study in six climatic zones of Morocco

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ABSTRACT

The rapid spread of COVID-19 caused a significant impact on many sectors, including the energy demand in building due to the quarantine. This paper overviews the impact of the restriction’s measures caused by the spread of COVID 19 on energy consumption in a residential building for three building constructions under six climatic conditions referring to the representative zones of the recent Moroccan climatic zoning. The three-building constructions are Reference House without any passive energy efficiency, Insulation House equipped with thermal insulation in external wall and roof and PCM House equipped with PCM (Phase Change Materials). The three houses are simulated by means of dynamic simulation using TRNSYS software. The quarantine in which the occupants have to stay all-time at home is compared to an ordinary occupancy scenario in terms of energy demand to reach the desired thermal comfort. The major finding of this work is that quarantine can significantly impact the cooling loads than the heating demand depending on building constructions and climatic conditions. The rising-rate in annual energy needs is the range of 10 %–35 %. The impact of the number of occupants is also investigated in respect to the two occupancy scenarios, the three-building constructions and under the six climatic conditions. The results show that when increasing the number of the inhabitants from 2 to 4, under the quarantine period, the energy demand of the PCM house is increased to 50 % depending on the climatic zones.

1. Introduction

On January 30, 2020, World Health Organization (WHO) announced the coronavirus disease 2019 (COVID-19) outbreak as a global emergency [1]. By March 15, 2022, there have been 456 M confirmed cases of COVID-19, including 6 M deaths worldwide; and 1.16 M confirmed cases with 16,039 deaths in Morocco [2]. Followingly, several governments tightened containment measures, quarantine for infected people, closure of public places for gathering and countrywide lockdown to slow the spread of COVID-19. These measures have caused great challenges to several sectors such as economy, transport, energy and many others in >213 countries.

According to the International Energy Agency (IEA), in 2020, global energy demand decreased by 6 % in comparison to 2019. This is mainly due to the strictness of confinement measures and the limitation of all activities, which is correlated to the global drop in overall energy consumption [3]. In the European countries, all energy sources have observed a reduction; for example, fossil energy production is dropped by 28 %, nuclear energy by 14 % and renewable energy by 15 % [4].

The confinement measures can negatively impact the building energy consumption as all the occupants are presented continuously at home with their associated behavior. Despite this obvious observation, a small group of researchers investigate the impact of COVID-19 on building energy consumption. The most published papers deal with assessing the impact of COVID-19 restrictions on energy demand and consumption at the national level [5]. For example, Norouzi et al. [6] investigated the impact of the quarantine caused by the COVID-19 spread on petroleum and electricity in China. Their results show that...
Fig. 1. Hourly temperature profile in the six climatic zones for a typical meteorological year.
pandemic status influences the energy demand in China. In Spanish, Santiago et al. [7] evaluate the electricity consumption decreased by 13.49% from March 14 to April 13 compared to the average value of five previous years. In the state of Qatar [8], there was a huge decrease in electricity demand in the industrial and commercial sectors during the pandemic period. Other scientists such as Abu-Rayash and Dincer [9] and Zhang et al. [10] investigated the same studies, evaluating the energy consumption and demand during the quarantine, respectively, in Ontario (Canada) and Sweden.

A few existing literatures overviewed the energy demand of individual buildings, including residential and tertiary sectors, during the pandemic. In the residential building sector, Abdeen et al. [11] investigate change point analysis, descriptive statistics, and k-means clustering, using measured electricity use data from 500 homes in Ottawa (Canada) before and after COVID-19. De Frutos et al. [12] analyzed the effect of 24/7 occupation due to quarantine on indoor air quality and energy demand of 12 dwellings located in Madrid. In Central Serbia, Cvetković et al. [13] conducted a numerical survey, following 4 scenarios (S1 – reference case, S2 – mild protection measures, S3 – semi-quarantine measures, S4 – complete quarantine), For a household located in Kragujevac (Central Serbia) to assess the impact of people’s behavior on the energy and water consumption. A small number of research deals with tertiary-sector buildings. Ding et al. [14] aimed to compare the electricity demand of educational buildings and residential buildings, in Norway, for the lockdown period 2020 with the normal condition in previous years. Their results indicate that the electricity demand reduced by one-third in building schools and increased by 27% in a small apartment. Geraldi et al. [15] conducted a study in Brazil to identify the gap between electricity demand during COVID-19 lockdown and previous years of municipal buildings. Their results confirmed that COVID-19 quarantine impacts the electricity demand of some building sectors like health centers, administrative buildings, elementary schools and nursery schools.

