Environmental Effects from the Use of traditional biomass for heating in rural areas. A case study of Anogeia, Crete

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Abstract

In several European rural communities, woody biomass is considered amongst the most important energy sources for heating and cooking. However, the use of old-fashioned fireplaces may affect indoor and outdoor air quality. To depict this situation and to plan the necessary improvement interventions, a pilot action was implemented in a typical mountainous Mediterranean area (town of Anogeia, Crete). The action involved: (i) identification of the quantities, use and source of the woody biomass used in the community based on the analysis of data collected through a systematic survey; (ii) on-site indoor and outdoor measurements of air quality (CO_2, CO, NO_X, PM), during wintertime and summertime. Based on the current survey, around 70% of the study area households in Anogeia using woody biomass for heating purposes in low energy efficiency systems resulted in high annual consumption of firewood. Fifty-three per cent of occupants didn't consider indoor air quality as a result of wood burning. The analysis of the air quality showed very high concentrations of indoor air pollutants in the majority of old buildings with seniors using traditional heating systems. The type of main/supplementary heating system used in a dwelling depends on factors such as the size of the dwelling, year of construction, education level and age of occupants. The results also demonstrate a strong correlation/liaison between the heating season (summertime/wintertime), and the (significant increase in the) concentrations of air pollutants in the sampling sites.

1. Introduction

In Europe and globally, hundreds of biomass exploitation plans exist at urban or rural level (Neves et al., 2015; Gould et al., 2018; Wood and Roelich, 2019).

Woody biomass constitutes a key renewable energy source to meet the 32% European target until 2030 (EC, 2018). The EU solid biomass production for 2017 was 99.8 Millions tonnes of oil equivalent (Mtoe), while the electricity production was 94.5 TWh (Eurobserv'ER, 2019). For more than 2.5 billion people, biomass is the primary heating and cooking source of energy, particularly in the (Mediterranean) rural communities, usually inhabited by low-income occupants. Recently, due to the severe economic crisis, it has been gaining prominence, given that it is cost-efficient compared to heating oil (Savvakis et al., 2018). The primary concern is the need to combine the current use of biomass with local environmental and health implications, as well as it's efficient and sustainable exploitation/utilization. Nowadays, the current potential social systemic modifications influence the selection of wood heating, so further research is required to promote its extensive possible exploitation (Edling and Danks, 2018).

The biomass exploitation has many advantages (renewable energy, carbon neutral, less dependence on fossil fuels, waste reduction, abundant availability). However, the combustion of timber can have significant social and environmental consequences causing health problems due to the emission of a complex mixture of air pollutants (Castro et al., 2018; Gautam et al., 2019). The extensive use of biomass can lead to: (i) atmospheric pollution (indoor and outdoor), caused mainly by CO, hydrocarbons, and other air pollutants (ii) health problems due to systemic exposure to increased concentrations of the produced air pollutants. It should be noted that the quality of the combustion is mainly determined by several factors such as: technology (e.g. old fashioned and energy-efficient fireplaces), the type of heating system (stove or fireplace), the chimney, the burning rate, the use of inappropriate materials (e.g. chemically treated wood), etc. Apart from the abovementioned, another negative impact of increased biomass use is deforestation, often caused by the uncontrolled cutting of trees for the acquisition of free timber.

There have been many studies dealing with modern methods and techniques for space and hot water heating that could meet current energy needs with the minimum possible environmental impact (Koukios et al., 1991; Vallios et al., 2009; Sonarkar et al., 2016). There has been relatively limited literature published on the role of bioenergy in (Mediterranean) mountainous rural communities and its connection to various factors, such as: (a) the climate of the area used(b) the income/ standards of living of the people using it(c) their education level(d) the number of dwelling occupants (e) the type of heating system etc.

In order to study the above, a pilot action was implemented in the Municipality of Anogeia (Crete). The area was selected due to its location on the outskirts of Mount Psiloritis, characterized as mountainous (800 m altitude), its increased heating needs and the high biomass potential of the area. Anogeia municipality is composed of two settlements, Anogeia and Sissarha, located 52 km away from the city of Rethymno, and 36 km from Heraklion. (Savvakis et al., 2018).

The climate of the region is predominantly temperate with mountain-type features. The average daily temperature during wintertime is 7.8°C (it ranges from − 6.0°C to 18.5°C) while during summertime is 22.1°C (varies between 12.3 and 36.0°C). Typically, winter lasts from October to April, and it can be described as rainy, whereas during the summer, almost absolute drought is noted. Snow is frequent in the mountainous region, with an average of 22 days/year.

The main actions involved:

i. the identification of the type, the amount, its use and the source of woody biomass burned in the Anogeia community.
ii. the analysis of data collected (a) through a structured questionnaire, alongside with (b) field research; instrumental on-site air quality measurements (CO_2, CO, NO_X, PM), during winter and summer for both indoor and outdoor environment.

An additional important point of our study was the verification/comparison of resident’s perceptions about the use and environmental impact of biomass with real-time instrumental measurements.

In summary, the main research objectives of this research were:

- To describe the current biomass heating practice in households and commercial uses

- To characterize and compare the concentrations of suspended particles and air pollutants during summertime and wintertime; also, to connect/correlate their levels with parameters such as the type of basic/ supplemental heating systems, the size and the year of construction of the dwellings sampled, the age of occupants, etc.
- To compare the results with the relevant standards of international organizations and the results of other compatible studies
- To study the probable relationship between meteorological conditions and measurements taken from the instrumental process.

2. Methodology

2.1. Field survey and instrumental measurement

In order to collect qualitative and quantitative data on the use of woody biomass in the area, two different approaches have been employed:

i. on-the-spot measurements of air quality in selected locations (indoor and outdoor environments) have been carried out. These measurements were taken using portable analysers to record the concentrations of air pollutants and suspended particles (CO_2, CO, NO, NO_2, volatile organic compounds -VOCs, PM_1, $PM_{2.5}$, PM_4, PM_{10}, TPM);
ii. additional data were provided by performing interviews via two structured questionnaires (one for households and one for restaurants/taverns), specifically designed for the research. The collection of data took place in the second half of 2017 and the beginning of 2018 (August 2017 - March 2018).

This implementation methodology included four main stages (Fig. 1).

2.2. Questionnaire methodology

This part of the study was implemented with the aid of structured questionnaires tested through a pilot study (Burns 2000). They included closed-ended questions: yes-no, ranking, multiple-choice and specified-answer questions. (Bradburn et al. 2004). For the statistical analysis of the collected data, we employed SPSS v. 23 (Green et al., 2000, Apostolakis et al., 2009); the questionnaires were tested for face-value validity, and their reliability assessed with the Cronbach alpha coefficient, which was calculated to have a value of about 0.7 (in each case).

The questionnaire survey was focusing at:

- Recording the methods, degree of use and quantities of woody biomass inside the settlement
- Registering the origin of the woody biomass being used, and its chronic energy exploitation practices
- Examining the knowledge and also the perception of occupants and professionals concerning the woody biomass

The main sections of the households' questionnaire were:

A. Residences' general characteristics (type, location, use, number of occupants)

B. Residences' energy characteristics and systems (heating type systems, biomass consumption, its origin, etc.), with subdivisions:

- **B1 Residence heating** (e.g. basic and supplemental heating systems, months and hours of their use etc.)
- **B1.1 Residence heating - with traditional or new combustion heaters** (e.g., traditional fireplace, energy wood stove, wood stove)
- **B2 Other uses of biomass besides heating**

C. Personal Information (demographics)

The questionnaire survey was conducted in two periods (summer and winter): the 1st took place during September 27, 2017 - October 8, 2017, while the 2nd one during 20 December 2017–5 March 2018 through face-to-face interviews in fifty (50) households (out of about 350) and ten (10) restaurants. The average interview duration was 15–20 minutes, while the sample profile was men and women, 18 years old and over, occupants of the Anogeia municipality. The route planning, as well as the detailed timetable for the interviews, was scheduled in conformity with the corresponding activities of the instrumental measurement process.

