Inferential monitoring-based study of indoor air quality assessment for biobased heating system in mountainous cold climate

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Abstract.
The pressure on forests is one of the main purposes of the environment depletion. Nevertheless, most research suggests solutions to limit the unsustainable woodland management. In mountainous cold climates, occupants usually use wood-burning heaters to assure thermal comfort in residential buildings. The use of this type of heater can directly affect the indoor air quality thus human health; the smoke produced throughout the combustion process can cause asthma or even lung and heart disease after a long-term exposure. This paper aims to assess the impact of olive pomace heating system on indoor air quality for a residential building located in Ifrane-Morocco through series of investigations. The study encompasses to delineate whether the olive pomace still a good alternative of wood by measuring some gaseous components such as CO_2, and particulate organic compounds like PM2.5 and PM10 with air quality monitoring system for a chosen period in the winter season based on ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) and WHO (World health organization) standards and guidelines. Results showed that the olive pomace-based central heater is a good alternative to wood-burning stoves, and it can reduce more that 50% of particulate matter emissions. But both technologies assure an ambience that respects limits and guidelines.

Keywords: Biomass, Buildings, Energy efficiency, Indoor air quality, Olive biomass, Wood stove.

1 Introduction

1.1 Background

Indoor air quality (IAQ) refers to the quality of the air inside buildings and structures, such as homes, offices, schools, and hospitals. It is determined by various factors, including the presence of pollutants, humidity, temperature, and ventilation. Poor IAQ can have negative effects on the health and well-being of building occupants [1-2-3-4-5] as they typically spend a significant amount of time indoors. The US Environmental Protection Agency (EPA) in the National Human Activity Pattern Survey (NHAPS) have shown that people spend approximately 87% of their time indoors on average, with some estimates suggesting this may increase to 90% in certain populations or during certain seasons [6-7-8]. Symptoms such as headaches, fatigue, allergies, and respiratory problems can result from poor IAQ [3]. Indoor air pollutants can come from a variety of sources, including outdoor air, building materials, furnishings, cleaning chemicals, and appliances [9-10-11-12]. Ensuring good IAQ involves measures such as proper ventilation, regular cleaning and maintenance of HVAC systems, use of low-emission building materials and furnishings, and limiting the use of chemicals and pollutants indoors. Monitoring and testing IAQ can also help identify problems and guide improvement efforts [13].

The aim of this paper is to assess the impact of olive pomace and wood heating systems on indoor air quality through several measurements and based on The WHO and ANSI/ASHRAE guidelines [14-15].

1.2 Particulate matter

According to the ASHRAE handbook (2021 version Chapter 11) [16], particulate matter (PM) is a term used to describe a mixture of solid particles and liquid droplets suspended in air, including PM10 (particles with a diameter of 10 micrometers or less) and PM2.5 (particles with a diameter of 2.5 micrometers or less). PM can originate from both indoor and outdoor sources, including combustion sources, cooking activities, and outdoor air pollution. PM2.5 may include bacteria, fungi, DNA viruses, allergens, and pathogens, which increases the probability of contamination [17-18].

The WHO recommends that the annual average concentration of PM2.5 in indoor environments should be less than 10 micrograms per cubic meter (µg/m3) and that the 24-hour average concentration should be less than 25 µg/m3. For PM10, the recommended annual average concentration is less than 20 µg/m3 and the 24-hour average concentration should be less than 50 µg/m3 [15].

1.3 Carbone dioxide

Carbon dioxide is a colorless, odorless gas that is a natural part of the Earth's atmosphere. In indoor environments, carbon dioxide can be generated by human respiration and combustion sources, such as gas stoves and heaters. According to the ASHRAE standards and to the WHO, the recommended limit for CO_2 concentration in residential buildings is 1000 ppm as a maximum limit, and 700 ppm as a desirable target [14-15-19-20].

