Faculty of Arts and Philosophy

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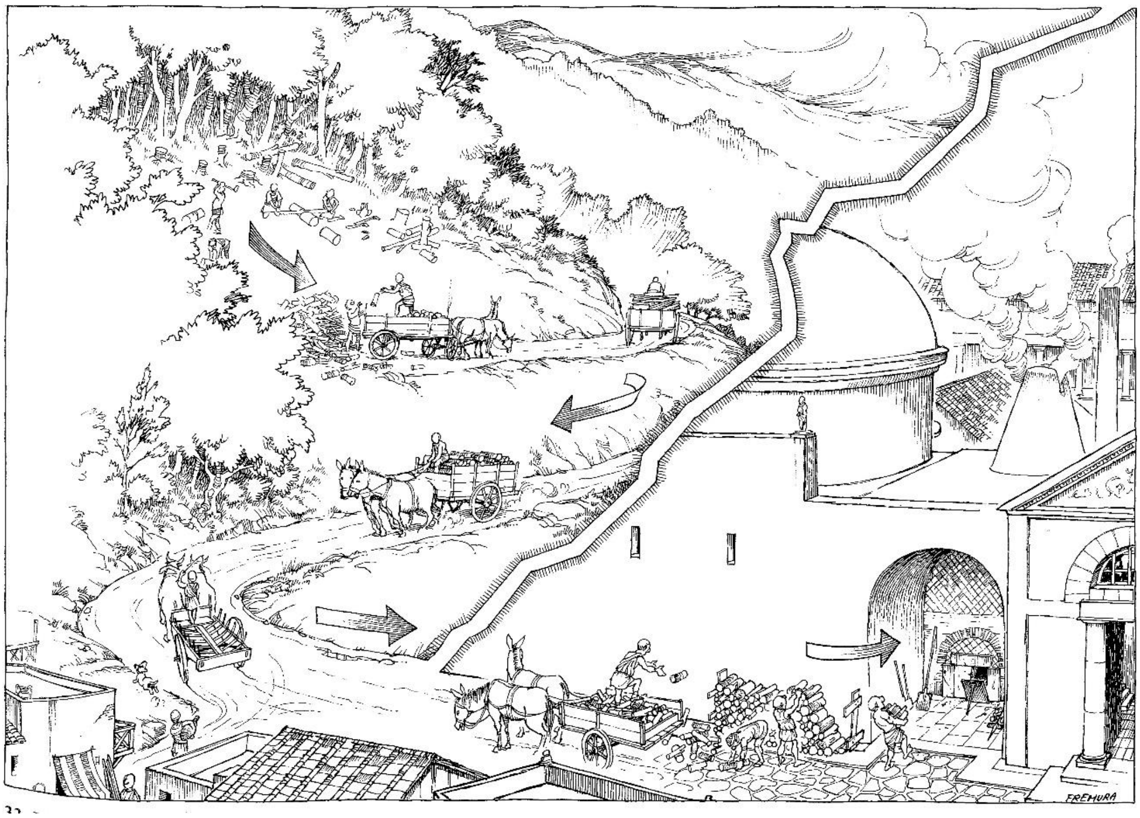
The Fuel Economy of Public Bathhouses in the Roman Empire

Classical History



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Cover image from Pasquinucci M. 1987. *Terme romane e vita quotidiana*, Modena, Panini. fig 33: “l'approvvigionamento del combustibile il legname”

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Short Summary

The supply of fuel for Ancient Roman public bathhouses touches some fundamental principles in our thought of ancient economic behavior. On the one hand this is the relationship between the city and its hinterland, on the other the way the ancients interacted with their environment. The baths are often seen as quintessentially Roman, and are often faulted for their wastefulness. They are often considered to have played a role in the –supposed- deforestation of the Mediterranean landscape. In this exploratory study, we shall try to guess the extent of this fuel consumption, on the basis of ancient textual evidence, and calculations based on archaeological reconstructions. Then, on the basis of ancient textual evidence, papyri and inscriptions, we shall try to explore how this consumption was financed and try to sketch a fuel supply chain. A small survey of archaeological studies might indicate however that there could have been a rationale toward the ancient's interaction with the environment. On the basis of the results of our survey, we shall try to argue the ancients might have provided some interesting answers to the challenges posed by the fuel consumption of the baths. These answers might have implications for our understanding of the Roman economy