2.3. Methodology of the instrumental measurements

The instrumental measurements were aiming at the assessment of the air quality of selected sites (open spaces, indoor and outdoor environment). These measurements were carried out at fixed (sample) points along the central street and adjacent roads within the settlement and were realized with the use of appropriate portable analysers under different meteorological conditions. The instruments used, the parameters measured, the operation range etc. can be seen in Table 1.

Also, a procedure was planned for the indoor and outdoor spaces of fifty (50) sample dwellings (selected through a stratified sampling), which use woody biomass for heating and practices. The strata, in this case, were the dwellings of the six sampling sites described below. In each of these sites, the households were chosen with the use of random sampling (weighed factors such as size and year of construction of households, type of heating systems etc).

Table 1
Basic parameters and measuring instrument

Parameter	Measuring instrument	Operation range	Instrument accuracy
Temperature	Anogeia meteorological station	na	na
Relative humidity			
Wind speed			
Wind direction			
CO	MX6 iBrid (i) (gas detector)	0–1.000 ppm	± 5%
CO_2		0–5%	± 5%
NO		0–1.000 ppm	± 1 ppm
NO_2		0-100 ppm	± 6%
VOCs		0–2.000 ppm	± 10%
Mass concentration of suspended particles of indoor and outdoor environment (TPM, PM_{10}, PM_4, $PM_{2.5}$, PM_1)	DustTrak DRX (ii) 8534 (handheld)	.001–150	± .01% ή.001
Flammable gases	Ventis MX4 (iii)	0-100% LEL	
(i), (iii): Industrial Scientific, USA (ii) TSI Incorporated, USA			

The instrumental measurements were also performed during two periods. The first period was September 27 - October 8, 2017. Repeated instrumental measurements of the parameters (15 minutes) took place concurrently with the field (questionnaire) survey. The second period was 20 December 2017–5 March 2018, chosen to record the change of the values of the monitored parameters at the time of increased biomass use in the Anogeia settlement.

The measurements were performed at selected locations taking into account the following criteria:

- Outdoor air samples should not be taken from points located ≤ 1m from adjacent buildings according to ISO 16000 – 1.2004 (planning of indoor air pollution monitoring).
- Measurements should not be taken during precipitation due to increased moisture content.
- Points that are exposed to direct sunlight should be avoided.

- Locations where there was an activity capable of affecting the air quality (e.g., building construction) should be regarded as unsuitable.
- Measurement points situated ≤ 10m from local sources of pollutants (e.g., chimneys, air-conditioning units, ventilation systems) should be excluded.

Instrument placement should be at least 1 m away from trees and vertical surfaces (e.g., walls) and at the height of 1.5–2.0m above road level (respirable fraction) (Fig. 2).

Instruments placement in indoor living areas should be compatible with the conditions described in ISO 16000 – 1.2004:

- The center of the site is the most appropriate point for sampling; nonetheless, in case that it is not feasible, instruments will be placed at a distance of at least 1m from the walls, 2m from the combustion hearth and at the height of 0.8–1.1m from the floor.
- Points that are exposed to direct sunlight should be avoided.
- During sampling, activities with a critical impact on the quality of the measurements (e.g., use of the kitchen hood, vacuum cleaning, household cleaning, smoking, etc.) should be avoided (Fig. 3).

The instrumental outdoor measurements were carried out at six selected open spaces in the Anogeia settlement (Fig. 4) (Municipal Theater "Nikos Xylouris", Anogeia Centre for Environmental Education (ACEE), Meidani Square - Agios Georgios, Armi Square - Town Hall, Livadi Square – Perachori and Chereti Street– Perachori). The locations were selected upon (i) the proximity to areas where increased use of biomass is observed (e.g. catering areas, households with traditional fireplaces, etc.) and (ii) the number of visitors to the site throughout the year.

Instrumental measurements of indoor air quality were planned for selected residences that use biomass for heating purposes (in fireplaces, stoves, etc.) and/or other use (e.g. cooking). In order to achieve a representative sample, the settlement was divided into five main zones (Fig. 5): (Metochi, Agios Georgios, Messochoria, Perachori, and Langos district, based on building density, spatial distribution, dates of the buildings' construction, and specific energy characteristics of the buildings (e.g., energy-efficient fireplace, traditional fireplace).

During the two periods of the field survey, instrumental measurements were carried out daily at the selected households, restaurants, and open spaces, alongside with the questionnaire survey. The measurements in households and open spaces were performed in the morning, from 10:00 to 15:00, and between 17:30–21:30, while during the weekends, the hours varied.

The process for households/residences included three main stages:

- **1st**: Measurement of the indoor controlled parameters.

- **2nd**: Personal interview with the residence´s owner (questionnaire completion) in parallel with the instrumental measurement of the 1st stage.
- **3rd**: Measurement of the outdoor controlled parameters

The open space process-consisted of two stages:

- **1st**: Measurement of the controlled parameters in the open study area of the settlement
- **2nd**: Personal interview with the restaurant's manager (questionnaire completion) just after the instrumental measurement process in the nearby, to dining place, sampling site.

The duration of each sampling for suspended particles, the parameters CO, CO_2, NO, NO_2, VOCs and flammable gases was 15 minutes, recorded per second.

In order to track the differences between indoor/outdoor, doors and windows remained closed throughout the measurement.

Finally, we must mention that the instrument measurements used for the statistical analysis are the mean values of the measurements taken.

3. Results

3.1 Qualitative results of the research

3.1.1 General characteristics of residences

Most of the sampled dwellings were single houses or duplexes (92%), privately own (95%), with an area of 80–120 m^2 (Fig. 6) and constructed after 1981 (59%) ; the average number of occupants per household was 3.56 (± 1.13). Regarding the residents' occupation, they were freelancers, employees, farmers or retirees. The average household income did not exceed 20,000 €/year (regarded as a medium to a low one).

Furthermore, the majority of the elderly occupants of the region (85.7%), who were mainly retired with low income, were living in small and old houses (built before 1980). On the contrary, families with at least 4 members were living in newer houses with an area of > 100 m^2 (≥ 60%). Finally, 7 out of 10 participants (69.4%) were high school graduates, while only 20% of these held a university degree.

3.1.2 Energy characteristics of residences

According to the findings of the survey, 31% of the dwellings were using the energy-efficient fireplace as the primary heating system, while 30.6% was opting for the traditional wood stove (Table 2) to heat more than two rooms (63.9%). Nevertheless, approximately 72% of households also employed a supplemental heating system. More precisely (Table 2), the traditional fireplace prevailed among these additional heating systems with a notable 47%, followed by an electric heater (19%).

Table 2
Percentage of primary and supplementary heating systems used.

