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Experimental Archaeology of Iron Age Firing Structures from the Western Mediterranean

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Within the project "*Transdisciplinary and experimental study of firing structures in the western Mediterranean during Protohistory (1st millennium BC)*", the TRANSCOMB project is an experimental research programme conducted at the *Ciutadella Ibèrica* (Iberian Citadell) of Calafell Archaeological Site (Tarragona, Spain) (See Figure 1 and Figure 2). The main objective of the research is to deepen our knowledge of how Iron Age combustion structures worked and were used by protohistoric communities living in the western Mediterranean. Six hearths and one oven, made with mud and other materials, such as crushed pottery and pebbles, were built inside buildings and outdoors. Later, they were put to use employing diverse types of fuels, while measuring time and temperatures reached under different conditions. Diverse analyses are being applied to samples taken from the experimental combustion structures.

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The TRANSCOMB project

This research project, which started in 2020 and is funded by the Spanish Ministry of Science and Innovation, is led by the Catalan Institute of Classical Archaeology (ICAC) and counts on the participation of about 20 researchers from different institutions. The project aims to analyse Iron Age combustion structures in the north-eastern Iberian Peninsula, the South of France, and the Balearic Islands (See Figure 1). The main aim is to obtain data about the functioning and efficiency of these structures during a range of domestic activities. These activities should have included lighting or heating of the spaces, in addition to food processing and cooking. Other variables explored are the fuels employed, and the management of natural resources related to them (See Figure 2).

food in it) for a long period (at least six hours).

To deepen these questions, the TRANSCOMB project was conceived as a transdisciplinary approach that included the application of diverse techniques of analysis to samples obtained from various combustion structures, both hearths and ovens, from archaeological sites in the study area and period (See Figure 3). We are applying the following techniques:

- Anthracological analyses: study of charcoal remains recovered on the firing surfaces of hearths and ovens or on pavements surrounding them; identification of genus and, if possible, species of woody plants (see Théry-Parisot *et al.*, 2010).
- Study of phytoliths (plant silica micro-remains) and other calcitic microfossils, including faecal spherulites that form in animal guts and can be found in dung, and wood ash pseudomorphs (primarily originating from wood and dicotyledonous leaves). This may allow the distinction between woody and dung fuel remains, or mixtures of both (see Table 1 in Portillo *et al.*, 2021).
- FTIR (Fourier transform infrared spectroscopy) is a technique based on how electromagnetic radiation from the middle infrared (number of waves between 4000-400 cm-1) interacts with materials. Berna *et al.* (2007) used it successfully in archaeological materials, revealing the presence or absence of thermoalteration (see also Saorin, 2018).
- Micromorphology (see Mateu *et al.*, 2019) is the study of soils and sediments in thin sections (in micro-scale) in order to provide information on their in situ composition, formation processes and possible use.
- Chemical analyses of hearths surfaces (see Pecci, 2021). These are aimed at identifying chemical traces of ancient human activities. In the case of hearths, these analyses can help in differentiating those that were used to cook food from those that were used only to make light or heat the rooms, although the use of different kind of combustion material (i.e. dung) could also influence the results of the analyses.
- Experimental archaeology (as detailed in this article)

The types of Iron Age combustion structures

Most combustion structures known from the Iron Age in the Western Mediterranean have common characteristics, particularly the hearths, which always contain an earthen surface for firing (See Figure 4). However, there is a certain variety in the techniques and materials employed in their construction. Some hearths consist simply of an earthen surface built directly on the floor, whilst others are semi-excavated in a shallow pit. The latter can have a preparation layer composed of ceramic fragments (See Figure 4b), pebbles, or a combination of both materials, always placed under the combustion layer, made of mud (Belarte, 2021). Some combustion structures were built with a border delimiting the structure. Mud bricks were also used to build fire installations (Abad and Sala, 1993, pp. 176-177; Chazelles, 1999, p. 59).

Apart from the different materials chosen to build these domestic structures, a variability can also be observed in their morphology. Hearths can be found with a round or oval morphology (See Figure 4b), but they can also be quadrangular, rectangular (See Figure 4a), irregular or semi-circular, with different shapes even occurring on the same site. Ovens are usually elevated on a stone or an earthen plinth and have an earthen vault, although this is not easily preserved or identified in the archaeological record (Belarte *et al.,* 2016).

There is also a certain diversity in the location of all of these combustion structures. They can be inside or outside buildings, or in the common areas of the settlements such as streets, courtyards, or corridors, as well as in a central, lateral, or corner position inside rooms.

