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Reviewed Article:

Experiment with Kindling Oil Lamps

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This article deals with the daily technology of ceramic oil lamps from the period of the 1st century AD until the first half of the 7th century AD. The questions underlying in this article include the following: How long did combustion take and what was its intensity? Were wicks pulled and when? Was the oil poured into an already-burning lamp to increase the burning time, as Dr. Amar Zohar, of Bar Ilan University suggests? If so, how was this done? And a last question: Were the ceramic lamps used for Hanukah and Shabbat?

For the experiment, I chose ceramic lamps from the 1st century AD and a type of early Islamic ceramic lamp dated to the first half of the 8th century AD. For kindling material, I used non-

distilled olive oil, castor oil, and linseed oil. Notably, olive oil was the most widely used oil in the Levantine region during the selected historical period. However, this oil was expensive, which is why poor people used castor oil (Bouras and Parani, 2008, p.3). I used cotton and flax as material for wicks. All weight measures and measures of light intensity were conducted with calibrated kitchen scale brand EC403 and a digital lux meter brand HP-881B, respectively. The experiment was documented with video and photos, and all the data was recorded into a table. The experiment was conducted indoors for health and safety reasons.

> The above shows that in the history of research on the problem of using and kindling oil lamps, only few experiments were conducted and although they did provide some answers, they also raised several new ones such as, what is the connection between the length of the wick, the material it is made from, and its burning time, and also, what is the relationship between oil capacity and burning time? Here we attempt to answer these two questions.

Preface

Fire has an important role in human history not only as a source of light and heat but also as having an ideological meaning of "purity", "cleansing", "death" and "life". Consequently, one question that archaeologists ask when they discover a ceramic or glass lamp is: "*What is the purpose of this lamp?*" Other questions that are interesting for archaeologists include: "*How long does the lamp provide lighting?*" and "*Does it require pulling out the wick?*" These answers can help us distinguish if a lamp is part of a religious ceremony, such as "*Kabalat Shabbat*" or "*Chanukah*". This is the primary reason for writing this article. The second reason is that in the world of academic research only a few studies in Europe and Israel have dealt with the kindling of ceramic oil lamps.

Before the description of the experiment itself, a few words are necessary concerning the ceremonial use of lamps and the history of the research on this issue. Two groups of academic studies have experimented with kindling oil lamps: Israel academic researches and European academic works.[1]

One of these studies, by Amar (*Wherewith may kindle?*, 2003) describes an experiment similar to the one conducted here, which was conducted in room conditions in order to answer such questions as to why, in the text of Mishna, part Shabbat, do the Sages emphasize the prohibition on using specific types of plants and flowers and some types of oils for lighting the Sabbath or Chanukah lamps? The results of that experiment, were rather controversial, and one purpose of my experiment was to confirm or refute Amar's results. Amar did not use linseed oil during his experiment, as he did not focus on the relationship between the length of the wick and its burning time, choosing instead the relationship between wick and quality of combustion. Einat Ambar-Armon (Bar-Ilan University, Vol. I, 2007) devoted part of her dissertation to the experiment of

kindling ceramic lamps from Maresha, Israel, and describes in detail her experiment and its results.

Both of these experiments are based on Neuburger's classical work about the kindling of ancient ceramic lamps. Neuburger (1930) experimented with kindling in order to confirm Philon's of Byzantium description regarding how it was possible to extend the burning time of a lamp. It is difficult understand from Neuburger's work if this experiment was successful or not. But he provided adescription and understanding of Philon's lamp and how it worked. According to Philon's description and Neuburger explanation, in the Philon's lamp, the physical law of atmospheric pressure was applied to increase the burning time. In Philon's lamp was a tube "*with a lateral hole*." (Neuburger, 1930, p. 241). This tube stands vertically in the center of the lamp's body and is filled with oil. Neuburger writes that oil "*reaches above the hole of the tube, the upper part of which is surrounded by reservoir containing the reserve supply*". (Neuburger, 1930, p. 241) At the bottom of lamp's reservoir, according Philon and Neuburger, were two lateral orifices. One was from one side and the second from other side. Neuburger writes that according to "*a simple physical law of atmospheric pressure, the oil can flow out of these orifices, but only if the external atmospheric pressure acts on the surface of the liquid in the reservoir*". (Neuburger, 1930, p. 241). This was similar in Amar's experiment, but an egg and extra vessel were used there, connected by faith to the main vessel. The basis for this option was the text of the Mishna on Sabbath's lamps.

The above shows that in the history of research on the problem of using and kindling oil lamps, only few experiments were conducted and although they did provide some answers, they also raised several new ones such as, what is the connection between the length of the wick, the material it is made from, and its burning time, and also, what is the relationship between oil capacity and burning time? Here we attempt to answer these two questions. But first, we present an explanation of the oils and materials from which wicks were made for oil lamps in the Roman and Earlier Byzantine periods.

According to Bouras and Parani (2008), all known types of vegetable oils were used in the Roman and Early Byzantine periods, including olive oil, castor oil, and linseed oil. Olive oil was the most popular and produced the clearest light. Usually olive oil was used for religious ceremonies, but it was also used by the nobles for illumination. According to Bouras and Parani (2008), olive oil was expensive, so poor people used castor oil for combustion, which was cheaper because of its strong odor. The situation with wicks for oil lamps was similar: cotton and flax wicks were expensive, while wicks from papyrus were cheaper. Besides cotton, flax and papyrus, wicks were also made from wool. Cotton, flax, wool, and papyrus were all used in the Middle East, and these materials were the most common fuel in this region during the Roman and Early Byzantine periods. The most popular materials were wool and cotton, while flax was more commonly used as fuel material in the Western part of the Roman world. On this background, the results of our experiment can now be presented.

Methods

For this experiment various measuring instruments were used alongside, ceramic lamps, and three types of oil and two types of materials for wicks. The experiment was recorded in a notebook and documented with a video and camera.

The measuring instruments

As measuring instruments in the experiment, we used a plastic ruler, a calibrated kitchen scale brand EC403, a caliper, and a digital lux meter brand HP-881B for measuring illumination. As the kitchen scale cannot measure capacity, we provide here only the weight of the clay lamps as measured when empty, when filled with oil, and after burning. The caliper was used to measure the width, height, length, and diameter of the filling hole and nozzle. A lux meter was used to measure illumination level. The term "*lux*" in Latin means "candle", "lighting". Notably, in addition to the lux meter, visual perception was used to estimate illumination, and therefore the results should be regarded as approximate and subjective.

Three types of oil and three types of wick material

Three types of oil were used in this experimental work: castor oil, flax seed oil and olive oil. All three types of oil are cold pressed. Modern cold pressing is as close as possible to the technology of oil pressing that was prevalent in the Hellenistic, Roman, and Early Byzantine periods. Cotton and a piece of linen (flax) cloth were used as material for the wick, which is the best I was able to find, as the technology to fabricate linen cloth and cotton has changed; the current materials are close but not identical. Consequently, I also used hemp as a material for wicks.

Ceramic oil lamps

In this experiment, three types of lamps were used, from the Herod the Great (king of Judea at 40-4 years BC) period, Roman-Early Byzantine period (1st BC-AD 7th centuries) and Early Muslim period (8th to 9th centuries AD) at Israel history. The body of the lamps of the Herod the Great epoch and the Roman epoch were made with the help of a wheel, but in the case of the lamps of the Herod the Great epoch, after the lamp's body was made, a nozzle was added on. On the other hand, the Early Muslim lamps were made using molds (See Figure 11). These are the differences between the three types of lamps that were used in the experiment.