2 Material and method

This paper aims to assess the impact of olive pomace heating system and wood-burning heater through several measurements. For that, two residential buildings in mountainous cold climate region in Morocco were under investigation during a period in the winter season. For heating, the first house is a villa that uses an olive pomace central boiler, and the second is a detached house that uses a wood stove. Each building accommodates five people. For this assessment, CO_2, PM2.5, PM10, temperature and relative humidity were measured hourly by using the monitoring system TEMTOP

M2000c 2nd (**Fig.** ***1***) wish is a multi-sensor air quality monitor [21]. The monitor was calibrated. For the first building, the measurements were carried out over six days (3 days without occupancy and with no heating and 3 days with occupancy and heating). In the other hand three days of monitoring have been done in the second building.

Model	M2000 2nd Generation	**PM2.5 Accuracy**	±10 μg/m³(0-100 μg/m³), ±10%(>100 μg/m³)
Dimensions	8.8 x 2.8 x 1.4in	**PM10 Measuring Range**	0-999 μg/m³ (Resolution 0.1 μg/m³)
Battery Capacity	3000mAH	**PM10 Accuracy**	±15 μg/m³(0-100 μg/m³), ±15%(>100 μg/m³)
Battery Last	6-8h with full charge	**CO2 Measuring Range**	0-5000 ppm (Resolution 1 ppm)
Input	DC 5V; 1A	**CO2 Accuracy**	±50 ppm + 5% reading
Operation Environment	0-50℃ (32-122°F), 0-90%RH	**HCHO Measuring Range**	0-2 mg/m³ (Resolution 0.001 mg/m³)
PM2.5 Measuring Range	0-999 μg/m³ (Resolution 0.1 μg/m³)	**HCHO Accuracy**	±0.03 mg/m³(0-0.3 mg/m³), ±10%(>0.3 mg/m³)

Fig. 1. Temtop M2000c 2nd monitoring system.

3 Results and discussion

3.1 The impact of the olive pomace heating system on IAQ

The impact of occupancy on PM2.5 level with heating ON

Fig. ***2*** shows that occupancy and olive pomace burning heating affect the level of PM2.5. **Table 1** summarizes the statistics of the boxplots. The large difference between median and average in some boxplots is explained with the existence of outliers. The high levels of particulate matter on these outliers are caused by some home cleaning activities like wiping dust [22].

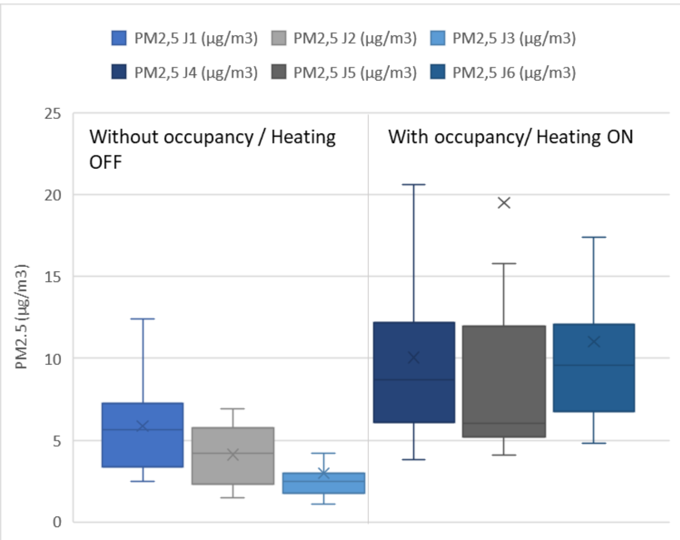

Fig. 2. Occupancy impact on PM2.5 level.

Table 1. Summary statistics obtained for PM2.5.