Heating technologies	Type of Use	
	Basic system (%) (n = 50)	Supplemental system (%) (n = 36)
Traditional Fireplace	5.4	47
Energy Efficient Fireplace	31	3
Wood or Pellet Burning Stove	30.6	17
Central Heating (oil fueled)	25	11
Electric Heater	0	19
Other	8	0
Air Condition	0	3

There is a statistically significant percentage difference, at a = 0.05 significance level, between the year of construction/size of the residency and the primary heating system. In older and smaller households, which comprised nearly 40% of the sample, the use rate of old heating systems, such as a wood stove or traditional fireplace, was 60.7% (z-score = 2.522, p-value = .0117). On the other hand, in the majority of the newer and larger houses, roughly 60% of the sample, the energy fireplace (38.1%) or central heating (33.3%) were the basic heating systems (z-score= -2.268, p-value = .0233).

Also, there is a statistically significant percentage difference in the education level and the use of (main) heating systems. Elementary education level occupants use more often traditional fireplaces (50% firewood stove) in contrast with high school/university graduates who use energy-efficient fireplaces or central heating system (52% of high school occupants and 71% for the university graduates). Also, the heating system used depends on: (i) the number of occupants, if 3 or 4 people reside in a house the main heating system is central heating (38.5% and 42.9% respectively) (ii) age of the occupants: if there are children, the basic heating system is energy efficient fireplace (42.1%) (z-score= -2.65, p-value = .008), while if there are elderly people, they often use burning stove (71%) (z-score = 2.806, p-value = .0005).

The type of supplementary heating system used in a dwelling depends on factors such as: size of the dwelling, education level of occupants (50% of elementary school graduates use an electric heater, while 38.1% of high school and 60% of university-level occupants use traditional fireplace), age of occupants (if there are children, 46.7% use traditional fireplace).

Furthermore, the heating period in the study area lasts approximately six months, usually from mid-October to May (58.3%) and the average daily usage of the heating systems ranges from 12 to 16 h (in 75% of the residences). On a daily basis, the occupants of old houses use the heating systems more often. In 61.1% of the households, the average consumption of firewood is < 8 t/y, whereas almost one out of two residences (46%) use their own firewood, coming from agricultural residues, pruning (85%), etc., in order to meet their heating needs (Fig. 7). Almost all the biomass used is firewood.

The majority of the occupants (52.8%) considered that there was no effect on the air quality by the use of heating systems; 4 out of 10 declared that the efficiency of the heating system was “very satisfactory” and almost 80% said that felt thermal comfort. A statistically significant difference exists between the number of occupants who think that the air quality is affected by the use of a heating system and: (i) the year of construction of the residence (66.6% of the occupants of an old house and 33.3% those of a new one think that it is affected) (z- score= -1.975, p-value = .0483) (ii) the size of the residences (38.5% of small and 52.2% of big ones believe that it is affected).

An additional fact pointing to this direction is that 53.3% of the occupants of old houses, and 61.5% of the small ones, leave a window always open (during the use of the heating system). Finally, new build house occupants feel heat comfort more often (85.7% of the time).

3.1.3. Uses and origin of woody biomass in restaurants

Drawing from the research results, the woody biomass in restaurants was used primarily for cooking. A significant proportion of businesses (67%) was using a grill daily for 8–10 h (mainly in summertime and wintertime). Moreover, 46% of restaurants were using self-produced woody biomass, whilst one out of three eateries was purchasing it. The total amount of required firewood in 2017 reached up to 53.5 t.

The total cultivated and productive areas in the Anogeia municipality equal to 5,048 ha and cover 38.5% of the entire territory (Payment and Control Agency for Guidance and Guarantee Community Aid, 2016). Most crops are located in the northern part of the municipality, while the size of grazing land is also significant (Fig. 8). More specifically, the cultivated and productive areas in the region are composed of the following crops: olive groves: 552.04 ha (10.93%), vineyards: 35.51 ha (.70%), citrus fruits: .06 ha (.01%), pome fruits: 1.06 ha (.02%), tree nuts: 10.36 ha (.21%), grazing land: 4,4118 ha (87.80%), fallow land: 12.02 ha (.24%).

Woody biomass potential consists mainly of agricultural residues of olive groves, vineyards and fruit trees (Table 3):

Estimating the increased demand for woody biomass in the study area, it is clear that the potential is insufficient to address the needs of the region since, the data of the survey revealed that the total annual consumption transcended the 450 t/y (Giamalaki et al., 2019).

Table 3
Woody biomass potential available in Anogeia municipality

Crop	Variety	Area		Biomass coefficient	Available biomass (40% humidity)	Availability	Biomass (final)
		ha	km^2	t/km^2	T		t
Olive groves	Koroneiki	523.87	5.24	280.5	1,469.82	.5	734.9
	Throumba	27.76	.28	280.5	78.54	.5	3. 3
Vineyards	Raisin production	30.53	.305	100	30.5	.5	15.3
	Wine production	4.98	.05	100	5	.5	2.5
Fruit trees	Citrus fruits, Pome fruits	1.12	.01	375	3.75	.5	1.9
Other	Tree nuts	10.36	.104	48	4.99	.5	2.5
				Total	**1,592.6**		**796.3**

3.2 Quantitative results of the instrumental measurements

The testing of air quality, inside and outside of the selected dwellings, was also performed in two periods. In particular, the first sampling period carried out between September 27 and October 8, 2017, when heating systems were not in use. In contrast, the second sampling period conducted during the period of operation of heating systems, from 20 December 2017–5 March 2018.

3.2.1. Quantitative results of the first period of the instrumental measurements

The results obtained from the processing of the instrumental measurements of the first period (summertime) are presented in Fig. 9.

During summertime, the average CO concentration, both indoor and outdoor, was very low and, in any case, within the European and national air quality standards (10 mg/m^3 - maximum daily value, 8h exposure). Regarding the CO_2 concentrations, the values, .038% vol (range 0 – .08% vol) and .005% vol (range 0 – .03% vol) for the indoor and outdoor environment, respectively, were also low and within the safe exposure limits (3% vol – maximum value for 15-minute exposure/ .1% vol - maximum value for continuous exposure) (Table 4).

Table 4
Summertime CO and CO_2 concentrations

	CO			CO_2	
	IN	OUT		IN	OUT
N Valid	42	42	**N Valid**	42	42
Mean	.0000	.0714	**Mean**	.0383	.0048
Std. Deviation	.00000	.46291	**Std. Deviation**	.01793	.00740
Range	.00	3.00	**Range**	.08	.03

In the tested households, there was no detection of NO_x. On the other hand, the average value of VOCs indoor was .1 ppm (range 0 – .9 ppm), which equals the safe 15-minute exposure limit recommended by the World Health Organization (WHO). Notwithstanding, given that, during this period, the heating systems were not in operation, the above results were anticipated. The recorded air pollutants were probably due to vehicles, the use of varnishes/paints, cleansers, deodorizers and/or air conditioning.

Another essential finding, which was prevalent in all measurements, was that the concentrations of suspended particles (PM_1, $PM_{2.5}$, PM_4, PM_{10}, TPM) in the interior of the dwellings were significantly higher than those of the ambient areas. In particular, the mean of PM_{10} particle concentrations for outdoors and indoors was .017 mg/m^3 (range .009 – .025 mg/m^3) and .083 mg/m^3 (range.014- .801 mg/m^3), respectively. Comparing the above results with the thresholds for health-harmful PM concentrations, it was observed that the values monitored in the indoor areas were above the .05 mg/m^3 limit (mean daily value, not to be exceeded more than 35 times annually).