Different characteristics, different interpretations

These differences are usually interpreted as resulting from a functional diversity of the structures. Particularly, the presence of a preparation layer (in which pebbles or reused sherds of broken pots are employed) is supposed to improve the efficiency of the hearths, allowing them to reach higher temperatures or keep the heat for a longer period. Obviously, other variables, such as their location (indoors *vs.* outdoors) or the fuels chosen, must have played an important role in this respect. As we have no proof of chimneys or other ventilation systems in protohistoric houses, one often accepted assumption is that the fire was not lit inside the buildings but outdoors, with the embers being moved to a hearth located indoors, for food processing, cooking, or keeping the spaces warm. Combustion structures were built for these daily uses, but some of them were also employed in pyrotechnological manufacture of goods: ceramics, metal (Martín *et al.,* 1999, p. 60, fig. 6.10; González and Ruiz, 2000, pp. 27-28; Guérin, 2003, pp. 18-19; Bonet and Vives-Ferrándiz, 2011, p. 152; Prados *et al.,* 2018, p. 88), as well as other fire-transformed products such as lime and gypsum plaster (e.g. Sanmartí and Santacana, 1992, p. 71; Abad and Sala, 2001, p. 100). Some combustion structures would also have had ritual functions (Bonet and Mata, 2002, p. 39; Guérin, 2003, pp. 17-18; Lorrio *et al.,* 2017, p. 94). Finally, firing installations created for a specific purpose can also be reused for different activities. Further insights into domestic combustion installations and fuel use come from ethnoarchaeological research (e.g. Zapata *et al.*, 2003; Portillo *et al.*, 2017).

The experimental approach

A key part of the TRANSCOMB project involves experimenting with replicas of Iron Age combustion structures for comparative purposes. Although similar works have been carried out and published on occasion for other areas, such as Italy during Later Prehistory (Cattani *et al.*, 2015; Peinetti *et al.*, 2019) or Ancient Egypt (Budka *et al.*, 2019), the use of domestic structures built for combustion purposes during prehistory and protohistory is a topic with a lot of unanswered questions.

Description of the experiments

The experimentation works are being carried out since 2021 at the Iberian Citadel of Calafell, in the coastal town of the same name located in the province of Tarragona, in Spain (See Figure 2). This is a reconstructed Iron Age site, dating from the sixth to the first centuries BC (Pou *et al.*, 2001) (See Figure 5) that is also an experimental archaeology centre and an Open-air Museum member of EXARC since 2007 (See https://exarc.net/members/venues/ciutadella-iberica-es)

The experimental archaeology program began with the construction of six hearths and an oven (See Table 1), located in both outdoor and indoor spaces. Hearths were of different types and locations, according to archaeological data coming from different sites (Belarte, 2021, pp. 258-259). Indoor structures were as follows:

1. One quadrangular hearth, much bigger than the other hearths, with a thick mud border (20 cm width and 11 cm high), mud bricks inside (ten complete blocks of about 28 x 13.5 x 10 cm and some fragments), composing an elevated platform covered by mud mortar. The interior area of the structure measured 55 x 80 cm (116 x 120 cm if we count the border) (Hearth 1, see Figure 9)
2. One semi-excavated quadrangular hearth of about 50 x 50 cm, attached to the wall and under a small opening, with a preparation layer of sherds and an earthen border with vegetal temper, of 6-7 cm high (Hearth 2, see Figures 1 and 10b)
3. One oval hearth with a preparation layer of pebbles, measuring 63 x 57 cm in plan, next to the door (Hearth 3 (See Figure 6)
4. One hearth in the centre of another room, elevated, of an almost trapezoidal plan, border of mud and both a pebble and a sherd preparation layer (Hearth 6). Its internal dimensions are 45 x 31 cm; total measures including the border are 63 x 51 cm. The border has a width of 9 cm; it is 6-8 cm high.

On the other hand, outdoors structures are as follows:

1. An oval hearth with a flat earthen surface attached to a low wall (Hearth 4, see Figure 8a), measuring 80 x 60 cm, and
2. A hearth with a rectangular structure of 72 x 52 cm, also only earthen made, but semi-excavated (Hearth 5, see Figure 8b and 10a).

All these firing structures (both indoors and outdoors) had an earthen combustion surface.

The oven is a mud-brick, outdoor, vaulted structure of oval plan (with diameter between 1m and 1,15 m, and a total high of 60 cm), plastered with earth (See Figure 7), with two openings: one a frontal oven door, the other on the top.

Combustion structures	Building conditions	Measures	Shape	Features	Preparation layer	Location	Fig. in the text
Hearth 1	Rebuilt from a previous replica of an archaeological structure	116 x 120 cm	Quadrangular	Already had an earthen border of 20 x 11 cm. Mudbrick infill	Mudbrick infill	Indoors	Figure 9
Hearth 2	Built from scratch	50 x 50 cm	Quadrangular	Excavated in a shallow pit of 6-7 cm in depth. Earthen border with vegetal temper (barley straw)	Ceramic sherds	Indoors	Figures 2, 10b
Hearth 3	Built from scratch	63 x 57 cm	Oval	Excavated in a shallow pit of 8 cm in depth	Pebbles	Indoors	Figures 6, 10c
Hearth 4	Built from scratch	80 x 60 cm	Oval	Directly on the ground, earthen layer of 1.5 cm	None	Outdoors	Figures 8a, 10d
Hearth 5	Built from scratch	72 x 52 cm	Rectangular	Excavated in a shallow pit of 7 to 15 cm in depth	None	Outdoors	Figures 8b , 10a

Hearth 6	Rebuilt from a previous replica of an archaeological structure	63 x 51 cm	Quadrangular	Already had an earthen border of 6-8 x 9 cm	Pebbles and ceramic sherds	Indoors	-
Oven	Rebuilt from a previous replica of an archaeological structure	150 x 60 cm	Oval ground plan, vaulted	Mudbrick structure, covered with mud mixed with vegetal temper (Barley straw)	None	Outdoors	Figure 7

TABLE 1. COMBUSTION STRUCTURES AND THEIR CHARACTERISTICS USED IN THE EXPERIMENTAL ARCHAEOLOGY PART OF THE TRANSCOMB PROJECT.