	Day	Median	Average	Min	Max
Without occupancy/ Heating OFF (µg/m³)	1	5,6	5,8	2,5	12,4
	2	4,2	4,1	1,5	6,9
	3	2,5	2,9	1,1	4,2
With occupancy/ Heating ON (µg/m³)	4	8,7	10,0	3,8	35,6
	5	6,0	19,5	4,1	202
	6	9,6	11,0	4,8	41,9

The impact of occupancy on PM10 level with heating ON

Fig. ***3*** shows that occupancy impact also the PM10 level. **Table 2** summarizes the statistics of the boxplots.

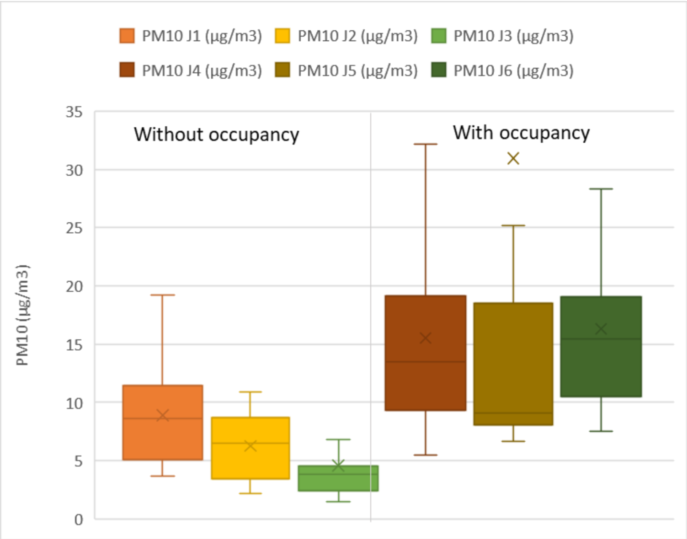

Fig. 3. Occupancy impact on PM10 level.

Table 2. Summary statistics obtained for PM10.

	Day	Median	Average	Min	Max
Without occupancy/ Heating OFF (µg/m³)	1	8,6	8,9	3,7	19,2
	2	6,5	6,3	2,2	10,9
	3	3,8	4,6	1,5	6,8
With occupancy/ Heating ON (µg/m³)	4	13,5	15,5	5,5	55,5
	5	9,1	30,9	6,7	330
	6	15,5	16,3	7,5	44,7

The impact of Olive pomace burning heating system on PM levels

To distinguish the impact of this biobased heating system without considering the other occupancy activities, a monitoring has been done with no occupancy. **Fig.** ***4*** and **Fig.** ***5*** demonstrate that olive pomace-based boiler doesn't affect the indoor air quality. There is a notable difference between the measured levels before and after switching the system ON, results shows almost a 45% difference on median values. **Table 3** gives a data summary of the **Fig.** ***4***. Based on **Table 1**, **Table 2** and **Table 3**, PM2.5 and PM10 levels don't exceed the recommended limits by WHO and ASHRAE [14-15-16].

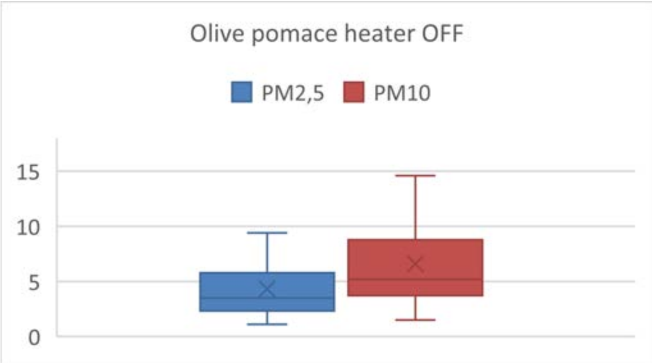

Fig. 4. PM concentrations when the olive pomace heater is OFF.