The bioclimatic architecture concept and the utilization of passive conservation measures can improve thermal comfort. A lot of studies deal with the utilization of Phase Change Materials (PCM) to improve the thermal mass of the envelop. Sun et al. [16] investigated numerically the use of PCM layer in a building wall for passive space cooling. The
study concerns the identification of the optimal PCM layer thickness and location. It is found that when increasing the thermal resistance of the wall, the optimal location of the PCM layer move slightly to the outside of the wall. Shahcheraghian et al. [17] studied experimentally the effect of adding a PCM layer on the external wall on the indoor air temperature. They found that the combination of PCM wall with TES offers better thermal insulation and thermal energy storage compared to sensible TES counterpart.

In the literature, a lot of papers investigated the effect of the PCM on the indoor air temperature without any occupants. These later can impact strongly the heating and cooling demand due to their heat emissions and their associated behavior like using appliances and light. This is why, the authors of this paper took into account the existence of the occupant in the house especially in the period of quarantine in which the inhabitant have to stay all time at home. Their continued presence increases the emission in form of sensible and latent heat and also increase the use of appliances and light and then increase the demand of heating and cooling to reach the desired thermal comfort.

The main objective of this study is to quantify the changes in energy consumption of residential buildings under the COVID-19 lockdown, taking into account the six climatic zones of Morocco detailed in the recent RTCM [20,21]. Three Moroccan envelope constructions are named here: Reference House, Insulation Houses, PCM Houses, and quarantine). Eventually, the main objective of this study revolves around finding the accurate envelope construction suitable for each climatic zone and each occupancy scenario in terms of energy demand reduction.

| Table 2 | Characteristics of the envelope materials of the Reference house [24]. |
|---------|-----------------------------------------------------------------------|
| Building component | Layers | Thickness (cm) | Thermal conductivity (kJ/(h m K)) | Density (kg/m³) | Thermal capacity (kJ/kg K) |
| Ground   | Stone  | 20 | 6.12 | 2095 | 1 |
|         | Concrete | 16 | 7.2  | 2450 | 1 |
|         | Cement  | 7  | 3.6  | 1700 | 1 |
| Roof     | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | Concrete | 14 | 7.2  | 2450 | 1 |
|         | Cement  | 3  | 3.6  | 1700 | 1 |
| Interior wall | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | Hollow brick | 7  | 0.75  | 664 | 0.74 |
| Exterior wall | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | Hollow brick | 20 | 0.75  | 664 | 0.74 |
|         | Mortar  | 2  | 4.152 | 2000 | 0.84 |

| Table 3 | Characteristics of the envelope materials of the Insulation house [24]. |
|---------|-----------------------------------------------------------------------|
| Building component | Layers | Thickness (cm) | Thermal conductivity (kJ/(h m K)) | Density (kg/m³) | Thermal capacity (kJ/kg K) |
| Ground   | Stone  | 20 | 6.12 | 2095 | 1 |
|         | Concrete | 16 | 7.2  | 2450 | 1 |
|         | Cement  | 7  | 3.6  | 1700 | 1 |
| Roof     | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | Concrete | 14 | 7.2  | 2450 | 1 |
|         | Cement  | 3  | 3.6  | 1700 | 1 |
| Interior wall | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | Hollow brick | 7  | 0.75  | 664 | 0.74 |
| Exterior wall | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | Hollow brick | 20 | 0.75  | 664 | 0.74 |
|         | Mortar  | 2  | 4.152 | 2000 | 0.84 |

| Table 4 | Characteristics of the envelope materials of the PCM house [24]. |
|---------|-----------------------------------------------|
| Building component | Layers | Thickness (cm) | Thermal conductivity (kJ/(h m K)) | Density (kg/m³) | Thermal capacity (kJ/kg K) |
| Ground   | Stone  | 20 | 6.12 | 2095 | 1 |
|         | Concrete | 16 | 7.2  | 2450 | 1 |
|         | Cement  | 7  | 3.6  | 1700 | 1 |
| Roof     | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | PCM    | 2  | Liquid state: 0.648 | 850 | See Fig. |
|         | Cement | 3  | 3.6  | 1700 | 1 |
| Interior wall | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | Hollow brick | 7  | 0.75  | 664 | 0.74 |
| Exterior wall | Mortar | 2  | 4.152 | 2000 | 0.84 |
|         | Hollow brick | 20 | 0.75  | 664 | 0.74 |
|         | Mortar  | 2  | 4.152 | 2000 | 0.84 |