The objective of the construction of these replicas was to determine if there was a correlation between the typology of the structure and different variables such as the temperatures reached or the duration of the heat, as well as to compare if any changes were detected when different fuels were used. We repeated the firing of the hearths numerous times during this first stage of the project. Although we had already obtained data with the first combustions, we were interested in comparing the efficiency and duration of the fire and temperatures reached with the different fuels. We also wanted to evaluate the alterations of the microstructure of the hearths after several combustions. The project is still continuing and this will allow us to have better quality data to compare with that obtained from the analyses of archaeological hearths.

The building and preparation of the structures were carried out during two working days at the beginning of May 2021. The first fire testing of the structures took place in mid-June and lasted five days, followed by a second testing of five days conducted in the middle of November. Before lighting the structures, samples of the earth layer were recovered in all cases for infrared spectroscopy and also as controls for other analyses (microfossil, chemical analyses). Experimental firing included the use of various fuel types (mainly oak and pine wood, pine cones, barley straw and weeds, wild grasses, and palm leaves, in addition to sheep and cow dung) (See Figure 8 and Table 2), based on the available archaeobotanical records obtained through previous analyses of archaeological combustion structures in the study area (wood charcoal and plant and faecal microfossils). For each combustion, the total amount of each fuel material was weighed.

We boiled water as well as cooked different products (legumes, animal bones) in replicas of hand-made Iron Age cooking pottery, expressly produced for the experimental program. We expected that preparing meals would leave traces of organic substances that could be identified through the analysis of chemical residues of samples of experimental hearths and pavements. Results of these analyses could serve as comparative reference material for the study of archaeological structures.

Fire structure	Comb. nº	Fuel	Weight of fuel (g)	Duration of the combustion	Highest Temperature On combustion surface / In the flames	Weight of ash + charcoal remains (ChR) (g)	Date
Hearth 1	1st	Wood, palm leaves, straw, grasses	12.481	8h	598°C / 756°C	294 + 1.532	16/06/2021
	2nd	Oak wood, pine cones	11.380	more than 7h	684°C / 785°C	No records	18/06/2021
Hearth 2	1st	Oak wood, branches, palm leaves, pine cones	6.923	more than 9h	523°C / 805°C	374 + ChR	15/06/2021
	2nd	Cow dung, pine branches, straw	10.004	more than 9h30min	379°C / 372°C	305	16/06/2021
	3rd	Cow dung, pine branches, barley straw	2.550	5h15 min	330°C / 756°C	762	10/11/2021
	4th	Oak wood, pine and oak branches, pine cones, straw	8.585	more than 18h	717°C / 780°C	317	11/11/2021
	5th	Cow dung, straw	1.030	6h	477ºC / 788ºC	534	12/11/2021
Hearth 3	1st	Oak wood, pine branches,	7.806	more than 8h30min	450°C / 779°C	374 + ChR	16/06/2021

		pine cones, palm leaves					
	2nd	Sheep dung, pine branches, straw, palm leaves	3.845	more than 8h30min	295°C / 706°C	1474	17/06/2021
Hearth 4	1st	Oak wood, pine branches, straw	10.505	6h	572°C / 754°C	360 + ChR	14/06/2021
	2nd	Oak wood, pine branches, pine cone, straw	5.984	1h15min	754°C / 805°C	140 + 970	15/06/2021
	3rd	Sheep dung, pine branches, straw	2.632	2h15min	522°C / 660°C	211 + ChR	16/06/2021
	4th	Oak wood, pine branches, pine cones, straw	12.285	more than 12h	759°C / 817°C	211	17/06/2021
	5th	Oak wood	No records	No records	No records	No records	17/06/2021
	6th	Cow dung, pine branches, pine cones, straw	1.780	5h30min?	404°C / 656°C	603	09/11/2021
	7th	Oak wood, branches, straw	2.175	more than 6h30min	579°C / 745°C	126 + 280	12/11/2021
Hearth 5	1st	Oak wood, palm leaves, grass	5.908	2h15min	550°C / 686°C	385 + ChR	14/06/2021
	2nd	Oak wood, pine cones, palm leaves, grass	7.403	2h40min	759°C / 758°C	575 + ChR	15/06/2021