As for the PM_1 particles' outdoor and indoor concentrations, their means were .008 mg/m^3 (range .003 – .019 mg/m^3) and .044 mg/m^3 (range .004 – .380 mg/m^3), respectively. One the other hand, the mean of the indoor concentration for $PM_{2.5}$ was .047 mg/m^3 (range .006 – .384), while for the outdoor was measured .010 mg/m^3 (range .005 – .019). Finally, the mean of the relative concentrations of PM_4 indoor and outdoor, was .054 mg/m^3 (range: .008 – .391), and.012 mg/m^3 (range: .007 – .020 mg/ m^3), respectively.

It is notable that higher concentrations of suspended particles (PM_1, $PM_{2.5}$, PM_4, PM_{10}, TPM) were observed in the interior of older and small dwellings, resided predominantly by elderly people. These results were not only expected but might also be correlated with the quality of the building materials of these homes and the everyday habits of the occupants.

3.2.2 Quantitative results of the second period of the instrumental measurements

The results obtained from the processing of the instrumental measurements of the second period (wintertime) are shown in Fig. 10.

It is notable that during wintertime, due to the operation of the different types of heating systems, the average concentration of the monitored air pollutants was higher than summertime, surpassing in some cases the safe exposure limits set by Greek legislation, WHO and other organizations.

The average indoor and outdoor CO concentrations ranged between 0–4.8 ppm (mean:1.27 ppm) and 0–5.2 ppm (mean: 1.96 ppm), respectively. These concentrations were within limits recommended by WHO (87 ppm - maximum allowable concentration for 15 minutes exposure). There is a significant difference in the mean CO concentration on factors such as: (i) year of construction (higher concentration in old houses); (ii) size (higher in houses of size > 100 m^2); (iii) age of occupants (higher if there are elderly); (iv) basic heating system (higher in residencies with basic heating system burning stove and traditional fireplace); (v) on the supplementary heating system; (vi) education (the higher the education the less concentration).

About the CO_2 concentrations, the mean values were .074% vol and .015 % vol for indoor and outdoor environment, respectively, were classified as non-hazardous and within the permissible exposure limits (3% vol. 15 minutes exposure / .1% vol. - maximum concentration for continuous exposure). Nonetheless, it should be stated that, in certain dwellings, the recorded levels exceeded the continuous exposure limit (.1% vol).

Furthermore, the range of variation of NO_x concentration was .042 – .19 ppm (mean .0646 ppm) for the indoor environment and .020 – .089 ppm (mean.0608 ppm) for the outdoor, which, in both cases, represented safe conditions as the permissible exposure limit suggested by the WHO is 1 ppm.

Table 5
VOC indoors (IN) wintertime * houses with old/new type heating systems

			Old/new type heating system		Total
			Old	**New**	
VOC* in exceedance	**under**	Count	2	3	5
		% within Old type heating system	33.3	37.5	35.7
	over	Count	4	5	9
		% within Old type heating system	66.7	62.5	64.3
Total		Count	6	8	14
		% within Old type heating system	100.0	100.0	100.0
PM_{10} in exceedance**	**under**	Count	0	5	5
		% within Old type heating system	0	50.0	31.2
	over	Count	6	5	11
		% within Old type heating system	100.0	50.0	68.8
Total		Count	6	10	16
		% within Old type heating system	100.0	100.0	100.0

** As regards VOCs (Formaldehyde), a short-term (15-minute) guideline of 0.1 ppm is recommended as preventing sensory irritation in the general population.*

*** According to the National legislation (Ministerial Decision 70601, Official Gazette B/3272/23.12.2013), the daily mean value of 0.05 mg/m^3 should not be exceeded less than 35 times annually.*

On the contrary, the average concentration of .38 ppm (range 0–1.80 ppm) for indoor VOCs, which was monitored in a significant number of the sampled dwellings, was well above the threshold of .1 ppm for 15 minutes exposure established by NIOSH. This observation was in tandem with the increased use of the old-style heating systems (e.g. wood stove, traditional fireplace) and the possible combustion of unsuitable wood. More precisely, the limit was exceeded in 66.7% of the houses with old-style heating systems, and in 62.5% with new type ones (Table 5).

There is a statistically significant difference of the mean concentrations of both NO_x (and VOCs) on factors such as: the year of construction (higher concentration in old houses) (t- score = 2.4, p-value = .03), the size of the dwelling (higher in houses of size > 100 m^2) (t- score = 2.467, p-value = .028) and the age of occupants (higher if there are elderly) (t- score = 21.301, p-value = .000).

The above results demonstrate a strong correlation/liaison between the heating season (summertime/wintertime) and the (significant increase in the) concentrations of air pollutants in all sampling sites (indoor and outdoor environments). Moreover, in some cases, specific pollutants exceeded the permissible limits of safe exposure.

Regarding the registered concentrations of suspended particles (PM_1, $PM_{2.5}$, PM4, PM_{10}, TPM), all measurements were higher in the interior of the dwellings than in the outdoor areas. More specifically, the mean value of the PM_{10} particles concentration for indoor and outdoor areas was .170 mg/m^3 (range: .034 – .537 mg/m^3) and .047 mg/m^3 (range: .013 – .145), respectively. Comparing these results with the air quality standards, it was observed that the indoor reported values (with a reduction to 24 h) surpassed the limit of .05 mg/m^3 (mean daily value, exceeded less than 35 times annually), a phenomenon that was attributed to the increased burning of wood in wood stoves and traditional open-air fireplaces. This exceedance was noted in the entirety of old-style houses and only in half of those with new type heating systems (Table 6).

Table 6
PM_{10} exceedance in houses with old/new type heating systems

			Old type of basic heating		Total
			Old	**New**	
PM_{10} exceedance	**under**	Count	0	5	5
		% within Old type heating system	0	50.0	31.2
	over	Count	6	5	11
		% within Old type heating system	100.0	50.0	68.8
Total		Count	6	10	16
		% within Old type heating system	100.0	100.0	100.0

PM_{10} particles concentration was much higher in old houses (20.4–7.3% in new ones), with older adults (28–5.4%) and with burning stove (33%) and traditional fireplace (26.5%) as the basic heating system.

With reference to the PM_1 particles concentration, outdoor and indoor mean values were .027 mg/m^3 (range: .009–0.059 mg/m^3) and .124 mg/m^3 (range: .012 – .448), whilst the mean registered values for $PM_{2.5}$ were .032 mg/m^3 (range: .012 – .061) and .131 mg/m^3 (range: .013 – .452 mg/m^3). Furthermore, for PM_4, the relative concentrations were .016- .464 mg/m^3 (mean: .141 mg/m^3) indoor and .012- .066 mg/m^3 (average: .037 mg/m^3) outdoor.

Table 7
Indoor and outdoor air quality measurements (wintertime)

Air pollutant	Units	Indoors	Outdoors	Recorded concentrations
PM1	mg/m^3	.123	.027	indoors 3.5x higher than outdoors
PM2.5		.131	.032	indoors 4x higher than outdoors
PM4		.141	.037	indoors 4x higher than outdoors
PM10		.170	.047	indoors 3.5x higher than outdoors
TPM		.202	.054	indoors 4x higher than outdoor
CO	ppm	1.26	1.84	average concentration nearly 50% higher outdoors
CO_2	%vol	.073	.015	indoors 5x higher than outdoors
NO_X (NO_2)	ppm	.071	.064	average indoor concentration slightly higher than outdoors
VOC		.38	0	average indoor concentration was high
LEL	%	0	0	

Summarizing, in the interior of old and small households resided primarily by seniors, were observed higher concentrations of suspended particles (PM_1, $PM_{2.5}$, PM_4, PM_{10}, TPM). This phenomenon is (probably) related to the use of traditional heating methods, the quality of the construction materials of these homes and the everyday habits of the inhabitants (Table 7).