| Table 5 | Internal heat gain [23]. |
|---------|-------------------------|
| Types   | Sensible power          | Duration          |
| Persons | 70 W per person         | Occupancy period |
| Appliances | Area related equipment heat gain based on SIA2024, category residential: | |
|         | • Convective Power equal 23.04[kj/h] | |
|         | • Radiative Power equal 5.76 [kJ/h] | |
| Light   | 6 W/m² On: L < 120 W/ m² | Off: L > 200 W/ m² |
Freezing Specific heat [J/kg.K]
10000 12000 14000
2000 4000 6000 8000
0 10 15 20 25 30

In July and the lowest value observed during January. The zone with meteorological year of the six climatic zones. It can be seen from the figure that, for these zones, the highest ambient temperature is observed.[20,21]. Fig. 1 shows the hourly temperature variation for a typical representative zones of the recent Moroccan regulation named RTCM 2.1. Meteorological data

2. Materials and methods

2.1. Meteorological data

The simulation refers to the six Moroccan cities based on the representative zones of the recent Moroccan regulation named RTCM [20,21]. Fig. 1 shows the hourly temperature variation for a typical meteorological year of the six climatic zones. It can be seen from the figure that, for these zones, the highest ambient temperature is observed in July and the lowest value observed during January. The zone with high ambient temperature (i.e. 45.5°C) is Marrakech and the zone with the lowest value (i.e. ~5.3°C) is Ifrane. As one can see that in Agadir city, the temperature amplitude all over the year is almost constant. In this city, the need for heating and cooling loads will be minimal.

There is a big gap in the ambient temperature that varies according to the zones. Table 1 shows this variation in climate type and the associate minimum and maximum temperature of each zone. Six types of climates are showed: Atlantic, Mediterranean, Continental, Cold, Semi-arid and Desert, respectively referred to Agadir, Tanger, Fes, Ifrane, Marrakech and Errachidia. This is why it is important to investigate the impact of COVID-19 on the heating and cooling loads with respect to the six climatic zones.

Table 6
Comparison of simulated and measured indoor air temperatures.

| Time  | 7 h   | 18 h  | 33 h  | 41 h  | 54 h  | 68 h  | RMS% |
|-------|-------|-------|-------|-------|-------|-------|------|
| ΔT [°C] | 0.55  | 0.26  | 0.68  | 0.23  | -0.43 | 0.18  | -    |
| Relative error [%] | 3.16  | 1.21  | 3.75  | 1.17  | 2.66  | 0.85  | 2.40 |

Normal timing
From 4 pm to 8 am
Heating: 20 °C when unoccupied
Cooling: 30 °C when occupied

Quarantine
24/7 occupation

Table 7
Occupation scenarios and its related indoor set point temperature for heating and cooling loads.

| Occupancy scenario | Stay duration at home | Indoor set point temperature |
|-------------------|-----------------------|----------------------------|
| No-occupant       | Without occupant      | Heating: 15 °C             |
|                   |                       | Cooling: 30 °C             |
| Normal timing     | From 4 pm to 8 am     | Heating: 15 °C when unoccupied |
|                   |                       | Cooling: 26 °C when occupied |
|                   |                       | 30 °C when unoccupied       |

2.2. Building architecture

The building under study is a single-family house with one floor of 2.5 m height, spread over 80 m² as seen in Fig. 2. Three house configurations are studied based on the building envelope composition named here: Reference house, Insulation house and PCM house. The thermal properties of their walls are presented in Tables 2-4. The thermal insulation used in the Insulation house is a Sisal/wool nonwoven previously developed and thermos-physically characterized by the authors [22].

Doors with light wood of 4 cm thickness and a heat transfer coefficient of 2.295 W/(m²-K) and single glazing of 2.5 cm thickness, U-value of 5.74 W/(m²-K) and G-value of 0.84 are used in this study. The internal heat loads are presented in Table 5.