	3rd	Cow dung, pine wood, pine cones, grass	2.160	5h45min	458°C / 725°C	484 + ChR	16/06/2021
	4th	Oak wood, palm leaves, straw	2.476	more than 12h	139°C / 507°C	720 (ash + *quercus* fragm.)	09/11/2021
Hearth 6	1st	Embers, wood	211 + 2 wood fragm.	more than 3h	437°C / 828°C	455 + ChR	17/06/2021
Oven	1st	Oak wood, branches, pine cones	7.788	7h	887°C / 856°C	No records	17/06/2021
	2nd	Oak wood, branches, pine cones	16.653	7h30min	490°C / 85°C	No records	18/06/2021
	3rd	Oak wood, pine cones, pine branches, straw	7.765	more than 12h	761°C / 800°C	660 + ChR	10/11/2021
	4th	Sheep dung, branches, pine cones, straw	4.479	8h	326°C / 684°C	664 + 2.857	11/11/2021

TABLE 2. SUMMARY OF THE EXPERIMENTAL COMBUSTIONS, WITH FUEL, DURATION OF THE COMBUSTION, MAXIMUM TEMPERATURES REACHED, AND DATE. THIS LAST VARIABLE IS IMPORTANT TO COMPARE THE FUEL BEHAVIOUR IN DIFFERENT WEATHER CONDITIONS (ELABORATED BY THE AUTHORS).

Most of the structures were exposed to several complete combustions, changing the fuels employed from one to another (See Table 2). During the firing period in June, we achieved 17 complete combustions, and we included eight new combustions in November. This produced the following results:

- seven combustions in Hearth 4
- five combustions in Hearth 2
- five combustions in Hearth 4
- five combustions in the Oven
- two combustions in Hearths 1 and 3
- one combustion in Hearth 6

All them were aimed at comparing the functioning of these structures within different climatic conditions, as well as to increase the data collection through new firing episodes.

The methodology of data recording was the same for all the firings. Time and temperature measurements along with firing activities, occurring between the initial fire lighting and the end of the combustion were recorded using two different types of portable thermometers (See Figure 9a). We used three K-type thermocouple pyrometers[1] with a detector placed within the burning fuel, to measure the temperature of the combustion surface (See Figure 9b). These pyrometers automatically record the temperatures at predetermined regular intervals. We programmed the pyrometer to record data every two minutes since the moment of the lighting and until the temperature was stabilised; then we reprogrammed the measurements to record temperatures every ten minutes. Simultaneously, we also employed two infrared pyrometers[2] to measure specific points within the flames and later the embers (looking for the highest temperature), in addition to the temperature of the oven walls, the surface of ceramic pots, and lids and the contents. The intervals between the measurements have been the same as with the K-type ones.

After each combustion, the fuel remains (both ashes and charcoal, in addition to partially burned plant and dung remains) were weighted and collected for integrated macrobotanical and microfossil analyses (See Figure 10a). Also, the systematic collection of samples for infrared spectroscopy (See Figure 10b) and biochemistry (See Figure 10d), and the extraction of blocks of the structures for thin section micromorphology (See Figure 10c) were carried out. After the samplings, the hearths have been repaired with a new layer of mud. They are thus ready for new experiments.

Results

Overall, this represents initial experimental records which provide an orientation for future research, and better interpretation of the archaeological data and taphonomical issues. Nevertheless, several considerations can be advanced:

All the structures have turned out to be functionally efficient, independent of the construction technique, fuel type and location. Hearths of different typologies and with different locations (indoors/outdoors) keep the necessary heat to maintain a pot with boiling water (and food in it) for a long period (at least six hours). In some cases, it was necessary to add fuel in order to heat the water over 100 ºC. Once the water was boiling, the temperature was usually stable for hours, but occasionally some fuel additions were needed. The total amount of fuel necessary to boil water for six hours varied from one hearth to another, ranging from 7 to 12 kg and combining different materials as fuels.

Thermo-alteration in the firing surface of each structure was visible after the first combustion, and their central area becomes reddish or grey-black. After each combustion, these changes of colour of the earthen firing surface were more visible (See Figure 10).

The differences of the construction technique, and more particularly the preparation layer under the combustion surface, do not result in gaining higher temperatures or keeping it for a longer period.

The location of the hearth and the air circulation are key points in fire lighting and management. In outdoor structures, fire should not be directly exposed to air streams that could make it unstable. In indoor fire installations, the existence of an aperture such a small window over the fire can function as a flue and help to evacuate the smoke; however, a side aperture (e.g. an open door) may provoke an increase of the smoke inside the room. Two hearths were lit inside a house, one under a window and the other next to the open door. The lighting of the first one produced smoke during the first minutes, then the smoke left easily through the window. On the contrary, in the second case the air stream between the open door and the window provoked much more smoke, and it did not evacuate through the window.