For the experiment, six lamps with different capacities were used, and each lamp was numbered as follows: The Roman clay lamp was number 6 (Figure 10); the early Muslim lamps were assigned numbers: 1 (Figure 5), 2 (Figure 6), 4 (Figure 8), and numbers 5 (Figure 9), 3 (Figure 7) were given to the lamps from the epoch of Herod the Great. Additional

characteristics of the lamps are presented in Table 1. Notably, in this experiment we used only lamps with one nozzle.

Model	Filing hole diameter	Wick hole diameter	Nozzle angle	Nozzle length	Lamp height	Lamp length	Cubic capacity	Weight
1	1.3 cm	0.6 mm	≈14°	≈3.8 cm	2.4 cm	7 cm	89 ml	65 gr
2	1.7 cm	0.7 mm	15°	≈4.1 cm	2.6 cm	8.3 cm	123 ml	101-102 gr
3	2.1 cm	1 cm	19°	2.5 cm	2.8 cm	7.4 cm	106 ml	83 gr
4	1.5 cm	0.6 mm	≈20°	≈4cm	2.6 cm	7.5 cm	119 ml	98 gr
5	2.3 cm	0.8 mm	30°	3 cm	3.2 cm	8.5 cm	196 ml	127 gr
6	2.4 cm	0.8 mm	26°	2 cm	3.2 cm	6.5 cm	127 ml	80 gr

TABLE 1: OIL LAMPS BASIC DATA.
NOTES: *LAMP NUMBER 1*—EARLY MUSLIM LAMP (7TH TO 9TH CENTURIES AD); *LAMP NUMBER 2*—CLAY LAMP OF HEROD THE GREAT EPOCH (1ST CENTURY BC TO 2ND CENTURY AD); *LAMP NUMBER 3*—EARLY MUSLIM LAMP (7TH TO 9TH CENTURIES AD); *LAMP NUMBER 4*—EARLY MUSLIM LAMP (7TH TO 9TH CENTURIES AD); *LAMP NUMBER 5*—CLAY LAMP OF HEROD THE GREAT EPOCH (1ST CENTURY BC TO 2ND CENTURY AD); *LAMP NUMBER 6*—ROMAN CLAY LAMP (1ST TO 2ND CENTURIES AD)

The living room size and plan

The living room plan

The experiment was conducted in a regular living room, commencing a series of experiments on potential illumination in different habitats: villa, temple, public building, catacombs, caves, burial caves, to try to answer how many lamps were required to illuminate a certain, closed space?

Today's dwellings are not so different from ancient living rooms or dining rooms. The living room plan presented below (See Figure 1), has a rectangle shape with a size of 2.32m X 3.93m, for a total living area of 9.12 square meters. The room has two small nightstands, one big nightstand and two windows. The layout does not indicate the location of the living room relative to the external world, since the experiment was conducted inside the home and did not consider the wind, which may have affected the burning time.

The location of the lamps during the experiment

As seen in the lamp location plans (See Figures 2, 3 and 4), each time the lamps were in different places in the room. However, the intensity of light was measured identically each time, with a lux meter.

Results

The experiment was conducted three times and each time results obtained were very similar. The results of the experiment are summarized below in Table 2 and Table 3. The first table shows the relationship between wick burning time and wick length and material. The second table shows the relationship between burning time, oil type, and lamp capacity.

Lamp (number)	Wick material	Wick length outside of the lamp	Wick soak time	Burning time
1	*Hemp*	7,5 cm	1 hour	20 minutes
	Flax	7,5 cm	Impossible to insert wick made from old flax dress	No results
	Cotton	7,5 cm	about 1 hour	around 2 hours
2	*Hemp*	7,5 cm	52 minutes	25 minutes
	Flax	7,5 cm	Impossible to insert wick made from old flax dress	No results
	Cotton	7,5 cm	about 1 hour	Around 1 hour
3	*Hemp*	7,5 cm	1 hour	20 minutes
	Flax	7,5 cm	around 40 minutes	25 minutes
	Cotton	7,5 cm	50 minutes	4 hours
4	*Hemp*	7,5 cm	1 hour	27 minutes
	Flax	7,5 cm	around 50 minutes	25 minutes
	Cotton	7,5 cm	57 minutes	3 hours and 30 minutes
5	*Hemp*	7,5 cm	52 minutes	20 minutes
	Flax	7,5 cm	50 minutes	27 minutes
	Cotton	7,5 cm	50 minutes	around 3 hours
6	Hemp	7,5 cm	54 minutes	20 minutes
	Flax	7,5 cm	around 50 minutes	around 43 minutes
	Cotton	7,5 cm	about 1 hour	around 3 hours

TABLE 2: THE RELATIONSHIP BETWEEN WICK BURNING TIME, WICK LENGTH, AND WICK MATERIAL.
NOTES: DURING THE EXPERIMENT OLIVE OIL WAS USED; FOR THIS EXPERIMENT HEMP, COTTON AND FLAX WERE USED AS MATERIAL FOR THE WICK; FOR THIS EXPERIMENT TWO PIECES OF LINEN FABRIC WERE USED; EACH PIECE WAS TORN INTO SIX STRIPS, FROM WHICH THE WICKS WERE TWISTED; LAMPS 1 AND 2 WERE NOT USED FOR THIS EXPERIMENT SEQUENCE DUE TO THE SMALL WICK HOLE DIAMETER; THE WICK WAS NOT LENGTHENED DURING COMBUSTION/BURNING.

Lamp (number)	Oil type	Lamp capacity	Burning time	Illumination (Lux)
1	Castor oil	29.6 ml	39 minutes	0.32 at a distance 1 cm from the light source; 0.01 at a distance of 130 cm

				from the light source
		59.3 ml	41 minutes	0.32 at a distance 1 cm from the light source; 0.01 at a distance of 130 cm from the light source
	Olive oil	29.6 ml	around 1 hour	0.35 at a distance 1 cm from the light source;0.02 at a distance of 130 cm from the light source
		59.3 ml	1 hour and 8 minutes	0.35 at a distance 1 cm from the light source;0.02 at a distance of 130 cm from the light source
2	Olive oil	41 ml	1 hour and 4 minutes	0.39 at a distance 1 cm from the light source;0.03-0.02 at a distance of 130 cm from the light source
		82 ml	1 hour and 3 minutes	0.39 at a distance 1 cm from the light source;0.03-0.02 at a distance of 130 cm from the light source
	Linseed oil	41 ml	around 50-55 minutes	0.08 at a distance 1 cm from the light source;0.02-0.01 at a distance of 140 cm
		82 ml	around 50-55 minutes	0.08 at a distance 1 cm from the light source; 0.02-0.01 at a distance of 140 cm
3	Linseed oil	35.3 ml	30 minutes	0.08 at a distance 1 cm from the light source; 0.01 at a distance of 150 cm
		70.6 ml	40 minutes	0.08 at a distance 1 cm from the light source; 0.01 at a distance of 150 cm
	Castor oil	35.3 ml	38-40 minutes	0.31 at a distance 1 cm from the light source; 0.01 at a distance of 150 cm
		70.6 ml	45-50 minutes	0.35 at a distance 1 cm from the light source; 0.00-0.01 at a distance of 150 cm
4	Linseed oil	39.6 ml	around 45 minutes	0.08 at a distance 1 cm from the light source; 0.01 at a distance of 128 cm
		79.3 ml	around 45 minutes	0.08 at a distance 1 cm from the light source; 0.01 at a distance of 128 cm
	Castor oil	39.6 ml	18 minutes	0.15 at a distance 1 cm from the light source; 0.02-0.01 at a distance of 120 cm
		79.3 ml	18 minutes	0.15 at a distance 1 cm from the light source; 0.02-0.01 at a distance of 120 cm
5	Olive oil	65.3 ml	14 minutes	0.32 at a distance 1 cm from the light source; 0.01 at a distance of 100 cm
		130.6 ml	17 minutes	0.32 at a distance 1 cm from the light source; 0.01 at a distance of 100 cm