The PCM house is constructed with the same materials as Reference house in addition to a PCM layer posed in the external wall and the roof, as seen in Table 4. The PCM used here is an organic paraffin used in a previous study by the authors [23] in which the thermo-physical properties are presented. Its density is about 850 kg/m³; its heat conductivity is 0.18 W/m.K for the liquid phase and 0.22 W/m.K for the solid phase and its heat capacity, which is a function of temperature, is presented in Fig. 3.

2.3. Physical model

The numerical code used in this paper is a dynamic simulation using TRNSYS software, already used by the authors [23], in which the transient thermal behavior is calculated by [25]:

\[ \dot{Q}_i = \dot{Q}_{out} + \dot{Q}_{vent} + \dot{Q}_{s,plg} + \dot{Q}_{e,c} + \dot{Q}_{s,vent} + \dot{Q}_{s,elec} + \dot{Q}_{s,heat} \] (1)

where,

- \( \dot{Q}_{out} \) is heat flux associated to the air infiltration (air flow from outside only);
- \( \dot{Q}_{vent} \) is the energy flow induced by the ventilation of the local area or components the node i (air flow from a user-defined source, like an HVAC system);
- \( \dot{Q}_{s,plg} \) is the convection heat flux due to airflow from/to the neighbor thermal zones;
- \( \dot{Q}_{e,c} \) is the internal convective gains (by people, equipment, illumination, radiators, etc.);
• $\dot{Q}_{\text{solar}}$ is the fraction of solar radiation entering an air node through external windows which is immediately transferred as a convective gain to the internal air;
• $\dot{Q}_{\text{ISHCCI}}$ is the absorbed solar radiation on all internal shading devices of the zone and directly transferred as a convective gain to the interior air;
• $\dot{Q}_{\text{surf}}$ is the convection heat flux from the opaque surfaces of the considered thermal zone.
• $\dot{Q}_i$ is the global energy flow for node $i$: The thermal load of a zone is the amount of energy that must be supplied to it for a certain period to maintain a fixed temperature, called the setpoint temperature.

This load is negative for heating and positive for cooling. This is because it depends perfectly on the air temperature of the thermal zone.

Temperature in each zone is determined hourly from its energy balance using:

$$c_p \frac{dT_{\text{air}}}{dt} = \dot{Q}_i$$  \hspace{1cm} (2)

More details of the numerical model can be found in a previous work of the authors [23].

In this paper, the heating loads are determined using setpoint

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Fig. 4. Hourly temperature profile in the six climatic zones.
temperature of 20 °C when the house is occupied and 15 °C when it is unoccupied; for cooling loads the setpoint temperatures are 26 °C and 30 °C, respectively when the house is occupied and unoccupied.

In a previous study of the author [26], they done a validation of the current model. They calculate the absolute error; percentage of the relative error and the root mean square percentage deviation (RMS) to quantify variations between predicted and measured values as follow:

$$\text{RMS} = \sqrt{\frac{1}{6} \sum_{i=1}^{6} \left( \frac{100^* (T_{\text{sim}} - T_{\text{Exp}})}{T_{\text{Exp}}} \right)^2}$$

Equation (3)

Table 6 presents the absolute, percentage relative errors and RMS for the indoor air temperature. The results show that the model performs slightly better with RMS not exceeding 2.40 %. Therefore, the built thermal model may be considered adequate for the analysis of the house's energy performance.

2.4. Description of the occupancy scenarios during COVID-19 period

The impact of COVID-19 on the energy consumption of a residential building is addressed here by comparing three occupancy scenarios as shown in Table 7. The first scenario is taken as a reference case where the house is unoccupied all over the year. As the house is unoccupied the comfort set-point heating and cooling temperatures are fixed, respectively, at 15 °C and 30 °C. The second scenario is an ordinary occupancy case widely used in Morocco in which the occupants go to work from 8 am to 4 pm. The last scenario represents the case of quarantine in which the occupants have to stay at home due to the restrictions of COVID-19 to limit its spread. In this last case, the comfort set-point temperature is always fixed at 20 °C and 26 °C, respectively, for heating and cooling loads.

3. Results and discussions

3.1. Thermal performance of the house without occupants

In this section, the house's thermal performance without occupants using the three construction configurations is analyzed in terms of indoor air temperature under the six climatic zones. The main difference between the three configurations remains in the external walls, roof, and ground composition, as seen in Tables 2-4. The objective here is to evaluate the impact of the envelope on the indoor air temperature and thermal comfort. Fig. 4 shows the hourly indoor temperature variation in three houses (i.e. Reference, Insulation and PCM).