3.2.3 Results of concentrations of air pollutants of the first and second instrumental measurements periods

By comparing the results from the processing of the first and second instrumental measurement period, it is obvious the significant increase in the indoor concentrations of air pollutants and suspended particles during wintertime, mainly due to (winter's low temperature and so on) the extended use of traditional heating methods (Fig. 11).

Table 8
Indoor air quality using different biomass heating systems during wintertime.

		Indoors (wintertime)		
Air pollutant	Units	Wood-burning fireplace	Woodstove	Energy fireplace
PM1	mg/m^3	.262	.189	.022
PM2.5		.275	.199	.026
PM4		.290	.218	.031
PM10		.330	.266	.048
TPM		.363	.299	.075
CO	ppm	3.200	1.980	0
CO_2	%vol	.050	.088	.073

3.2.4 Correlation of second period's instrumental measurements results with the type of heating system

In order to compare the indoor air pollutants produced by different biomass heating systems, a particular representative sample of the population was selected (Table 8).

The recorded concentrations for PM_1, $PM_{2.5}$, PM_4, PM_{10}, TPM in residences with wood-burning fireplace were up to 12, 11, 10, 7 and 4x, respectively, higher than the corresponding values for households without. Also, the average CO concentration in residences with wood-burning fireplace was high, while it was zero in households without. Finally, the CO_2 concentration in residences without a fireplace was slightly higher than those with a fireplace.

Comparison of the results of the present study with those obtained from other similar studies revealed that the mean concentrations of CO_2 (.074 %) are slightly higher than those reported by Castro et al. (2018) and Vicente et al. (2020) but lower than the corresponding value.114% reported by Salthammer et al. (2014). As concerns CO, the mean value 1.27 ppm was recorded below the concentration values of 3.2 ppm and 2.8 ppm reported by Vicente et al. (2020) and Salthammer et al. (2014), respectively.

According to the PM measurements, the values of $PM_{2.5}$ and PM_{10} are analogous with studies. For instance, Castro et al. (2018) reported an average PM_{10} concentration of .059 mg/m^3 during the operation of an open fireplace installed in the living room of a rural Spanish house. The concentrations values of PM_{10} reported by Stabile et al. (2018) in 30 dwellings equipped with closed fireplaces (10 homes), open fireplaces (10 homes) and pellet stoves (10 homes) were in the range from 24 mg/m^3 to 552 mg/m^3, 29 mg/m^3 to 227 mg/m^3 and 16 mg/m^3 to 70 mg/m^3, respectively.

Concerning VOCs, the range of concentration from 0 ppm to 1.8 ppm is larger than the corresponding range from .056 ppm to .338 ppm reported by Salthammer et al. (2014) in seven German households equipped with closed (6 homes) and open (1 home) wood-burning appliances.

3.2.5 Analysis of the environmental and health risks from the extended use of biomass burning

Biomass burning heating systems are currently recognized as a worthy solution for indoor heating purposes due to the competitive running costs and the carbon neutrality of wood-biomass. Nevertheless, the environmental issues associated with burning wood should be evaluated in-depth, since a noticeable increase in pollutants has occurred. More specifically, combustion phenomena of solid fuels are more complex than gaseous fuels and produce significant emission of hazardous chemicals, while increased biomass consumption in some European regions was recently linked to the rise of particulate matter and other types of gas emissions.

Moreover, a growing body of literature (WHO, 2015; Sigsgaard et al., 2015; Hystad et al., 2019; Tamire et al., 2019) has highlighted the role of household air pollution arising from biomass fuel combustion on several respiratory and no respiratory diseases, such as asthma, pneumonia, chronic obstructive pulmonary disease, lung cancer, low birth weight and infant mortality, cardiovascular disease, cataract, nasopharyngeal and laryngeal cancer, etc.

Specifically, biomass smoke (e.g. airborne particulate matter- PM_{10}) is considered as a major component of indoor air pollution and was classified by the International Agency for Research on Cancer (IARC) as probably carcinogenic to humans (Category 2A) (IARC, 2010). Its effect is strictly related to the toxic compounds attached to the particle surface, since toxic compounds such as PAHs and dioxins/furans, heavy metals may be easily carried into the lungs (Stabile et al., 2018). This hypothesis is supported by recent epidemiological and toxicological findings from several studies (Capistrano et al., 2017; Assad et al., 2016).

According to the abovementioned findings, it is clearly stated that an increase of biomass-burning in a region can be evolved a major public health concern. The restriction of use or replacement of traditional wood-burning appliances is recommended to avoid this condition.

4. Conclusions

Recently recent researches put in question the current quality of the indoor- versus the outdoor-environment in contrary to the common belief that the built environment is well protected (Mendoza et al., 2021). In Anogeia, more than half of occupants had the perception that there was no deterioration in the indoor air quality as a result of wood burning; notwithstanding, it should be noted that one out of two left a window open.

Based on the current survey, around 70% of the study area households in Anogeia use woody biomass for heating purposes in low energy efficiency systems, resulting in high annual consumption of firewood. Also, the majority of the households employ a supplemental traditional heating system. The type of the heating system depends on the size and age of the household, education level of the occupants, number and age of the occupants.

The analysis of the air quality instrumental measurements/data showed increased concentrations of suspended particles during summertime, mainly inside of the residences. The use of woody biomass in traditional fireplaces or wood stoves determined the indoor air quality significantly, with particles and other air pollutants; in some cases, the indoor concentrations of air pollutants exceeded the permissible limits.

The majority of the occupants engaged in farming or being retired were using traditional heating fireplaces; the household income affected the choice of the heating system. In contrary, indoor concentrations of air pollutants due to energy-efficient fireplaces were considerably lower than those of a traditional fireplace.

Critical results of the survey were discussed with the local inhabitants, in an effort to inform them about their current biomass use impacts. In particular, it was mentioned that converting conventional wood fireplaces into high-efficiency ones (energy fireplaces/stoves up to 90% efficiency) would contribute to: (i) the saving of woody biomass (ii)the reduction of uncontrolled tree cutting and (iii) the improvement of air quality indoors. This is due to the fact that energy-efficient fireplaces or stoves emit fewer air pollutants (Karkania et al., 2012).

Additionally, it was noted that the use of other biomass types (except firewood) and the operation of a wood process plant (e.g. pellets, wood chips), for the exploitation of the local woody biomass potential could: (i) reduce the heating cost of households in the area (ii) address the consequences of poor-quality biomass fuel (olive kernel), while simultaneously (iii) could strengthen the local economy (Vamvuka and Tsoutsos, 2002).

Finally, future points of research interest could be: (a) conduct a similar survey to an area of lower altitude and compare the results (b) repeat the survey to Anogeia after a period of time and try to see if there are behavioural changes in the biomass exploitation and use.