Korte Samenvatting in het Nederlands

De brandstof economie van de Romeinse publieke baden raakt enkele fundamentele principes van ons denken over de antieke economie. Deze zijn aan de ene kant de plaats van de stad ten opzichte van het hinterland, en de omgang van de antieken met hun omgeving. De baden worden er vaak gezien als typisch Romeins, en worden omwille van hun zogezegde verspilzucht er van verdacht een rol gespeeld te hebben in de –vermeende- ontbossing van het Mediterrane landschap. In deze verkennende studie wordt aan de hand van antieke bronnen en archeologisch-geïnspireerde berekeningen getracht te schatten welke omvang de brandstofconsumptie van de baden had. Hierop volgend wordt getracht na te gaan hoe deze werd bekostigd en zal worden getracht een brandstof bevooradingsketen te schetsen op basis van antieke bronnen. Een kleine enquete van archeologische studies toont aan dat er echter een zekere logica zat in de Romeinse omgang met hun omgeving. Op basis van de resultaten van onze enquete zal worden geargumenteerd dat de Romeinen een aantal interessante antwoorden hadden op de uitdagingen die de brandstofconsumptie van de baden bood. Deze hebben een weerslag op onze manier van interpreteren van de Romeinse economie

Figures and Pictures in the Text

Introduction

The supply of fuel for Ancient Roman public bathhouses touches some fundamental principles in our thought of ancient economic behavior. Studying the ancient fuel economy might elucidate new information on the influence of institutions on economic performance and their role in ecological behavior. The study of ancient Roman baths has already offered a wealth of information. This ranges from insights and understanding in the daily life and habits of people in Roman times, to the study of urbanization. From the Early Empire onwards bathhouses started popping up in all cities on the Italian Peninsula.[1] By late Antiquity a lot of cities across the empire would have had one or several public bathing institutions alongside a myriad of private installations. Studying Roman bathhouses can also further the study of the socio-economic history of an ancient city, and the interaction between the ancient city and its hinterland.

In this work the use of the words 'public' and 'private' for bathhouses should be interpreted as pertaining to their nature of ownership and not whether the bath was open to visitors or was a more personal installation, unless explicitly stated. There is an equivalent use of terminology in Latin that supports this distinction: *balnea publica* for publicly owned baths, and *balnea meritoria* for privately owned baths.[2] Another restriction will be that military baths will largely be ignored. These baths would have been constructed where soldiers were stationed and might even have been open to family of the military personnel.[3] These military baths however are not the municipal public baths that served as public amenities to a city. We realize this could be a shortcoming, as settlements could be built around a military presence.

Over the last twenty years, there has been a steady increase in attention devoted to the role of fuel and fuel use in ancient Roman Economy. One of the challenges is trying to gauge fuel consumption, seeking to quantify and provide guesstimates to the fuel economy's magnitude. Robyn Veal's doctoral thesis (received in 2009 and awaiting publication), of the fuel consumption of Pompeii (and her other work) will undoubtedly advance our understanding even further of the Roman economy, especially with respect to the connection between city and hinterland. Her work demonstrates which types of fuels were used, where these came from and how far removed these were from their destination.[4] Accompanying this was a quantitative model to guesstimate the order of fuel consumption within the city walls. This model uses a couple of basic equations (cfr. addendum2) to allow us to gauge the pressure put on the local surroundings of a certain city. It is applied to ancient Campania and sketches how ancient Campanians might have organized and exploited their surroundings (briefly shown at the end of addendum 2). The model currently broadly includes all fuel uses and its primary reasoning is based on demographic figures. Thus a higher population translates to a higher estimation of the consumption of fuel, regardless of industrial activity or local amenities. We believe the model can be expanded and would benefit from specialist additions. For example by accounting for industrial activity: bread- and pottery bakers, by glass-, brick- and tile makers. A pottery-making industry producing for export would have used vastly more fuel per number of people than one producing for local consumption. Furthermore these different industries sometimes interacted or cooperated in a way that could have affected economic activity.[5] If we lack a deeper understanding of the

[1] See for example Nielsen, I. (1993), or Fagan, G. (1999)

[2] Maréchal, S. (2016), p 55

[3] Allason-Jones (1999) "Women and the Roman Army in Britain" in Goldsworthy, A. and Haynes, I (eds.) *The Roman Army as a Community, JRA Suppl. 34,* pp 41-51, esp. P 43 for Roman Egypt.