The first observation of the figure shows that for all climatic zones, the high and low indoor air temperatures occur during January and August, respectively. This tendency follows the external air temperature of all zones presented in Fig. 1. On the other hand, the Reference house, where no energy efficiency measure is considered, as presented in Table 2, shows large indoor air temperature fluctuations. This means that the heat losses in winter and energy gain in summer will be significant in this house compared to the Insulation and PCM houses. The thermal resistance of the Insulation house and thermal mass of the PCM house helps these two houses to stabilize the indoor air temperature. The reference house's temperature fluctuations are largely dependent on the external temperature of the six climatic zones. The PCM house shows the minimum temperature amplitude due to the capacity of the Phase Change Materials (PCM) to store heat. For winter and summer comfort, this fluctuation is close to the comfort set-point temperatures of 20 °C and 26 °C, respectively. As one can see, in the summer season, reduction of the indoor air temperature of the PCM house is more important than the Reference house in the winter season. This can be explained by the fact that the melting and freezing temperatures of the PCM, respectively 22 °C and 18 °C, are close to the ambient temperature of summer rather that of winter, which translate to a fully melting in summer and partially freezing in winter. It is important to mention that this thermal performance of the three houses is analyzed with no-occupants. The comparison between the six climatic zones shows that the high fluctuation of indoor air temperature is occurs in Fes and Marrakech. Ifrane city has the minimum indoor air temperature (about 0 °C in January) which follows the fluctuations of the exterior air temperature.

These results can be affected by taking into account the presence of the occupants which will be discussed in the next sections.

3.2. Energetic performance during COVID-19

This section analyses the impact of COVID-19 restrictions on energy demand in the three houses and for the six climatic zones. For this purpose, the inside air temperature is kept constant at a set-point temperature according to Table 7.

The impact of COVID-19 restrictions is evaluated by comparing three occupation scenarios (No-occupant, normal timing and quarantine). The first scenario is taken as a reference case where the house is unoccupied. The second scenario is an ordinary one used by the typical family in Morocco, where the occupants go to work from 8 am to 4 pm. The final scenario is the quarantine due to COVID-19 restrictions to limit the virus's propagation. In all scenarios and houses, the indoor air temperature is kept at 20 °C when the house is occupied and at 15 °C when the house is unoccupied for the heating period; for the cooling period, this temperature is kept at 26 °C and 30 °C, respectively when the house is occupied and unoccupied.

3.2.1. Energetic performance of the reference house during COVID-19

In this sub-section, the investigation will focus on the reference house’s monthly heating and cooling loads according to the three houses and three occupancy scenarios under the climatic zone 5 represented by Marrakech city. Based on Fig. 5, we can see that, for Marrakech city, the heating need is required only for a short period. The maximum heating needs are shown in January which are 26.29, 35.16 and 45.24 kWh respectively for No-occupant, Normal timing and Quarantine. The maximum cooling needs are shown in August which are 3.08, 59.64 and 72.43 kWh respectively for No-occupant, Normal timing and Quarantine. Based on this result, we can say that the quarantine affects strongly the cooling loads than the heating demand. This can be explained by the fact that the occupants and their associated behavior in the house help increase the cooling demand due to their sensible and latent emissions.

It is also noticed that the No-occupant house's heating and cooling loads are the lowest, followed by Normal timing house then the Quarantine house. This is due to the occupancy period of the occupants described in Table 7. These observations can be explained by the fact that the presence of the occupants in the house allows to release a significant amount of heat in the form of sensible and latent heat as presented in Table 5. Indeed, the presence of the occupants in the house...
Fig. 6. Annual heating and cooling demands of the three constructions according to the three occupancy scenarios for the six cities.
allows the use of more appliances which affects strongly the heating and cooling loads.

It is clear that the quarantine impacts strongly the cooling loads than the heating loads. This finding can be explained by the fact that, in this scenario the occupants have to stay at home all day which translate to a high internal gain due to the occupants and their associate behavior (Appliances).