	Linseed oil	65.3 ml	around 50 minutes	0.08 at a distance 1 cm from the light source; at a distance 1 cm from the light source; 0.01 at a distance of 110 cm
		130.6 ml	1 hour and 12 minutes	0.08 at a distance 1 cm from the light source; 0.01 at a distance of 110 cm
6	Castrol oil	42.3 ml	15 minutes	0.14 at a distance 1 cm from the light source; 0.01 at a distance of 130 cm
		84.6 ml	15 minutes	0.14 at a distance 1 cm from the light source; 0.01 at a distance of 130 cm
	Olive oil	42.3 ml	1 hour	0.17 at a distance 1 cm from the light source; 0.01 at a distance of 130 cm
		84.6	1 hour	0.17 at a distance 1 cm from the light source; 0.01 at a distance of 130 cm

TABLE 3: THE RELATIONSHIP BETWEEN LAMP BURN TIME, ILLUMINATION, OIL TYPE, AND LAMP CAPACITY.
NOTES: LAMPS 1 AND 6 WERE FILLED WITH CASTOR OIL; LAMPS 5 AND 2 WERE FILLED WITH OLIVE OIL; LAMPS 4 AND 3 WERE FILLED WITH LINSEED OIL. AFTER THE FIRST PHASE, THE OIL WAS CHANGED. LAMPS 1 AND 6 WERE FILLED WITH OLIVE OIL, LAMPS 5 AND 2 WERE FILLED WITH LINSEED OIL, AND LAMPS 4 AND 3 WERE FILLED WITH CASTOR OIL; IN THE FIRST PART THE LAMPS WERE FILLED AT 1/3 OF THE LAMP'S CAPACITY. DURING THE SECOND PART OF THE EXPERIMENT, THE LAMPS WERE FILLED AT 2/3 OF THEIR CAPACITY; THE WICK USED IN THIS WAS A COTTON WICK.

Discussion

As stated previously, fire and light play an important role in human history. They are essential to everyday life, providing heat and light, while at the same time they have sacral aspects, separating the pure and impure. Lamps also play a direct role as controllable light/flame, since they are the source of light. where we must review and discuss the experiment's results in relation to Jewish Halacha (kindling of Shabbat lamps), and early Christian liturgical practice.

According to the results of the experiment, ceramic lamp burning time varies from fifteen minutes to four hours. Based on these results, the mean burning time is between 1.5–2 hours, with burning time depending on the wick material and length, the temperature inside and outside the room, and oil type. An additional parameter affecting burning time is the volume of the lamp, and here we must be careful. Many archaeological finds of ceramic lamps are fragments of lamp's bodies and broken nozzles, and although both types of fragments provide information about the type of lamp (Herodian lamp, Byzantine lamp, lamp from Beit Shean, etc) ... However ceramic lamps belonging to the same group or type were not made strictly according to the same template, so it is difficult to calculate the total capacity of lamps from the same group or type base on certain fragments. Only the capacity of given lamp can be calculated. This does not mean that the capacity of the same lamp will the same as the given lamp. Therefore, this question will be the subject of a separate, detailed study.

The temperature as a factor affecting burning time

One of the factors affecting burning time is the temperature inside and outside the room. Walls of building are heated differently in summer and winter, and consequently walls also give off heat in different ways, affecting indoor temperature. If the temperature is plus 35 degrees inside and plus 50 degrees outside at the same time, burning is faster. This is typical for the Israeli summer climate. During the winter season, the temperature inside and outside is lower, from plus 15 degrees till plus 20 degrees inside living room and from plus 17 degrees till plus 25 degrees outside, the burning is slower.

Wick length, thickness, and material

As mentioned, the length of the exposed wick can affect the burning time and the size of the flame, which affects the rate at which the fuel is used. In this experiment we used a wick 7.5 cm long, as we assumed that in the Hellenistic (4th-1st centuries BC), Roman-Early Byzantine (1st century BC-7th century AD), or Early Muslim (8th-9th centuries AD) periods typical wicks were no longer than 7 or 8 cm. It is possible that wicks longer than this were used for religious ceremonies, and lighting large places such as synagogues, churches, the imperator's palace, and the triclinia of the rich and influential. This hypothesis is based on the New Testament: in the Acts of the Apostles, Paulus enters a house where people are celebrating the First Day of the New Month according to the Jewish tradition, and there are quite a few lamps in the room (20:7-8).

As can be seen from table number 1, one of the main factors influencing lamp burning time was the material from which the wick was made. The material usually used for making wicks, from the Hellenistic period (4th BC-1st BC) till Early Islam (8th-9th centuries AD), was flax, and this remains so even in contemporary Israel, Jordan, and Lebanon. A bronze wick holder with linen inside demonstrates that flax (or linen, to be precise) was a popular material (See Figure 12). Jewish literary sources such as the Mishna (Mishna, Bava Kamaa. 10:9; Babylonian Talmud; Hebrew-English edition) inform us of the growing of flax and the manufacture of linen in Israel, which is also validated by archaeological finds such as facilities for soaking (Safrai, 1988). Regarding flax wicks, we must note that according to our results, it is not possible to use old linen cloths torn into strips, as the strips are too thick to insert into the wick hole—the diameter of the wick hole is smaller than thickness of the wick. We have accepted that we made a considerable error in making a wick from old linen cloth. Amar (*Wherewith may kindle?*, 2003) notes that the linen fabric was torn into strips as thick as a finger, folded and then burned at both ends so that its shape would hold. Amar (2003) reinforces this assumption with the Mishna text: "*A wick made of cloth which was twisted but not singed*"(Mishna, Shabbath. 4:28; Babylonian Talmud; Hebrew-English Edition). We missed this detail in this experiment and have this prioritized for examination in a future study.

Wick materials in Jewish tradition

According to the texts there were two traditions for using old linen cloths or fabrics for wicks, especially for the Shabbat lamp. Using flax wicks from old linen cloths is ritually unclean and that is why it is forbidden for Shabbat, a position held by Rabbi Eliezer. His opponent, Rabbi Akiva (Appendix, table C), was a supporter of the idea that this practice promotes purity: "*A wick (made) of cloth which was twisted but not singed, R. Eliezer said: It is unclean and one may not light (the Sabbath lamp) therewith, R. Akiba maintained: It is clean, and one may light therewith*." (Mishna, Sabbath. 28:2; Babylonian Talmud; Hebrew-English Edition). So, during the period of the end of the 1st century AD to the first part of the 2nd century AD, there were two main traditions. This begs the question, is it authentic to use old linen cloth wicks for the Shabbat lamp? According to the Mishna, before the destruction of the Second Temple there were different traditions regarding the materials for the Shabbat lamp wicks. One of the traditions was to ban the use of old cloths for Shabbat lamps (Mishna, Sabbath. 18:2; Babylonian Talmud; Hebrew-English Edition). Perhaps this is connected to the economic situation: prior to the Temple's destruction in 70 AD, Jewish communities were rich and people could buy more expensive materials for Shabbat lamp wicks. After the destruction of the Temple the socio-political climate become more volatile, changing in many ways for the worse. During this period the use of flax or linen was considered pure (Forbes, 1964, p.42). As a confirmation of what has been said, two fragments from the text of Talmud can be quoted: "*Whatever comes forth from a tree You may not light (the Sabbath lamp) therewith, save flax; and whatever comes forth from a tree cannot be defiled with the uncleanness of tents, except linen*" (Babylonian Talmud, Sabbath. 27:2 Hebrew-English Edition) and also the following statement: "*A Hol ha-Moed of Festival clearly sowed wheat/flax*" (Babylonian Talmud, Baba Batra. 147:1 Hebrew-English Edition).