Animal dung (that of both cow and sheep have been tested) has excellent properties as a fuel source since it can burn for longer than wood when it is completely dried. However, generally speaking, the temperatures of the combustion surfaces are not as high as when wood is used as fuel. Also, the climatic conditions, especially the relative humidity, clearly affect dung properties as fuel. The results of burning dung in June or in November were different in terms of temperatures reached or stability of fires (See Figure 11a and 11b), due to different weather conditions. In November, the weather was rainy during the previous week and also during the experimental works. RH was 75%, and the medium temperature was 14.1 °C (compared to 59% of RH and 30 °C most of the days in June)[3] . As a result, if the dung was not dry enough, it was difficult to reach temperatures as high as those obtained with wood. As an example of this, it was not possible to get water to boil after hours of combustion using fuel in a hearth built indoors. Comparison of charts 11a and 11b allow to see the different temperatures obtained in the same hearth (Hearth 5, located outdoors) in June and in November, using in both occasions dung as main fuel, with a similar weight and without adding fuel during the combustion.

In general, maximum temperatures reached in all the structures were higher in June than in November. This was particularly noticeable in the case of the oven (See Figure 12 and Table 2), that in June reached a temperature as high as 850 ºC whilst in November the maximum temperature was of 760 ºC with wood and slightly over 300 ºC with sheep dung.

Also, in November, we were able to appreciate that on wetter days outdoor hearths did not keep the temperature for as long as indoor structures, using the same fuel type.

The different interdisciplinary analyses (macrobotanical and microfossil analyses, infrared spectroscopy, biochemistry and thin section micromorphology) of the experimental hearths and oven are still in progress, and we expect that the obtained results and the comparison with those coming from archaeological structures will contribute to a better knowledge of the functioning of these installations. They also will allow us to confirm the accuracy of the methodology of study of the archaeological combustion structures.

Systematic records from experimental combustions as conceived and applied within this project are much-needed to deepen the knowledge of construction, use and maintenance of combustion structures, fuel management and use, and activities related to fire installations. This kind of approach, which includes a collaborative network through which diverse specialists such as bioarchaeologists, geoarchaeologists, and staff at an experimental archaeology centre exchange knowledge, has no precedents for this area and period.

Further experimental combustions are still needed to complete the records and refine the interpretations. Nevertheless, the implementation of this project is in itself a significant achievement.

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1 Two pyrometers Data Logger Hibok 18, and one pyrometer TM-934S.

2 PCE-889B.

3 Data from the meteorological station located at Cunit, 5 km from Calafell. Source: Catalan Service of Meteorology (www.meteo.cat).

Keywords furnace, kiln or oven
fuel

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FIG 1. MAP OF THE STUDY AREA WITH THE LOCATION OF THE CIUTADELLA IBÈRICA DE CALAFELL ARCHAEOLOGICAL SITE AND OTHER SITES MENTIONED IN THE TEXT: 1) MAS CASTELLAR (PONTÓS, GIRONA), 2) SEBES (FLIX, TARRAGONA) AND 3) MOLÍ D'ESPÍGOL (TORNABOUS, LLEIDA). (MAP ELABORATED BY AUTHORS; BACKGROUND MAP USED WITH PERMISSION BY ITS AUTHOR, H. BOHBOT)

FIG 2. ONE OF THE EXPERIMENTALLY BUILT COMBUSTION STRUCTURES IN USE (HEARTH 2).

FIG 3. TAKING SAMPLES FROM A COMBUSTION STRUCTURE IN THE ARCHAEOLOGICAL SITE OF MAS CASTELLAR (PONTÓS, GIRONA, SPAIN).

FIG 4. A. HEARTH BUILT IN A SHALLOW PIT FILLED WITH EARTH, FROM THE SETTLEMENT OF SEBES (FLIX, TARRAGONA, SPAIN). B. HEARTH WITH A PREPARATION LAYER OF POTTERY FRAGMENTS, FROM THE SETTLEMENT OF MOLÍ D'ESPÍGOL (TORNABOUS, LLEIDA, SPAIN) (PHOTO: JORDI PRINCIPAL).

FIG 5. THE RECONSTRUCTED IBERIAN CITADEL OF CALAFELL. A. VIEW OF ONE OF THE STREETS. B. DOOR AND THE INSIDE OF ONE OF THE HOUSES.

FIG 6. THE PROCESS CARRIED OUT TO BUILD HEARTH 3: A. PERIMETER. B. SHALLOW PIT EXCAVATED. C. LAYER OF PEBBLES. D. FINAL MUD SURFACE.

FIG 7. THE OVEN, BEFORE (A) AND AFTER (B) BEING REPAIRED AND REPLASTERED FOR THE EXPERIMENTAL ARCHAEOLOGY PROJECT.

FIG 8. COMBUSTIONS MADE WITH DIFFERENT FUELS. A. WOOD USED IN HEARTH 4. B. DUNG USED IN HEARTH 5.

FIG 9. TEMPERATURE MEASUREMENTS. A. MEASURING TEMPERATURES IN HEARTH 1, WITH TWO TYPES OF DEVICES. B. PLACING THE DETECTOR OF A K-TYPE THERMOCOUPLE IN HEARTH 4.

FIG 10. SAMPLES TAKEN AFTER COMBUSTION. A. OF FUELS FOR MACROBOTANICAL AND MICROFOSSIL ANALYSES IN HEARTH 5. B. OF SEDIMENT FOR INFRARED SPECTROSCOPY AND BIOCHEMISTRY IN HEARTH 2. C. FOR THIN SECTION MICROMORPHOLOGY. D. FOR BIOCHEMICAL ANALYSES.