[4] Summarily repeated in: Veal, R. (2012) and Veal, R. (2013)

[5] See for example Leitch, V. (2011) where it is argued that pottery makers favored co-locating with the oil pressing industry to reduce fuel cost.

relationships that could occur between industries, say brick- or pottery makers, our estimates toward the fuel economy could prove inaccurate.

Studying the fuel economy is deeply interrelated with questions regarding how performative the ancient economy was and how it was structured. Similarly, big public amenities like the temples or the public bathhouses, would also benefit from a more defined integration into Veal's model. The Xylarch project hopes to do just that for the city of Sagalassos, integrating not only demography, but the pressures of industry and public amenities into the study on the ancient environment of Pisidia.[6] This project continues the trend toward mapping the structural determinants of the Roman economy, not in the least the intimate link between the ancient economy and its environment.

At the same time these quantifying models of course make assumptions to the character of the ancient city. We've noted how Veal's model relates to the connection between a city and its hinterland. The defining approach to this relationship for the ancient city was by Finley. In *The Ancient Economy*, Finley argued cities were a non-productive part of the ancient economy. He called these 'consumer cities' because they were a point of extraction or redistribution of the wealth created in (local) agriculture. The surplus production in agriculture was appropriated by the city through taxes or rents, basically systems of political or social entitlement. Finley's view of the 'consumer city' was attacked for downplaying the engagement of the land-owning upper classes in commerce and the complexity of urban economic activity. Erdkamp however reinvigorated Finley's view by replacing its focus. Instead of using the perspective city versus hinterland, he argued we should analyze the economic relations between surplus producing agriculture and other sectors of the ancient economy, which consume and redistribute it (which Erdkamp calls 'the consumer economy').[7] This model emphasizes that trade between cities, even manufacture for export, was based on 'non-reciprocal exchange' with agricultural production. By this it is meant that the agricultural production is still claimed on the basis of political or social rights, and the agricultural sector will receive no 'relevant goods and services' in return for its surplus. What commercial agriculture developed was still dependent on the surplus of agricultural production, and no investment was made to increase basic food stuff production. Specialization did not occur to increase profits, instead it was meant to secure wealth and therefore was not reciprocal in nature. Trade between cities was based on political, economic and social entitlement of the agricultural surplus. This is why Rome, for example, could draw upon the entire Mediterranean as its hinterland for resources. This means the majority of trade would have been basic, bulky food stuffs. Somewhat related to this is the framework developed by Horden & Purcell, where ancient trade was brought on by the differences between the micro-regions of the Mediterranean. This framework, inspired by ecology, considers trade the result of different regions exchanging goods with one another to reduce the impact of local calamities and once networks have been established, reduce the risks put on by this variability in climate (fickle Mother Nature). This degree of 'connectivity' between groups of people and between places emphasizes 'flows' of goods, people, diseases or energy.[8] Such models of course are based on the surplus production of basic food stuffs, though often they've neglected to fully appreciate the importance of fuel.

In his contribution to the Cambridge Companion to the Roman Economy, Wilson suspects that the demand of fuel for the baths would have been massive.[9] Owing to their supposed fuel hungry nature and their widespread use from Hellenistic times onwards, the ancient bathing habit is often associated

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[6] My thanks to Prof. Zuiderhoek and Prof Verboven for tipping me on this project

[7] Erdkamp, P. (2001). Erdkamp's model reminds somewhat of the physiocrat François Quesnay's T*ableau Economique*, which emphasizes a productive agrarian class producing a surplus, a rentier class which extracts rents, and a 'neutral' artisanal class, which does not add to creating more surplus, yet interacts with the agrarian class to procure resources and sells their products to the rentier class

[8] Horden, P. & Purcell, N. (1998) The corrupting sea: a study of Mediterranean history

[9] Wilson, A. (2012) "Raw Materials and Energy" in Scheidel, W (2012)

with woodland depletion and deforestation.[10] Increasingly, it is believed, ancient forests had to be managed and other fuel sources were incorporated. Across the empire, several different varieties of fuel were used (olive pits, dung, coal). Wilson further speculates that problems with the fuel supply might have led to a trade in firewood or charcoal, and notes evidence for trade in coal in Roman Britain, Western Gaul and Germania.[11] His arguments neglect however to fully appreciate the use of olive pits, chaff and other by-products of agriculture. Some of these 'alternate' fuel sources in fact burn hotter and cleaner than hardwood, a possibility Wilson notes himself for dried dung.[12] Whereas textual sources hint at this variety of fuels used, it is mainly archaeological research that confirms this diversity. Underlying Wilson's depiction of the ancient fuel economy are three expectations in the case of heated baths: (a) that fuel-costs for heating the baths put a heavy strain on resources, so that heating the baths was expensive. This leaves us to expect that (b) fuel preferentially would have been as cheap as possible and easy to procure, meaning that (c) firewood was generally used (and not the more expensive charcoal). Where firewood was scarce (or became scarce), either firewood was imported or other low-cost and ubiquitous fuel varieties were used.