Cotton was also used by the Jews as wick material. According to R.J. Forbes (1964), cotton was famous in the Near East from Sennacherib's time (705 BC-681 BC) but was not cultivated in Palestine until Talmudic times (3rd-6th centuries AD). During the Hellenistic period and the rule of the Maccabees, people in Israel and Lebanon bought raw cotton and cotton fabrics from Bahrein and India, which enjoyed a monopoly in the growing and selling of cotton and their products (Forbes, 1964). Cotton was very expensive, and therefore the Jewish communities in Rome, Carthage, and South Galia apparently used hemp. The hypothesis that Jewish communities in Rome and Carthage used wicks from hemp is based on a fragment from Persius (quoted in Stern, 1974, p.436). He mentions that when Herod's day[2] arrived, the Jews begin to light their lamps and all the room are filled with smoke, soot, and grease. Persius mockingly asks: "*What deity is pleased that he is met so*?" (quoted in Stern, 1974, p.436). Thus, according to the Mishna, cotton was a valuable material for the wicks (Mishna, Shabbath. 22; Babylonian Talmud; Hebrew-English Edition).

Wick materials in early Christian tradition

The early Christian tradition does not contain any rules about the manufacture of wicks and proper materials for use in the liturgy. According to early Christian sources, we can assume that ceramic lamps were used during services and liturgy in the first centuries AD. The Didache is the earliest literary Christian source that mentions ceramic lamps and their use during religious ceremonies, but it does not provide details regarding the requirements for making wicks ("*Didache*", 16). The next references to ceramic lamps used in the early Christian Church are in chapter 4 and chapter 7 of St. Jerome's work *Against Vigilantius*. It is similar to the Didache text, although he did not write about the technical details or requirements. Based on Jerome's text, it can be assumed that during the ceremony of reading the Gospel, as part of the Christian liturgy, Christians were already using oil lamps by the end of the 4th century AD. and the beginning of the 5th century AD. We cannot say exactly what the early Christians used as wick material, and therefore this question remains unanswered (Bouras and Parani, 2008).

Initial burn time and extension

As has been noted, the average burning time according to the experiment is no more than a couple of hours. This result differs from Howland's result. Ambar-Armon writes that according to Howland, the average burning time is four hours—a result he obtained by calculating the lamp's volume (Howland, 1958 cited in Ambar-Armon, 2007, p.271). We cannot comment one way or another on Howland's conclusions, because the experiment was not intended to verify the capacity of the ceramic lamps, but the problem came up in the course of this work and will be discussed in detail in another study.

This experiment did not attempt to extend the burning time by pouring oil into an already burning lamp. Nonetheless, extending the burning time is an important issue vis à vis the Shabbat, so we will discuss two questions: (1) How was it possible to extend the burning time and (2) Were the lamps that are known from archaeological excavations used as Shabbat lamps?

Amar and Shviki (2003) analyzed the Mishna text which describes extending the burning time of the Shabbat lamp and concluded that the average duration of burning is two hours and forty minutes. According to Amar and Shviki (2003) this is enough time for Kiddush, the Shabbat feast, for meeting with the family and for Torah studies. Obviously, a lamp's capacity is limited, but it is possible to extend burning time by pouring oil into an already burning lamp. However, the Mishna says that is forbidden to pour oil into an already burning lamp or to move the lamp or the wick (Mishna, Shabbath. 29:2; Babylonian Talmud; Hebrew-English Edition; The Tosefta, Shabbath. 1:12-13). This prohibition was bypassed in several ways, according to the Misha. For example, one way to extend burning time is to use an additional vessel, a bowl, for instance. Then the already-burning lamp is connected to an additional lamp by a thread, made from the same material as the wick (Supplement: Illustration, fig. 15). The

wick absorbs the oil and slowly this oil moves to the burning lamp. Amar confirmed in his experiment that burning time can be increased in this manner (Amar and Shviki, 2003, pp. 22-23). Another way is to use an egg (Supplement: Illustrations, fig. 15) as mentioned in a fragment from the Mishna: "*A man may not pierce an egg shell, fill it with oil, and place it over the mouth of the lamp, in order that it should drip, and even if it is of pot;...*" (Mishna, Shabbath. 29:2; Babylonian Talmud; Hebrew-English Edition).

We did not examine means used to extend burning time, as we assumed that it would be easy to do so by replacing the wick during burning. However, this is a desecration of the Shabbat, just the same as moving the wick or pouring oil into an already-burning lamp. Another solution is an additional mechanism inside the lamp, which is known from archaeological excavations, as seen in this luminary dated to the 1st century BC which was found in the archaeological excavations at Beit Natif and Herbet Otza (See Figure 13).

Regarding the prohibition of adding oil to an already-burning lamp, it can be argued that there was such a practice during the 1st to 3rd centuries AD, based on the following text from the Mishna: "*A man must not fill a dish of oil...*" (Babylonian Talmud, Shabbath. 29:2 Hebrew-English Edition). We do not encounter this practice in Christian tradition, perhaps due to a different perception of light in the Early Christian liturgy. But this remains only a hypothesis, which requires additional research.

The question of extending burning time is also relevant for the Early Christian tradition, as we read twice in Christian sources that lamps should not go out. One source is the New Testament, which relates the story of the ten virgins that go from their houses to meet the bridegroom, who is Jesus (Matthew. 25:1-13). Five girls took with them lamps that were burning and extra vessels of oil. The other five did not take extra vessels with oil, only oil lamps that were burning. At midnight all the lamps went out when all the girls were sleeping. Suddenly, one of them wakes up and sees the bridegroom. She fills her lamp and goes to meet him and cries out to the other girls. The girls who took extra vessels with oil fill their lamps and light them. The five girls who did not take extra vessels with oil ask for help, but nobody gives them oil; they are forced to go and buy extra supplies. When they return, nobody opens the door for them. The second literary Christian source is the Didache. At the end of the text we read the phrase: *Let your lamps not go out* (*Didache*, 16). This would appear to indicate that the Christians solved the problem of extending burning time in another way. In other words, if the Mishna forbids refilling oil during burning time, the Christians did the opposite. The basis for this lies in the Christian perception of light, which signifies not only esteem and honor for the heavens, as light and flame are symbols of the soul, but also a passage to a new life without sin. Therefore, in Christianity it was important that lamps were kept burning especially during the liturgy.

The oil

As can be seen from the Mishna, and early Christian literary sources, as well as the results of the experiment in the Talmudic period (3rd -6th centuries AD) and even earlier, people used various types of oil to kindle ceramic lamps, including fish oil, radish oil, nut oil, and olive oil. However, for religious services and festivals, olive oil was used exclusively: "*Rabbi Tarfon said: Only may it (kindle) with olive oil only*" (Mishna, Shabbath. 20:2; Babylonian Talmud; Hebrew-English Edition). Olive oil was cheaper in the eastern part of the Mediterranean, while in the western part, castor oil or flax oil were cheaper (Bouras and Padani, chapter: *How oil lamps work*; 2008, p.3). Another detail which bears mentioning is the technology of growing olive trees and manufacturing olive oil, which differs from contemporary practices and results. Obviously, the contemporary olive oil used in the experiment is not the same as the olive oil used in ancient times.

Illumination

The illumination of all lamps in the experiment was 0.01 lux. This is reasonable for a meeting of people doing nothing but commune. However, according to ancient Latin and Greek resources such as Seneca (Stern, 1974, Vol. I, p.433) and Persius (Stern, 1974, Vol. I, p. 436) as well as early Christian resources (The New Testament, *Luke*, XII, 35; *John*, V, 35; *Jerome*, *Against Vigilantius,* 1893, verse: 7), ceramic lamps were used for liturgical purpose, which raises the question, how many lamps were required to illuminate a room of 10.45 square meters?