3.2.2. Effect of the envelop construction

In this subsection, the impact of the occupancy scenarios is investigated under three envelop constructions (Reference, Insulation and PCM). The thermal properties of these houses are presented in Tables 2-4. Fig. 6 shows the variation of the annual heating and annual cooling demand under the three occupancy scenarios, the three envelop constructions and the six climatic conditions.

The first observation of the figure shows that, in the climatic zones represented by Tanger, Ifrane and Fes, the heating loads are highest than the cooling loads and this for the three occupancy scenarios and the three constructions. However, in the zones represented by Agadir Marrakech and Errachidia, the heating loads are lowest than the cooling loads. This confirms the need to study the effect of the occupancy scenarios and constructions envelop under the six climatic conditions. A whole section below will be dedicated only to investigate the effect of the climatic conditions on the energy need under the quarantine.

In all climatic zones, the heating need is high in the reference house followed by the insulation then the PCM house. The difference, in the heating loads, between the reference house and two other houses is very important. It should be noted that the houses are occupied by two occupants in the Normal timing and Quarantine scenarios. This result can be explained by the fact that the Reference house which is relatively light envelop with high transmission coefficient, as seen in the Table 2, and then losses a significant heat to the external environment and then required high heating energy to achieve thermal comfort compared to Insulation and PCM houses. However, the three houses have approximately the same heating need except of thermal zones Agadir and Tanger in which the Insulation house presents the highest value of heating demand compared to the Reference and PCM house. In the next sections, we will regroup the heating and cooling demand into one parameter called energy demand in order to compare the energy efficiency of the houses under the three occupation scenarios based only on one parameter (i.e. Energy demand).

Based on these results we can say that in the climatic zones in which the heating demand is very significant than the cooling demand, the use of thermal insulation and PCM panels can be useful to reduce the energy demand compared to the reference house. However, in the climatic zones in which the cooling demand is very important than the heating loads, the insulation causes the overheating and then it is not a good solution. The PCM house showed the lowest values of heating and cooling loads. This is due to the capacity of PCM to store heat coming from solar heat and from internal gain for later use. This result is in agreement with the interior air temperature seen in Section 3.1 in which we saw a stabilization of indoor air temperature of the PCM house around the comfort set point temperature. It should be noted that the fusion and solidification of this PCM are respectively 18 °C and 22 °C which are very close to the comfort temperatures of summer and winter.

It is also observed that occupancy scenario named Quarantine, in which the occupants are forced to stay home, represents the high energy demand of cooling. This result can be explained by the fact that the occupants generate a sensible and latent heat because of their activities inside the house and also their associate behavior represented by the appliances as presented in Table 5. In the houses with No-occupants no need to the cooling demand is necessary for all climatic zones.

However, in the Insulation and PCM houses, the heating loads are showed in the scenario No-occupant in which the house is unoccupied. This is occurred because the presence of the occupant's help reduces the heating demand because they release a sensible and latent heat to the ambient. In order to understand the impact of the occupants on the energy demand in the case of Normal Timing and Quarantine, we dedicate a section to investigate the influence of the number of occupants on energy demand. Moreover, we will regroup the heating and cooling demand into one parameter called energy demand in order to draw a clear conclusion on the impact of the quarantine on global energy demand according to the construction building and climatic zones.

As whole, the thermal insulation and PCM panel can mitigate the impact of the quarantine on the energy demand. However, in the climatic zones in which the cooling demand is very important than the heating loads, the insulation causes the overheating and then it is not a good solution.

3.2.3. Effect of the climatic conditions

As showed previously, the heating and cooling demand significantly depends on the climatic conditions. This is why, we dedicated a whole section to investigate the restrictions of COVID-19 on heating and
Fig. 8. Annual heating and cooling energy needs of the three constructions for two, three and four occupants according to Normal timing and Quarantine.
cooling demand under the six climatic conditions of Morocco. In order to draw clearer conclusions, the heating and cooling demand are regrouped under the annual energy demand expressed in (kWh/(m²-year)) as displayed in Fig. 7.

Based on the Figure, it can be seen that the highest values of energy demand are observed for the Reference House which reach 13 kWh/(m²-year) for Tanger city followed by Insulation and PCM Houses with 4.6 kWh/(m²-year) for Ifrane city, as a maximum.