Declarations

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Figures

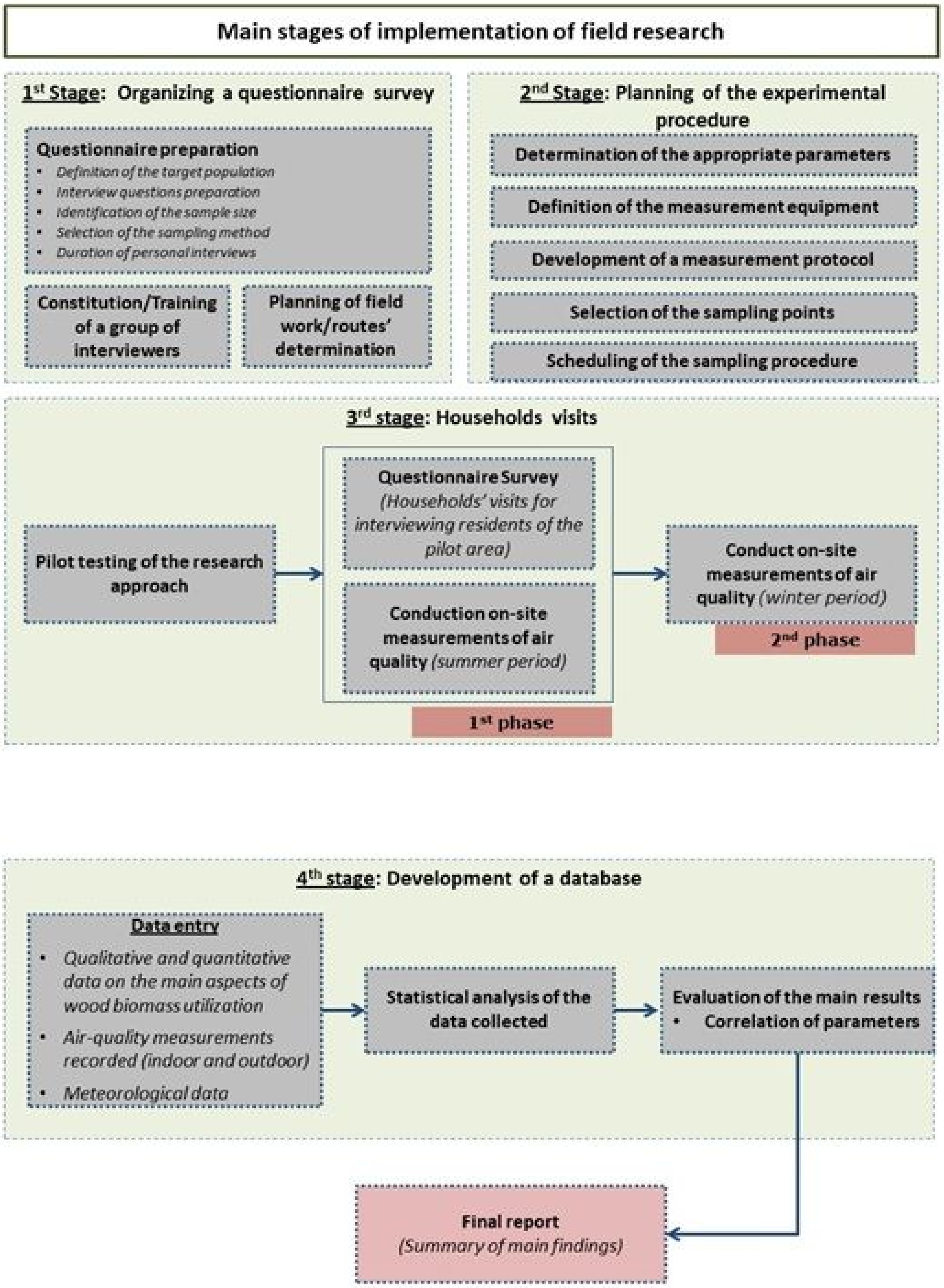


Figure 1

Overview of the methodology

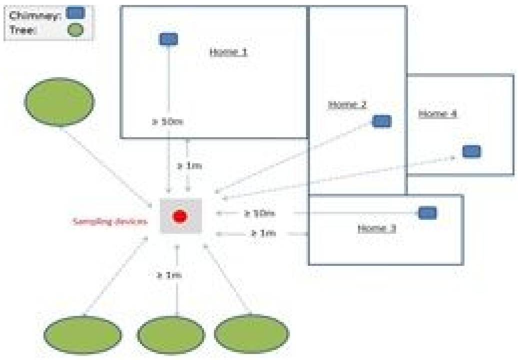


Figure 2

Schematic view of outdoor sample position selection

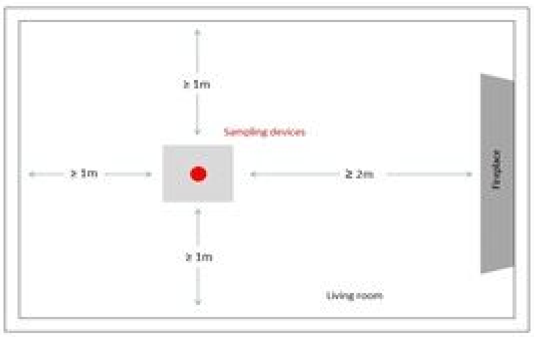


Figure 3

Schematic view of indoor sample position selection

Figure 4

Map of the Anogeia settlement and the open spaces sampling sites

Figure 5

Anogeia settlement and the sampling zones

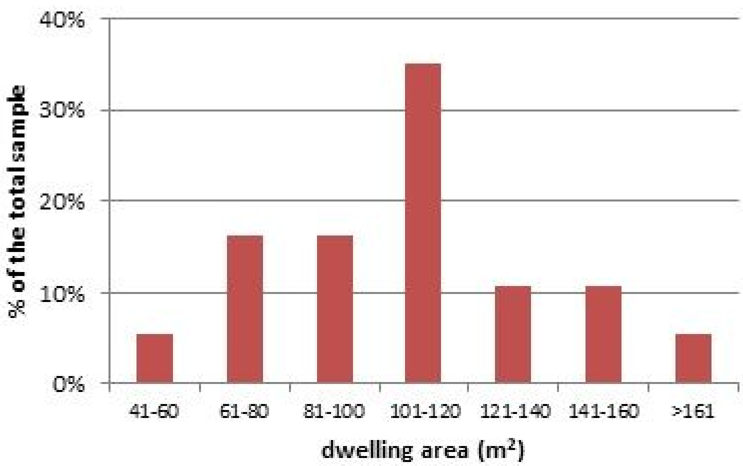


Figure 6

Area (m2) of sampled residences.