According to the formula that illumination should be 1 lux for 1 sqm, about 10 or 11 ceramic lamps are required, each one giving off 0.01 lux 1.30 meters from the lamp itself. These 10 or 11 ceramic lamps give enough light for a meal for 10-20 people or for reading the Gospel during the liturgy in the early Christian community. But this is possible only if there are windows or openings in the room that allow light to come in from outside. A separate question is how many ceramic lamps are required to illuminate a space such as a cave or catacomb where outside light does not penetrate. This question remains for a future experiment.

The results of the experiments can be summarized below:

1. The ceramic lamps that were used during the experiment became heated.
2. It was impossible to use them outside, especially during windy weather. They had to be closed with a special cover and used as lanterns.
3. The combustion time is different for each kind of ceramic lamp and is related to the length of the wick.
4. A wick needs to be pulled every 40–45 minutes with pincers.
5. The nozzle form was not only aesthetic; it replaced the wick holders that were typical in Hellenistic ceramic lamps and in some simple Egyptian ceramic lamps.

Conclusion

To summarize, we used copies of clay lamps of three historical and archaeological periods: Herodian (years of range: 40-4 BC), Roman-Early Byzantine (1st BC-7th century AD) and Early Muslim (8th-9th centuries AD).

Burning time

The average burning time was one hour, using wicks that were 7.5 cm long. Possibly, longer wicks will burn for a longer time. Here, it is only possible to say that temperature was the one thing that affected burning time: When it was cold inside and outside, burning time was longer and vice versa.

Wick

According to literary sources, during the Hellenistic, Roman, Byzantine and Early Muslim period cotton, flax and hemp were used as materials for wicks. Cotton was expensive and according to the Mishna used only for holidays or Shabbat lamps. In the Near Eastern Mediterranean, poor people used flax as wick material, and in Israel they used hemp. During the main experiment we used only cotton wicks. Unfortunately, we were unable to make a wick from old flax (linen) fabric. The technology of making wicks from old flax (linen) fabric is described in the Mishna and was reproduced by Amar (Amar and Shviki, 2003). It is necessary to return once again to this issue in another experiment to confirm or refute what has been said in the Mishna. It is necessary to conduct a new experiment with wicks 10 cm and 17 cm long, and then compare the results of burning time and illumination with the results of this experiment.

Illumination

The illumination of all the clay lamps was around 0.14-0.30 lux near the lamp and 0.01 lux at 120 cm from the light source. According to the Mishna, this allows simple things such as writing and preparing meals or for sleep. It can be assumed that the clay lamps discovered during excavations could be used as ceremonial lamps for Shabbat or Hanukah. This is based on the results of the experiments and Latin literature resources such as Seneca and Perseus. Consequently, the Shabbat ceremony, for example, was significantly different in ancient times; most likely, it was significantly shorter.

The same may be assumed regarding the use of clay lamps during the early Christian liturgy. Early Christian sources focus on the use of clay lamps and candles during the Easter ceremony and during the Gospel reading. For these ceremonies one would need a lot of illumination sources, which means that it is likely that ceramic lamps with several nozzles were used, as they have a large volume. About 10-11 ceramic lamps are required to illuminate a room of 10.45 sqm, on condition that there are windows or openings in the room that allow light to penetrate from outside. The question of the number of ceramic lamps needed to illuminate a closed space such as a cave or catacomb remains for future research.

Oil

In this experiment were used three types of oil: olive oil, castor oil, and linseed oil. The following results were obtained during the experiment: A lamp filled to 1/3 and 2/3 of lamp's capacity with castor oil burns for 38-40 minutes. If the lamp is filled with castor oil, burning time is between 41-50 minutes. The castor oil flame is even and strong but not high. According to the Mishna, it was forbidden to use this type of oil for festivals and Shabbat lamps. If linseed oil is used, burning time is about 30-45 minutes regardless of whether the lamp is completely full or at 1/3 and 2/3 the capacity. It can be assumed that this type of oil was used in everyday life and not for Shabbat and festivals. The optimal oil for festivals or Shabbat lamp is olive oil. It does not give off a smell and smoke during burning. The flame is strong, high and bright enough. However, olive oil was expensive and was used mostly in the south of the Roman Imperia and in the Middle East (Lebanon, Israel, Syria, and Egypt). The following should be noted in conclusion: the flame is affected by the temperature inside and outside of the room. If it is cold, burning time lengthens and the flame is lower and vice versa. The lamp type has no significant effect on oil burning.

Ceramic lamp volume

We did not consider ceramic oil lamp volume in this experiment, which remains to be examined. The purpose of the next research is to analyze a ceramic oil lamp, for example a Herodian lamp, and see if it is possible to calculate its volume if we have only the body or nozzle.

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1 From recent European studies at "kindling ancient oil lamps", the following studies should be mentioned: Christian-Heinrich Wunderlich, "Light and Economy: An Essay about the Economy of Prehistoric and Ancient Lamps" (Nouveautés Lychnologiques, 2003, pp.251-264) and Dorina Moullou and Karen Garnett, "Capacity and Capabilities for Terracotta Lamps from Corinth: A Measurement Procedure" (Monographies Instrumentum, 63, 2019). Among the Israeli researches, two works in particular must be mentioned here: the doctoral dissertation by Israeli researcher Avivit Shwiki and Zohar Amar (Ph.D. and archaeologist) titled Wherewith may we kindle? (Eretz Hefetz Institute, Orot Israel College, 2003and the doctoral dissertation of Einat Ambar-Armon, The oil lamps from the Hellenistic period in the Land of Israel in light of the Murasha excavations (Bar-Ilan University, Martin (Szusz) Department of Land of Israel Studies and Archaeology, 2007).

2 We can assume that here tells about the Passover. According to Jewish tradition, the coronation of new king took place on the first day after the Passover Evening. As well as today, it was customary to light lamps on Passover, and most likely they were lit on the day of coronation. Thus, let us suppose that here tells about the Herod's the Great coronation day, that was during the Passover. This day was celebrated by Herod's supporters living in Rome.