Hoping to contribute positively to these projects this thesis will explore this one aspect of the public services in the Roman economy. Because few studies have been attempted specifically for our subject and because bathhouses became so widespread, we shall use a generalizing approach. This framework fits both the Ancient sources we shall employ, and the survey of archaeological studies we've conducted (cfr section 3). In the first section on fuel consumption, we shall try to provide guesstimates for the ideal-typical hypocaust baths, based on both ancient sources and archaeology-inspired calculations. These will be crosschecked with each other and compared. Based on productivity estimates of certain tree species, we shall try to extrapolate to a required area needed for sustainable exploitation. This might allow us to better comprehend the impact of the baths on the ancient countryside, and perhaps eventually gauge whether or not the impact would have been as disastrous as many have suggested.

In the second section we shall see how the baths functioned in an economic context and try to reconstruct a supply chain for the baths specifically related to the fuel supply. We'll try to analyze how this fuel consumption was funded, who managed the baths (and the fueling), and how the fuel got to the baths. For this section however, we are almost entirely surrendered to ancient sources, mostly benefactions and texts of law. Especially reconstructing the cost of fuel (in price) and the cost of transport (in a variety of ways), based on textual evidence, has weaknesses which need to be addressed. We've tried to follow the example of Veal and Blyth and produce estimates that stand up to historical comparison, yet in the end these remain speculative at best and are largely based on wood.

Ancient sources reference fuel (and fuel types) only in passing. The archaeological record however shows a rich variety of fuels used. We shall try to synthesize from these various sources from across the Empire, instead of focusing on one particular area. This has drawbacks, but also some benefits, which shall be discussed at the beginning of section 3. Based on a typology by Visser, we shall try to argue the ancients knew managed silvicultural systems, which probably grew in importance. We shall compare these to the small survey of archaeological studies we've undertaken, to see to what extent the ancients managed, rather than exploited their hinterlands. We shall also quickly explore whether raw wood or charcoal was used. The latter of course is often considered in urban consumption, as it contains a higher calorific value,[13] provides a more clean burn, and is much lighter, making it easier to trade. We shall then emphasize the different non-wood fuel varieties we've encountered in our

[10] See for example Hughes, D. (2011)
[11] Wilson, A. (2012), pp 150-151
[12] Wilson, A. (2012), pp 150-151
[13] The calorific value is the measure for the amount of energy a fuel will give off in a fire. This can be expressed in calories or in joule, or in kilowatts per hour.

survey, a variety perhaps hinted at in the wide definition of fuel in the *Digesta*. The various fuels encountered allow us to construct a broad typology of what kind of fuels would have ended up in the public baths. These were likely as easy to procure as raw wood (perhaps a fair bit lighter and close-by), resulting from by-products in agricultural production.

Finally, in the last section, we shall try to engage with the various models of the fuel economy, both in the quantitative sense and in the qualitative sense. This will allow us to evaluate and formulate a response to Wilson's assumptions.

Corpus

1. Fuel Consumption

There are three ways to try and gauge the amount of fuel consumption of the public baths. The first is by checking ancient sources. These do give us notions on the quantities of fuel that might have been used. Because here we are explicitly looking in ancient sources for volumes of fuel consumed, only several benefactions can be featured. Certain benefactions, leases and contracts could be used to calculate fuel volumes, but these are expressed in monetary cost. They will be dealt with in the following chapter (Chapter 2 Bath Operation and Cost. Bath management). This is because these aforementioned sources feature the cost of fuel, i.e. financial payments, and they do not readily convert to volume. They require among others to check what is actually priced and to factor in the cost of transportation. The second way to gauge fuel consumption is by analyzing its components, or comparing the hypocaust system to more modern installations. For example, we have no real knowledge of the temperatures inside the heated rooms themselves but hammams provide a good comparison for example to gauge the temperatures used in these baths, as the systems they use are somewhat similar. These can be cross-checked with our ancient sources. The third way to gauge fuel consumption is via archaeological reconstruction, thermal analysis and heat transfer studies.[14] In the Cambridge Companion Andrew Wilson gives an example of a calculation for the requirements of heating a pool in a caldarium (hot room). These kinds of studies have made a remarkable advance in recent years and are growing increasingly reliable. The work of Miliaresis in this respect promises not only to reduce general arbitrariness in these calculations, but eventually to provide a blueprint than can be applied to any local bathhouse. This will no doubt prove to be a next step in reducing guess work and help further quantify the fuel use in the Roman economy. Combined with ancient sources it will help in furthering our understanding on bath management and the social relations of the fuel economy of baths.