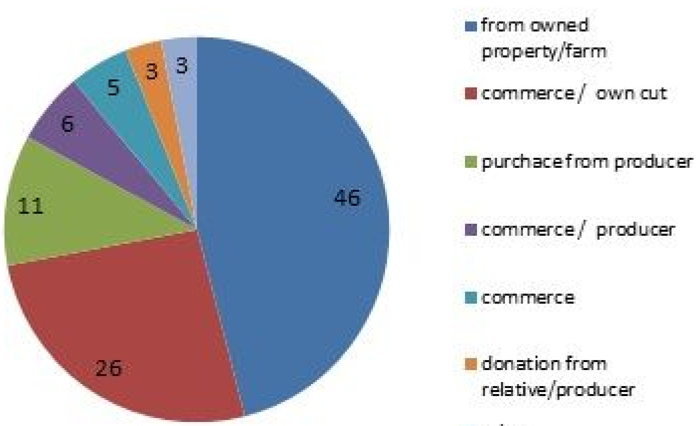


Figure 7

Origin of the biomass used in the Anogeia residences

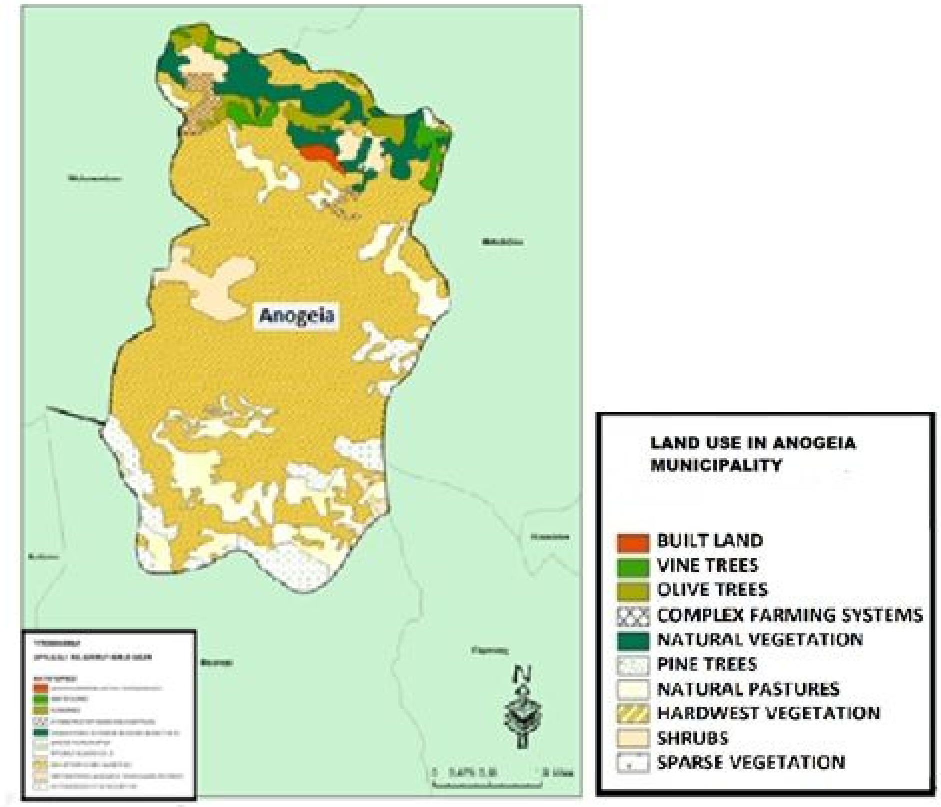
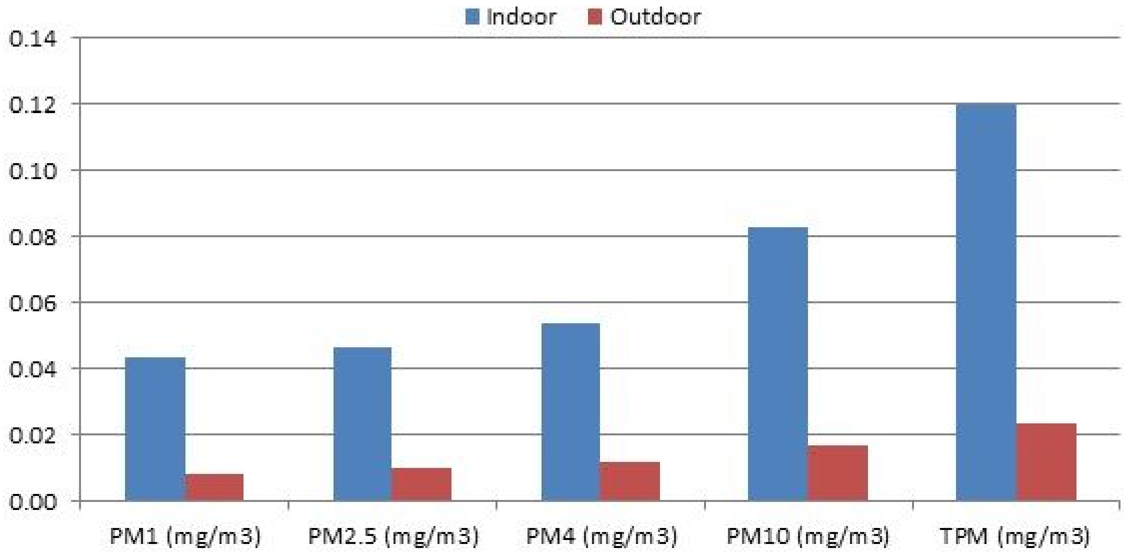


Figure 8

Land use in the Anogeia municipality



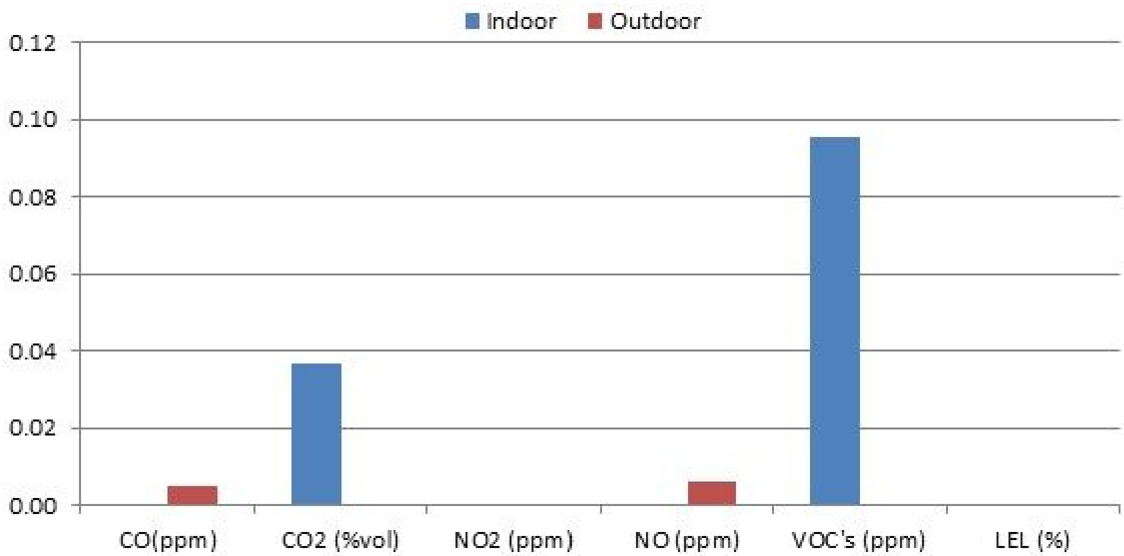


Figure 9

Indoor and outdoor concentrations of air pollution control parameters, (summertime).