Keywords fire

Country Israel

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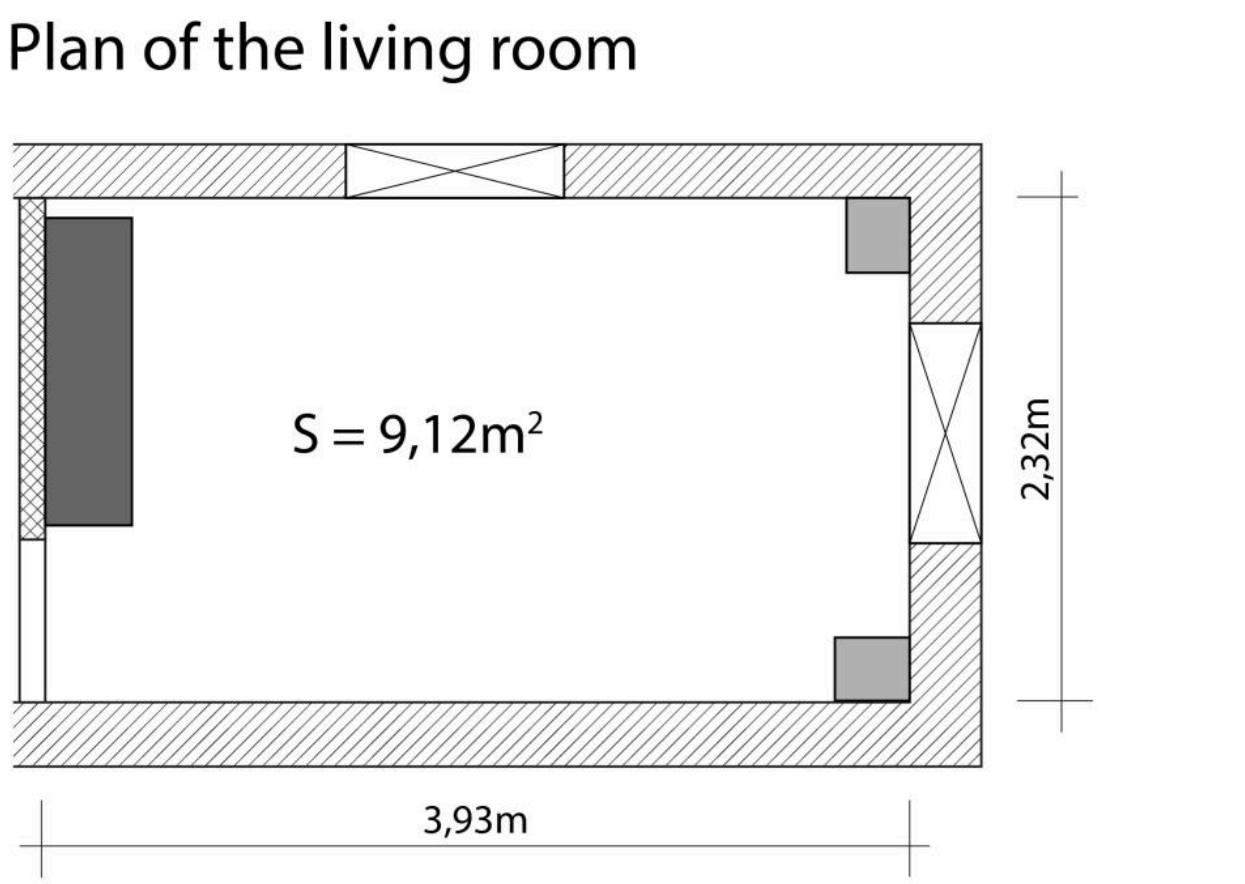

FIG 1. LIVING ROOM PLAN. DRAWING BY M. ZIELINSKA BASED ON SKETCH BY VAIMAN ALEKSEI

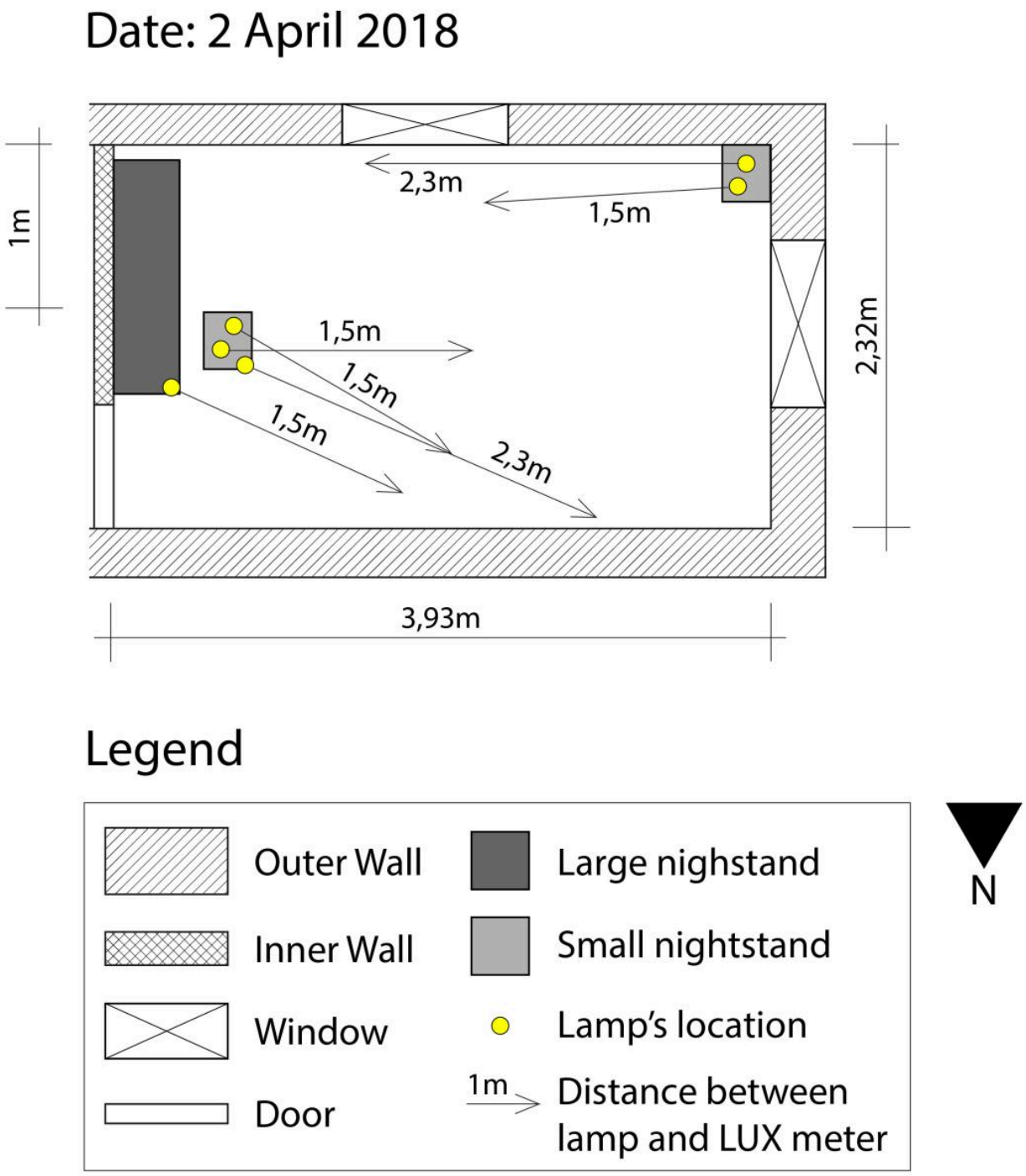

FIG 2. LOCATION OF THE LAMPS IN THE ROOM DURING EXPERIMENTS #1. DRAWING BY M. ZIELINSKA BASED ON SKETCH BY VAIMAN ALEKSEI