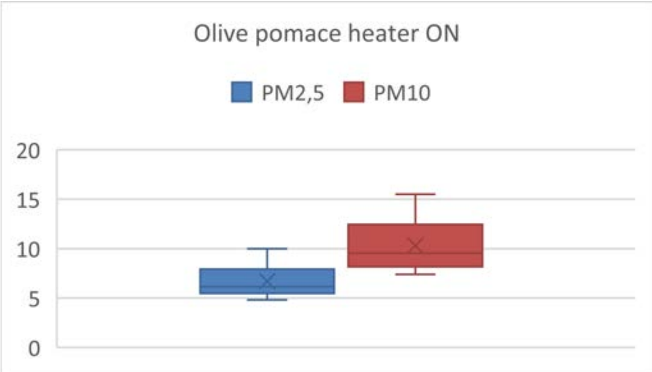

Fig. 5. PM concentrations when the olive pomace heater is ON.

Table 3. Data summary for the boxplots

		Median	**Average**	**Min**	**Max**	**Max limit**
Heater ON ($\mu g/m^3$)	PM2.5	6,2	6,7	4,8	10,0	10,0
	PM10	9,6	10,3	7,4	15,5	25,0
Heater OFF ($\mu g/m^3$)	PM2.5	3,5	4,3	1,1	9,4	10,0
	PM10	5,2	6,6	1,5	14,6	25,0

The boiler schedule

Fig. ***6*** shows the schedule clock of the boiler. According to this figure, the boiler functions 17 hours and half a day.

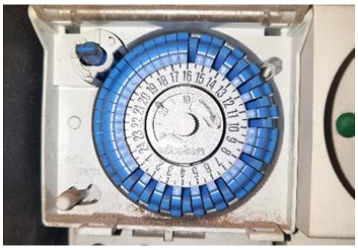

Fig. 6. The boiler schedule clock

3.2 The impact of the wood burning stove on the IAQ

In ***Fig. 7***, ***Fig. 8*** and ***Fig. 9*** the statistics of the PM2.5, PM10, and temperature measured in the building are reported. The light blue areas refer to the periods in which the stove is on fire. In the three days, the charts show that the PM level increases instantly and then start decreasing. This sudden change is due to the smoke produced during the ignition process. Unusually, on the second day, there is an increase in the PM concentration before the combustion process. Which can be explained by cleaning activity or by the stove's door opening and ashes rising. Table 4 shows that the PM concentrations don't exceed the limits required by the WHO and ASHRAE [14-15-16].

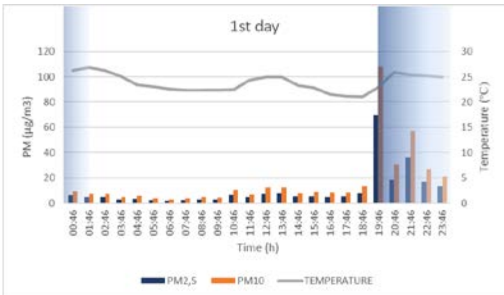

Fig. 7. PM concentration and temperature variation in wood-burning heated building (first day)

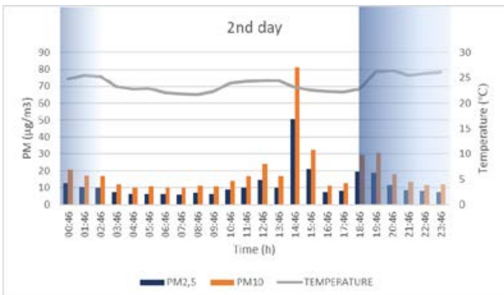

Fig. 8. PM concentration and temperature variation in wood-burning heated building (second day)

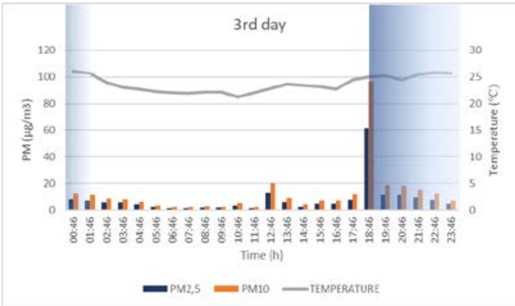

Fig. 9. PM concentration and temperature variation in wood-burning heated building (third day)