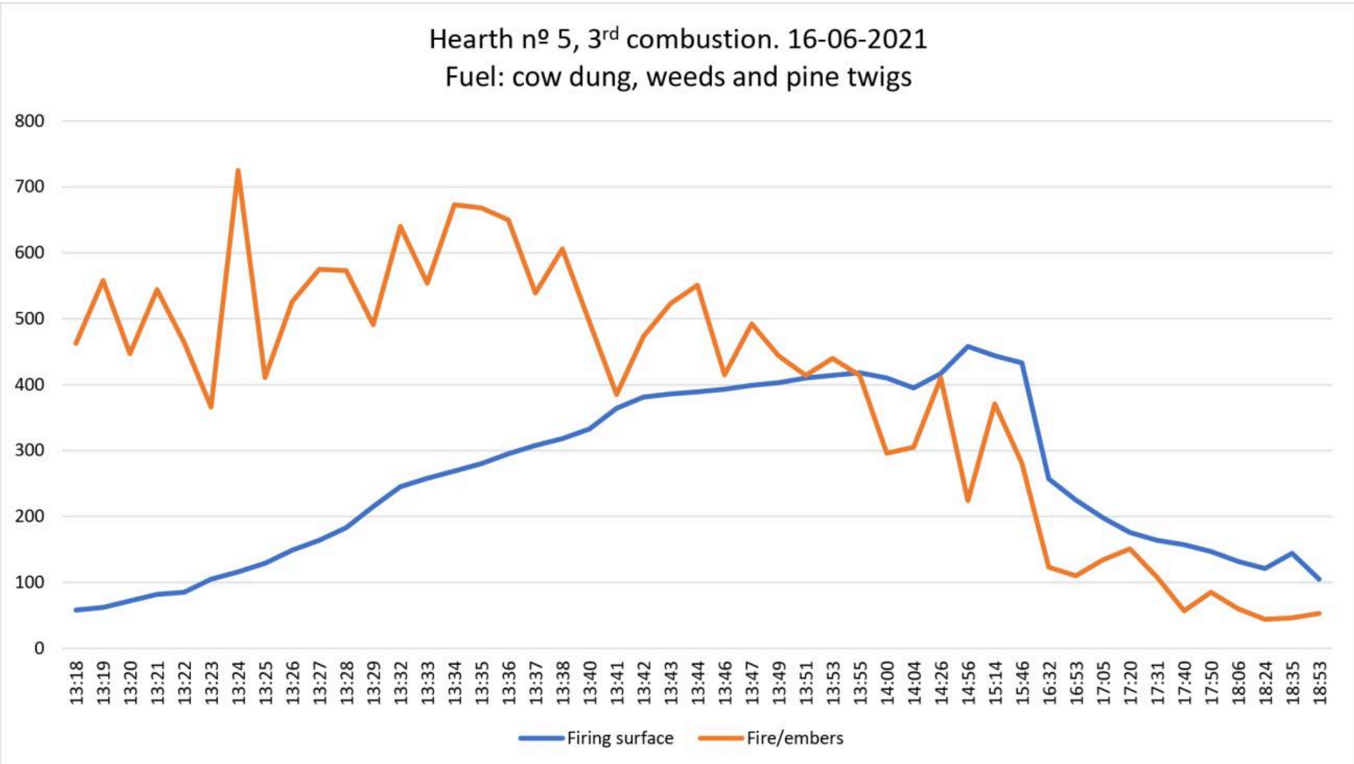

FIG 11A. LINE CHARTS COMPARING COMBUSTIONS USING DUNG, IN JUNE. TEMPERATURES ARE EXPRESSED IN ºC IN THE Y AXIS; THE X AXIS SHOWS THE TIME IN HOURS AND MINUTES.