1.1 Ancient Sources

An inscription from Misenum from the late second century CE records a donation by a duumvir to the town's baths of 400 cartloads of hardwood.[15] This amount was to be given each year *in perpetuum*. It seems likely these covered the full costs of heating. Seeing as a cartload is 1200 *librae* or 393 kg's, then the amount donated would be 157 200 kg of hardwood. To guess how much area was required to supply this we can integrate the yield for coppiced woodland. To this end we will used figures cited in Blyth to receive 3.5 tons per hectare for ash (Fraxinus sp.), 2.3 tons per hectare for chestnut (Castanea sp.) and 1.75 tons per hectare for oak (Quercus sp.).[16] To support this, we note that Veal reports that these species are plentifully discussed by ancient authors with respect to being used for coppice.[17] It should be noted that the Mediterranean is very diverse, and yield figures will normally vary a great deal depending on climate and soil conditions.[18] Furthermore, it is unclear if Blyth

[14] See McParland, L. et al(2009), Blyth, P.H. (1999), Rook, T. (1978) or the Sardis experiment with among others Yegül, "Roman Bath at Sardis," NOVA/WGBH, 1998-99 Program *ROMAN BATH* aired on national PBS Television, February 22, 2000, which we believe has been made public on the PBS YouTube channel <<https://www.youtube.com/watch?v=FKBc3_fKHtA>> last check 07/2015

[15] CIL X, 3678

[16] Blyth, P.H. (1999) p 88. The figures he cites come from P.T. Maw (1912) *The Practice of Forestry* (London-Leipzig).

[17] Veal, R. (forthcoming), p 142

[18] Muys, B et al (2010), p89

accounted for moisture content in wood, as he makes no mention of it.[19] This means these figures provide only a rough estimate and could be off due to a variety of factors. Ideally local conditions and habits should inform our guesstimates. However finding published coppice yields for various locations proved well-nigh impossible. Using Blyth's figures nonetheless would mean an area of 45-90 hectares (ha) was used to supply these baths, depending on which mixture we give an assembly of the three species.[20] An 'average' daily supply could have been provided by about 25 ares.[21]

Not every bath would have been supplied with hardwood. We are not the only ones who think this benefaction should be read as an act of largesse where accordingly the fuelwood was qualified as 'hardwood' (*lignus durum*) as opposed to say trimmings and brushwood of the ubiquitous Mediterranean maquis vegetation.[22] If we take Grove and Rackham's estimates of the productivity of maquis vegetation for fuel wood per year, then this would mean a similar year's supply would have been provided by 157 ha of maquis.[23] The 'average' daily supply could have then been provided by about 43 ares.[24] We can compare these figures to another inscription that records an area of woodland that was donated in the late first century. Here a duumvir and his daughter built and donated baths to the city of Aurgi, Hispania Tarraconensis, along with an aqueduct, and 300 agnua of woodland to supply the baths, which is about 36 ha.[25] The yield figures Blyth cites in converted form are: for chestnut 0.57- tons of wood per iugerum, for ash 0.87 tons of wood per iugerum, meaning a yearly yield between 85 500 kg – 130 500 kg.[26] For oak this has been calculated to 65 625 kg.[27] This amounts to between 166 and 217 cartloads (loaded with 1200 librae or 393kg's), which averages to somewhat less than half compared with the Misenum inscription in order of magnitude.