For the Reference House, the highest energy demand is observed for the climatic zone represented by Tanger with 13.40 kWh/(m²-year) and the lowest value is seen in Agadir (1.07 kWh/(m²-year)). This result is in concordance with the ambient air temperature of Agadir city seen in Fig. 1 in which the annual temperature oscillations between the season is minimal which required a minimum of heating and cooling demand. Always in the reference house, it is concluded that quarantine increases the energy demand compared to Normal timing. The maximum rise in energy demand is observed for Tanger city with 35 %.

The insulation and PCM houses have a similar trend of the annual energy demand regarding the climatic zones. For these two houses, the highest value is 4.59 kWh/(m²-year) for Ifrane city which is characterized by a long and drastic winter period as shown in Fig. 1 and the lowest value is observed for Agadir city characterized by Atlantic climate. The quarantine scenario increases the energy demand of 14, 10, 12, 13, 13 and 14 % compared to Normal timing respectively related to Agadir, Ifrane, Errachidia, Marrakech, Fes and Tanger cities. In Agadir city, the energy demand is almost the same in the Reference house as well as in the Insulation and PCM houses whether in No-occupant, Normal timing and Quarantine. This city is characterized by an Atlantic climate and stabilization of the ambient air temperature all over the year as seen in Fig. 1. This explains also why, in this city, the minimum energy demand is observed compared to other climate zones.

We can also see, that when using the PCM panels, the difference in the energy demand between the six climate zones is reduced compared to Reference house due to its capacity of storing heat for later use. Indeed, the PCM panels mitigate the impact of the quarantine on the energy demand.

### 3.2.4. Effect of the number of the occupants

The number of occupants affects the demand for cooling and heating to achieve the desired comfort. In this subsection, the same investigation is done, but this time taking into account the number of occupants (two, three and four occupants). The heating and cooling demand are regrouped in annual energy demand per m², which is taken as a comparison criterion. Fig. 8 shows the annual energy demand per m² for the three constructions (Reference, Insulation and PCM), for the two occupancy scenarios (Normal timing and Quarantine), and for three numbers of occupants (two, three and four occupants) and this under the six climatic zones.

As one can see, for climatic zones in which the cooling demand is more important than the heating demand, like Agadir and Marrakech (See Fig. 6), more the number of occupants increases, the annual energy demand increase accordingly. This is explained by the fact that more the number of occupants increase, the energy emission of the occupants increase also which required additional cooling energy demand. However, in the climatic zone, like Ifrane in which the heating loads are more significant than the cooling demand (As presented in Fig. 6), the increase in the number of occupants decrease the energy demand. This is occurred because more the number of occupants increase more is the energy gain presented by their presence. It will be noticed that, the presence of more occupants in the house is associated with their behavior like more light and appliances.

### 4. Conclusion

In this work, we assessed the impact of the pandemic lockdown on energy consumption in residential building. The building under study is simulated according to three building constructions in the six Moroccan climatic zones. The three-building constructions are Reference House without any passive energy efficiency, Insulation House equipped with thermal insulation in external wall and roof and PCM House equipped with PCM (Phase Change Materials).

The idea behind this study is to see the impact of fully staying at home due to the quarantine (in order to limit the spread of COVID-19) on heating and cooling demand compared to an ordinary occupancy scenario. The obtained results show that:

- The PCM House shows the minimum indoor air temperature amplitude, in the six climatic zones, due to the capacity of the Phase Change Materials (PCM) to store heat and release it when need it.
- The quarantine in which the inhabitants have to stay all-time at home impacts strongly the cooling loads than the heating loads due to the internal gains of the occupants and their associate behavior (Appliances).
- The quarantine impact strongly the total energy demand compared to an ordinary occupancy scenario. The rising-rate in annual energy needs is the range of 10 %–35 % depending on the climatic zone and building constructions.
- In the climatic zones in which the heating demand is very significant than the cooling demand, the use of thermal insulation and PCM panels can be useful to reduce the energy demand compared to the reference house. However, in the climatic zones in which the cooling demand is very important than the heating loads, the insulation causes the overheating and then it is not a good solution.

### CRediT authorship contribution statement

Gounni Ayoub: Conceptualization, Methodology, Software, Investigation, Writing.
Ouhaibi Salma: Original Draft, Writing, Review & Editing.
Naval Belouagaddia: Supervision, Resources, Writing, Review & Editing.
El Alami Mustapha: Drafted the article and revised it critically for important intellectual content.

### Declaration of competing interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers’ bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

### Data availability

No data was used for the research described in the article.

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