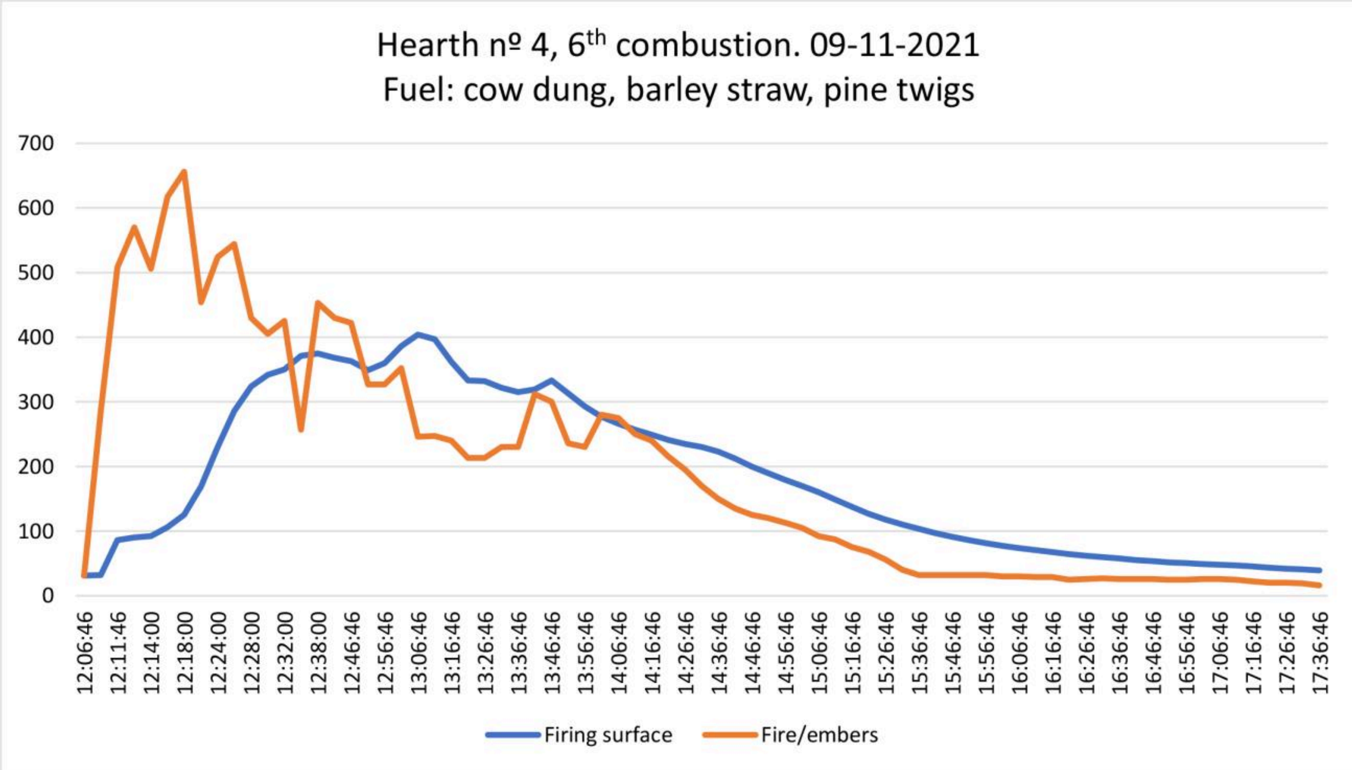

FIG 11B. LINE CHARTS COMPARING COMBUSTIONS USING DUNG, IN NOVEMBER. TEMPERATURES ARE EXPRESSED IN ºC IN THE Y AXIS; THE X AXIS SHOWS THE TIME IN HOURS AND MINUTES.