Table 4. Summary statistics of PM in wood-burning heated building

		MEDIAN	AVERAGE
HEATER ON (µg/m^3)	PM2.5	11,6	17,4
	PM10	18	27,5
HEATER OFF (µg/m^3)	PM2.5	5,3	6,6
	PM10	8,6	10,6

3.3 CO_2 concentration

In order to anticipate and assess occupancy levels, CO_2 is often measured as a proxy for indoor air quality [23-24]. As shown in ***Fig. 10***, the CO_2 concentration in the first building is within the limits and guidelines established by the WHO [15] and the ASHRAE [14]. However, in contrast, the CO_2 levels in the second building exceed these recommended limits, indicating an unhealthy indoor air quality.

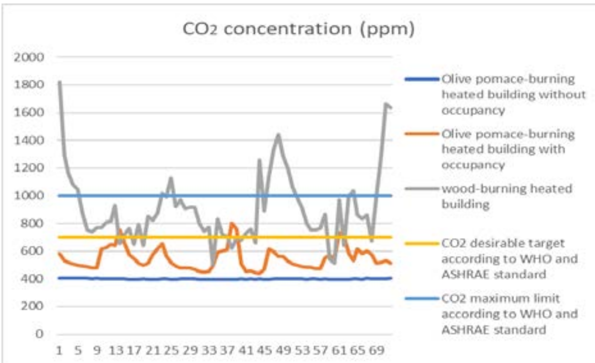

Fig. 10. CO2 Concentration

Given the detrimental health effects associated with high levels of CO_2 [25-26-27], the need for proper ventilation in the second building is crucial to improve indoor air quality [28-29] and mitigate any potential health risks for occupants. These findings underscore the importance of regular monitoring and maintenance of indoor air quality parameters in buildings to ensure the health and wellbeing of its occupants [30].

3.4 The impact of humidity on indoor air quality

The WHO [15] recognizes that humidity is an important factor in indoor air quality. In its guidelines for indoor air quality, the WHO recommends keeping indoor humidity levels between 30% and 60% to minimize the growth of harmful pollutants and maintain comfortable conditions. The WHO acknowledges that high levels of humidity can promote the growth of mold, bacteria, and other allergens, which can lead to respiratory illnesses such as asthma, allergies, and hypersensitivity pneumonitis [3]. On the other hand, low humidity can also cause dryness and irritation of the eyes, nose, and throat, as well as respiratory problems [31]. Additionally, low humidity can increase the transmission of respiratory viruses and bacteria, leading to an increased risk of infection. Therefore, maintaining appropriate levels of indoor humidity is essential for ensuring good indoor air quality and promoting the health and well-being of building occupants. **Fig. 11** shows that the relative humidity level in both buildings is healthy and won't affect the IAQ.

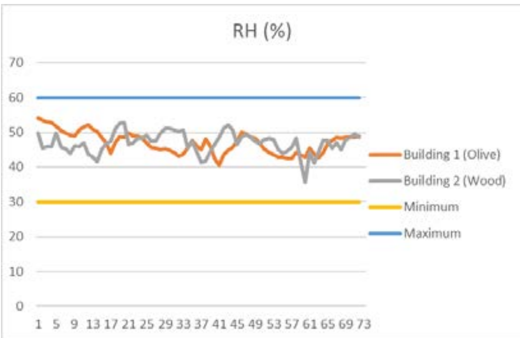

Fig. 11. Relative humidity

4 Conclusion

Upon analysis of the statistical data presented in **Table *1***, **Table *2***, **Table *3***, and ***Table 4***, it is evident that the particulate matter emissions during the utilization of a wood-burning stove are approximately twice as high as the emissions released during the operation of an olive pomace-based central heater. This finding indicates a significant discrepancy in the quantity of particulate matter emissions produced by these two heating methods, highlighting the potential environmental impact and health implications associated with the use of wood-burning stoves.