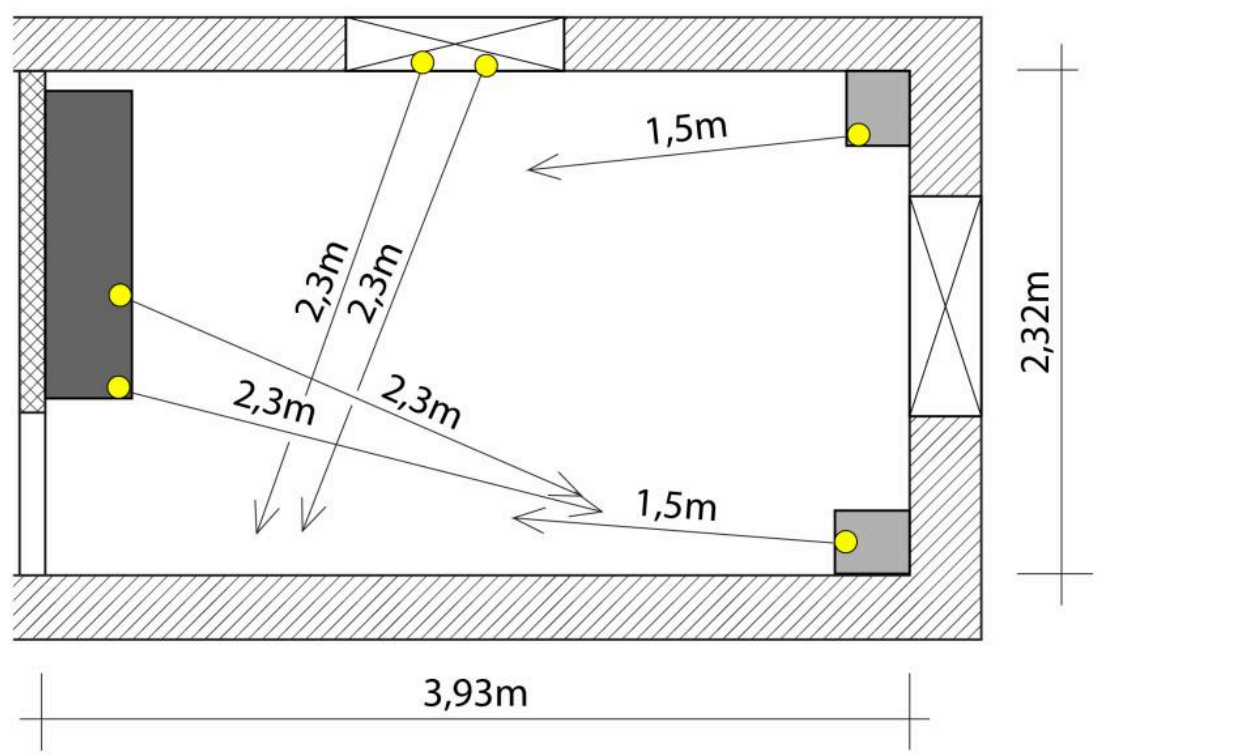

FIG 3. LOCATION OF THE LAMPS IN THE ROOM DURING EXPERIMENTS #2. DRAWING BY M. ZIELINSKA BASED ON SKETCH BY VAIMAN ALEKSEI

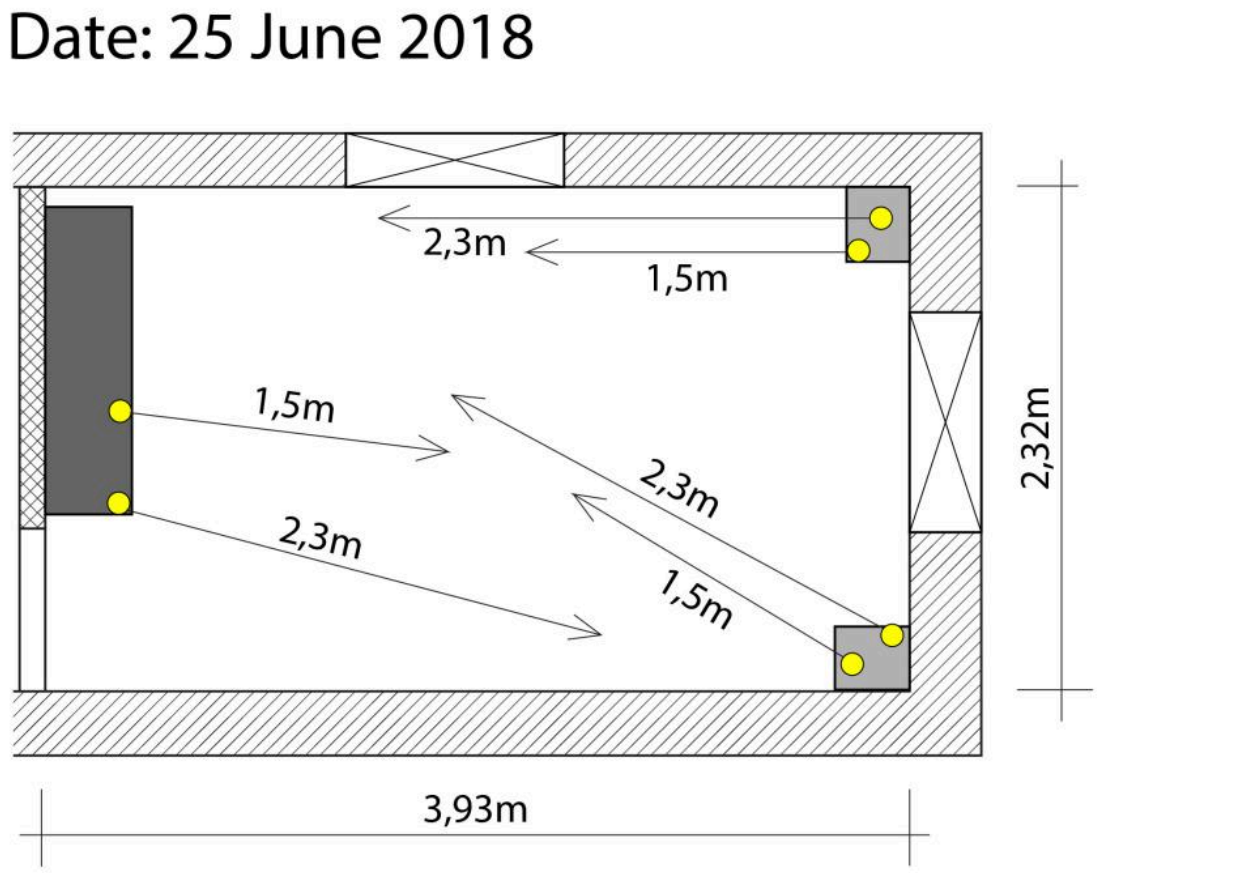

FIG 4. LOCATION OF THE LAMPS IN THE ROOM DURING EXPERIMENTS #3. DRAWING BY M. ZIELINSKA BASED ON SKETCH BY VAIMAN ALEKSEI

FIG 5. MODEL NUMBER 1 (LEFT - ORGINAL: ISRAELI AND AVIDA, 1989, PP.39, 160, 162, RIGHT - REPLICA). EARLY MUSLIM PERIOD, 7TH TO 8TH CENTURIES AD THIS KIND OF CERAMIC LAMP WAS DISCOVERED DURING THE ARCHAEOLOGICAL EXCAVATION OF HAR MAFGAR, NEAR JERICHO. THIS LAMP IS DECORATED WITH FLOWERS AND PLANTS.

FIG 6. MODEL NUMBER 2 (LEFT - ORGINAL: ISRAELI AND AVIDA, 1989, PP.39, 160, 162, RIGHT - REPLICA). THE SAME TYPE OF EARLY MUSLIM CERAMIC LAMP AS MODEL 1 (FIGURE 5), THE DIFFERENCE BEING IN SIZE, AS THIS LAMP IS A LITTLE LARGER. LIKE MODEL 1, THIS LAMP HAS A "CANDLE BASE".

FIG 7. MODEL NUMBER 3 (LEFT - ORGINAL: PHOTO BY AUTHOR, ARCHAEOLOGICAL MUSEUM (ROCKFELER CENTER) AT JERUSALEM; ARCHAEOLOGICAL AUTHORITY OF ISRAEL, RIGHT - REPLICA). "HERODIAN OIL LAMP". 63 BC—140 AD (ACCORDING TO THE DATING OF SUSSMAN, 1972). ROUND-MOLDED, CLOSED BOWL TYPE, NO DESIGN.