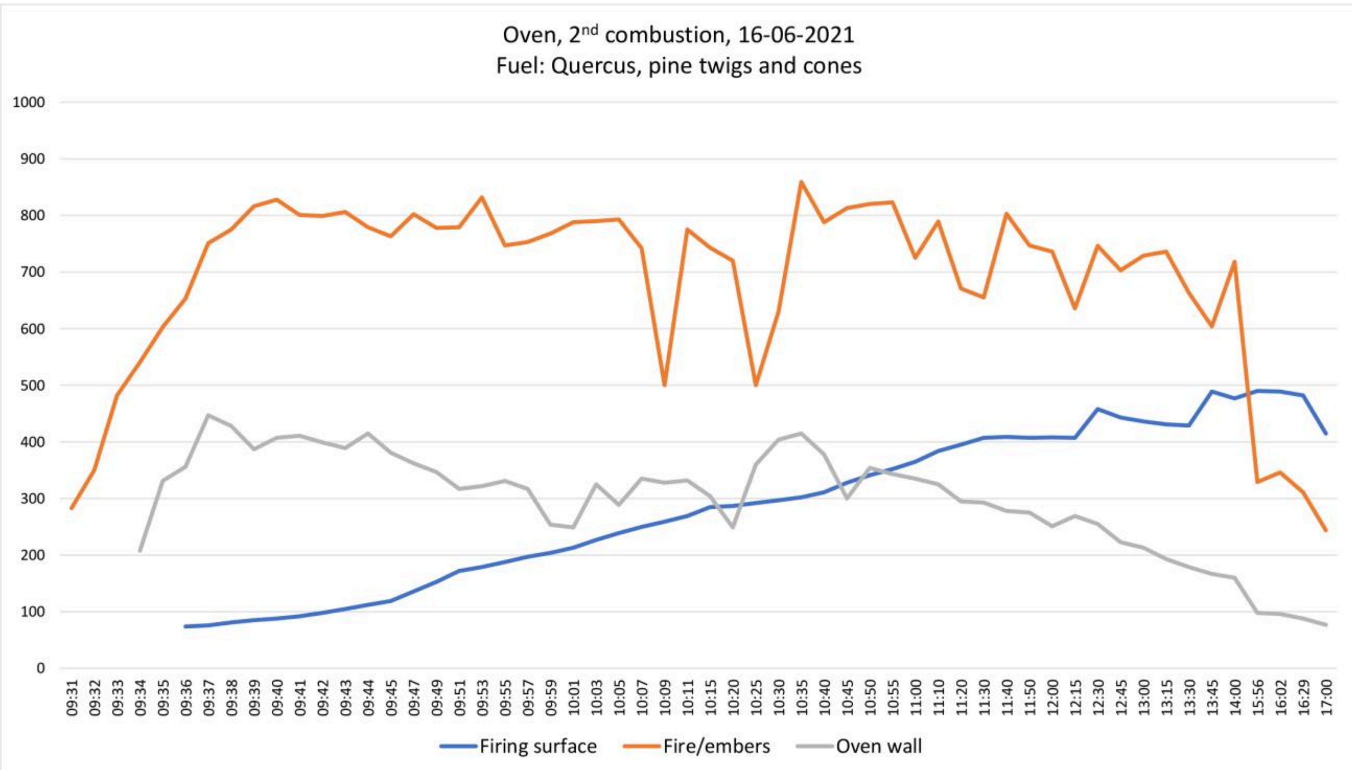

FIG 12A. LINE CHARTS COMPARING TWO COMBUSTIONS OF THE OVEN IN JUNE. TEMPERATURES ARE EXPRESSED IN ºC IN THE Y AXIS; THE X AXIS SHOWS THE TIME IN HOURS AND MINUTES.

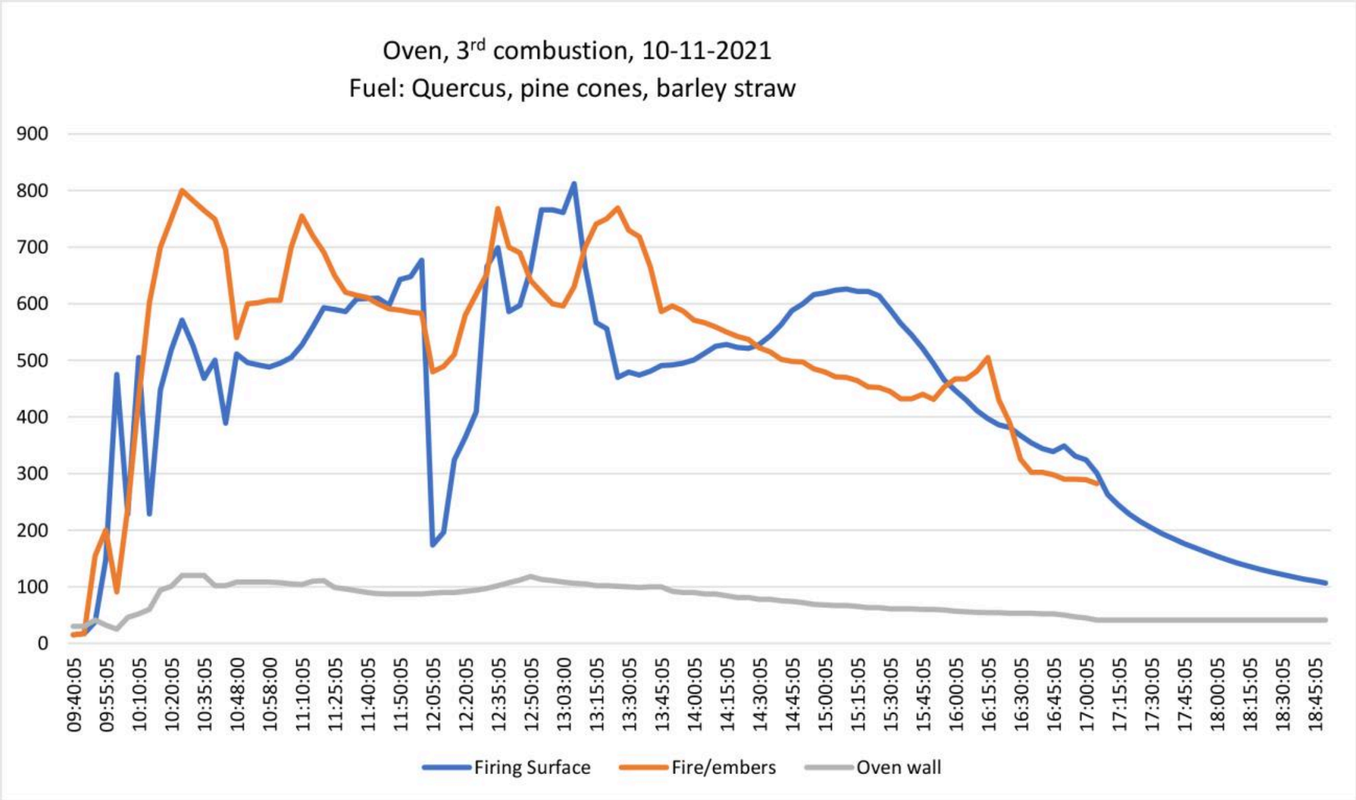

FIG 12B. LINE CHARTS COMPARING TWO COMBUSTIONS OF THE OVEN IN NOVEMBER. TEMPERATURES ARE EXPRESSED IN ºC IN THE Y AXIS; THE X AXIS SHOWS THE TIME IN HOURS AND MINUTES.