In addition to emitting significantly lower levels of particulate matter, olive pomace-based central heaters have several other advantages over wood-burning stoves. Firstly, the use of olive pomace as a fuel source is more sustainable and environmentally friendly since it is a byproduct of olive oil production, which reduces waste and promotes circular economy practices [32].

Moreover, the combustion of olive pomace produces ash that can be used as a natural fertilizer, which is an added benefit for agricultural regions, or its use in the production of eco-friendly fired clay bricks [33]. These advantages make olive pomace-based central heaters a more sustainable and practical heating option compared to wood-burning stoves.

The main conclusions are as follows:

- The olive pomace is a good alternative to wood.
- The use of olive pomace-based central heater can reduce more that 50% of particulate matter emissions compared with the wood burning stove.
- To assure good indoor air quality, ventilation is a mandatory necessity.

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Thank you for reviewing our paper and providing valuable feedback. We appreciate the opportunity to address the specified amendments and meet the requirements outlined. Please find below our response to each of the points raised:

1. We acknowledge the need to clearly identify the problem that was investigated. We revised the introduction section to explicitly state the problem and its significance.

2. We understand the importance of providing sufficient background information on the subject. We enhanced the presentation of the background information to ensure it adequately supports the study and provides the necessary context.

3. We appreciate your suggestion to include sections 2.1 and 2.2 as part of the Introduction. We modified the structure accordingly to improve the flow and coherence of the paper.

4. We apologize for the incorrect use of the chemical symbol for carbon dioxide. We corrected this mistake throughout the paper.

5. We understand the importance of providing details about the equipment used, including manufacturing information, concentration range, zero stability, and calibration. We included this information in the revised version, ensuring transparency in our experimental setup.

6. We acknowledge the oversight in not providing sufficient details about the buildings where the experimental work took place. We included some important information about the buildings, such as their types and any potential impacts on the results.

7. We appreciate your concern regarding the duration of measurements and the choice of three days without occupancy and heating. Due to unforeseen technical problems during the monitoring process, we encountered limitations that restricted us from conducting a longer-term study at the time. However, it is important to note that our work is still in progress, and we are actively planning a comprehensive long-term monitoring study to gather more extensive data. Regarding the potential effects of nearby occupied flats on the results, the studied buildings are not flats, we added this information in the paper.

8. We apologize for the lack of clarity regarding "occupancy with heating." In the revised version, we specified the number of people, heating levels, and activity levels in the building to provide a comprehensive understanding of the experimental conditions.

9. We acknowledge the omission of a mention in the text for Figure 6. We made sure to reference and discuss the findings presented in Figure 6 appropriately.

10. We apologize for the missing units for PM values in Tables 1-4. We rectified this error by providing the appropriate units in the revised version.

11. We appreciate your observation regarding the inconsistency between the statement on line 5 from the top of page 5 and the data presented in the table and plots. We carefully reviewed and reconciled these inconsistencies, ensuring the accurate representation of the results in both the text and visual elements.

12. We understand your feedback regarding the clarity and readability of Figures 10 and 11. We revised these figures to improve their visual quality and make them more accessible to readers.

13. We acknowledge your comment about the sufficiency of the provided data for drawing the presented conclusions. In the revised version, we assured a match between the presented data and conclusions.

14. We appreciate your suggestion to amend the style used for listing references on page 9. We reviewed and modified the reference formatting accordingly.

15. We understand your recommendation to provide more background information on the use and availability of olive pomace. We expanded on this aspect to provide a comprehensive understanding of the subject matter.

16. We acknowledge the need for more detailed information about the data collection process using TEMTOP M2000c, including frequency and resolution. We included these details in the revised methodology section.

17. We appreciate your feedback regarding the readability and size of the tables. We added the recommended max concentrations in table 4, and we ensured that all tables are appropriately sized and easily legible, addressing the specific concerns raised for figures 9 and 10.

Once again, we sincerely appreciate your thorough review and constructive comments.