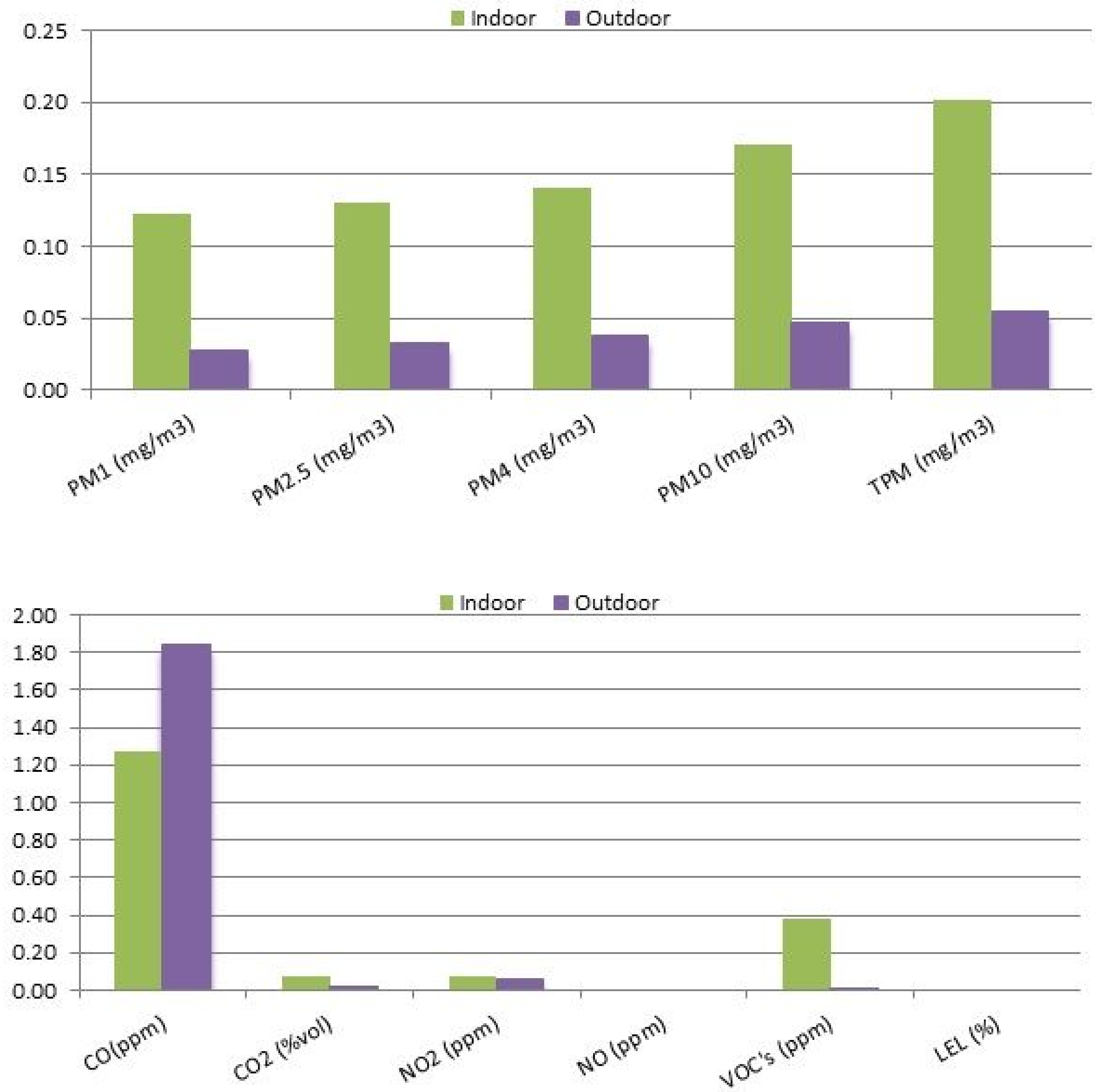


Figure 10

Indoor and outdoor concentrations of air pollution control parameters (wintertime)

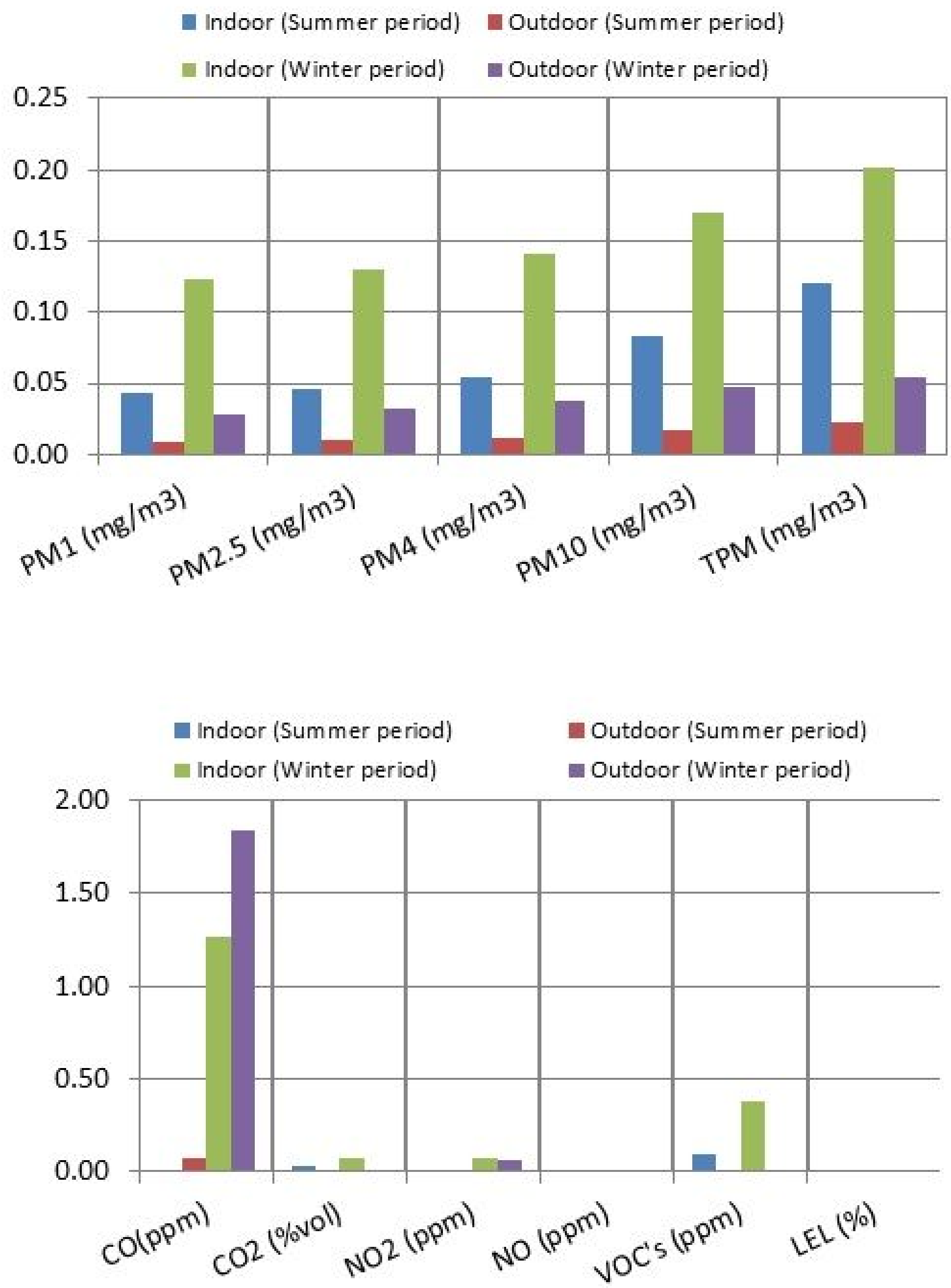


Figure 11

Indoor and outdoor concentrations of air pollution control parameters (summertime and wintertime).