FIG 8. MODEL NUMBER 4 (LEFT - ORGINAL: ISRAELI AND AVIDA, 1989, PP.39, 160, 162, RIGHT - REPLICA). EARLY MUSLIM PERIOD, 7TH TO 8TH CENTURIES AD. THIS KIND OF CERAMIC LAMP WAS DISCOVERED DURING THE ARCHAEOLOGICAL EXCAVATION OF HAR MAFGAR, NEAR JERICHO. THIS TYPE OF LAMP IS DECORATED BY GEOMETRIC ELEMENTS WITH PLANTS OR FLOWERS; SOMETIMES THIS LAMP IS DECORATED BY PLANTS OR FLOWERS INSIDE ARCHES. THE REPLICA (IMAGE RIGHT) IS NOT AN IDENTICAL COPY; IT WAS MADE FROM A LAMP THAT DIFFERS SLIGHTLY IN THE NOZZLE'S DECORATION. BUT THE STYLE OF GEOMETRIC DECORATION WAS PRESERVED; ONLY THE GEOMETRIC ELEMENT IS DIFFERENT.

FIG 9. MODEL NUMBER 5 (LEFT - ORGINAL: ISRAELI AND AVIDA, 1989, PP.39, 160, 162, RIGHT - REPLICA). "HERODIAN OIL LAMP". COLOR IS GREY, NO DESIGN, CLOSED BOWL TYPE. DATING: 63/62 BC—135 AD

FIG 10. MODEL NUMBER 6 (LEFT - ORGINAL: SUSSMAN, 2017, PP.122-124, RIGHT - REPLICA). LATE BYZANTINE/EARLY MUSLIM PERIOD OIL LAMP. IT WAS FOUND DURING THE ARCHAEOLOGICAL EXCAVATION AT THE SETTLEMENT OF TALMEI YAFEH, NEAR ASHQELON. THE DATE OF THIS LAMP IS: 6TH TO 7TH CENTURIES AD THE REPLICA (IMAGE RIGHT) IS NOT EXACTLY THIS TYPE, DIFFERING SLIGHTLY IN DETAILS, SUCH AS THE NOZZLE.

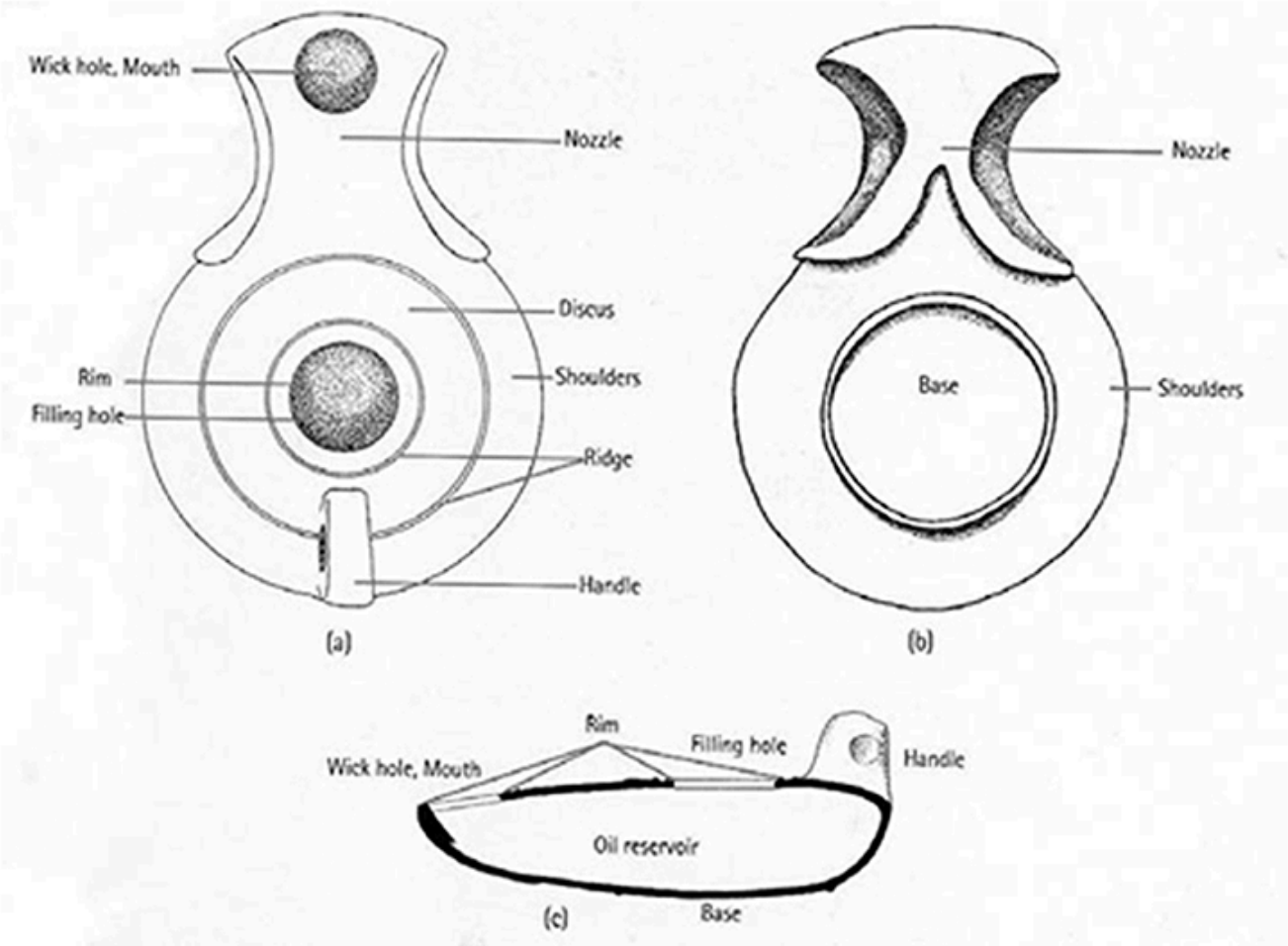

FIG 11. DIAGRAM OF OIL LAMP FEATURES (WESTENHOLZ, 2004).

FIG 12. A SMALL BRONZE WICK HOLDER WITH A LINEN WICK INSIDE; FOUND IN SHIVTA. AMIT, C., 2018. SMALL OIL LAMP WICK FROM 1,500 YEARS AGO FOUND IN SHIVTA, DECEMBER 10TH, 2018. [IMAGE ONLINE] AVAILABLE AT: <HTTPS://WWW.JPOST.COM/ISRAEL-NEWS/SMALL-OIL-LAMP-WICK-FROM-1500-YEARS-AGO-FOUND-IN-ANCIENT-DESERT-TOWN-573962> [ACCESSED 03 MAY 2019].

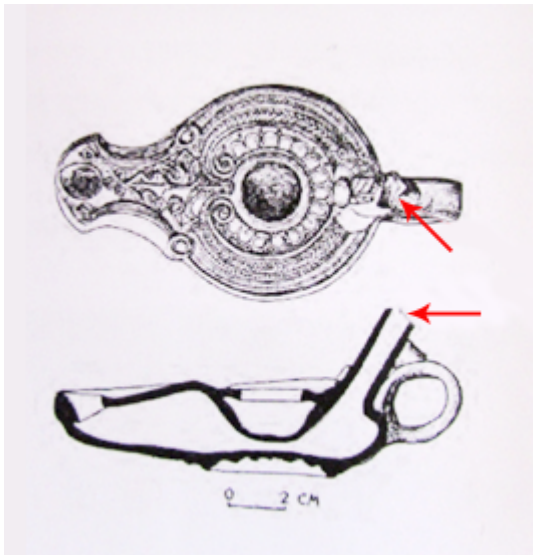

FIG 13. CERAMIC PIPE FOR CONNECTION TO SEPARATE VESSEL (SEE RED ARROW). THIS ALLOWS THE ADDING OF OIL WHEN THE LAMP IS LIT. FROM AMBAR-ARMON, 2007, P.264