Suppose the Misenum inscription did not specifically mention the use of 'hardwood'. We could then also compare with yields for a forest of pine (Pinus nigra), a softwood. This species is still common in Spain, Turkey and the Balkans. If we use the total amount of wood donated at Misenum (157 200kg), and take yield estimates from the Xylarch project, we would get an area of 40.89 ha.[28] These figures are different from the one Blyth uses because of several reasons. Firstly factors such as wood density and moisture content have been accounted for. [29] Secondly, pine grows faster than oak or chestnut. Thirdly, the figures from Pinus nigra are from clear felling, instead of coppice. Lastly, the figures featured in the project are based around conditions that derive from Sagalassos, Turkey. This site is

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[19] Blyth, P.H. (1999), p 88

[20] An example of such a calculation goes: 157 200 kg is donated. We divide this by 1750 kg/ha = 90 ha for a mixture of only oaks. For a supply of only ash this would mean 45ha, for only chestnut this would mean 68ha. To further simplify, if this last figure is seen as coming from a single plot, this would mean an area 750x1200m. Various mixtures can provide a range between these results, but seeing as these figures are rough estimates to gauge the range of areas needed, they have been omitted.

[21] Using a year of 365 days and without accounting for seasonal differences. As above, simplified, this means an area of 50x50m.

[22] Blyth, P.H. (1999), p 87

[23] Grove, A.T. and Rackham, O. (2001) p 172, the figure being 1 ton of wood per hectare. As above, if seen as coming from one plot of land, 157ha roughly means an area the size of 1000x1600m.

[24] As above, this means an area the size of 62x70m.

[25] CIL II.3361. One agnua is 1262 m^2, and is roughly half of one iugera, which is 2523m^2.

[26] 300 agnua is 150 iugera, so 150x0.57= 85.5 tonnes of wood. Similar calculation for ash. A iugerum is about 0.25 ha

[27] 1750 kg/ha, with 1 iugerum about 0.25 ha means 437.5 kg yield per iugerum or for 150 iugera a yield of 65 625 kg

[28] Xylarch Project (Muys,B; Jansen, E; Poblomé,J and Degryse, P.), Leuven, and from personal correspondence. The figures and calculations are the following: There is 157200 kg wood with an estimated moisture content of 30%. Pinus nigra has an oven dry wood density of 414 kg/m^3. This means a burnable volume of 265,78 m^3 . The average growth rate for Pinus nigra forests locally was estimated at 6.5m^3/ha/year meaning that for sustainable exploitation an area of 40.89 ha is needed.

[29] There is evidence the ancients were aware of moisture content in woods and felled trees at certain times e.g. in fall where moisture content was high, to counter rot. See Nenninger (2001), pp 38-41

at 2000m above sea level and features cold winters and specific soil conditions. It is commonplace in forestry to assign a number value to the conditions for a tree species (called a 'sideclass') to grow and thrive; ranging from 1 (less ideal) – 5 (ideal soil and climate/altitude).[30] This means the same species in different locations can grow to different proportions and produce different yields. Again these are 'guesstimates' and not exact calculations. These figures (40 ha) and lower range of Blyth's figures (starting from 45ha) do correspond somewhat to the amount donated by the duumvir at Aurgi (36 ha).

Another inscription from 5th Century CE Catania, eastern Sicily, reports that the daily use of wood in the Achillean baths was reduced from 32 pensae to 18 pensae each day.[31] According to Herz, when calculated to modern weights, the corresponding values are 4960 kg, to 'only' 2790 kg each day. The fact that these figures are expressed in 'daily use' is interesting. One would expect there to be differences between fuel use in summer and winter, even for Sicily.[32] The lack of distinction between summer and winter in this inscription could of course be explained away as being 'average figures'. Another argument is that the differences in temperature did not matter for how much fuel was used. Perhaps because of contractual obligations the same amount was stoked each day, regardless of temperature or comfort. Of course this would be against the spirit of this inscription, which proves that Romans were –at least sometimes- aware and sensitive to how much fuel was used. Calculated to a year (where the baths are active 365 days) the inscription tells us fuel usage dropped from 1 785 600 kg to 1 018 350 kg. This figure is about ten times the amount that would have been used at Misenum, if the calculations above are correct, and about twenty times that of Aurgi. Correspondingly, the area needed to sustainably supply the original amount of wood, would be between 776-1020ha, dropping to 442-582 ha, using Blyth's figures for the yield of coppice from chestnut or oak. Using the figures for Pinus nigra from the Xylarch project would give us 464 ha dropping to 265 ha. Again, though the Xylarch figures are more recent estimates than the figures cited by Blyth and Grove and Rackham, they normally applied to the area of Sagalassos of ancient Pisidia (modern province of Burdur, Turkey), and are for clear-cutting instead of coppice, so they might be inaccurate for this location. It has proven difficult however finding published estimates of yields figures (using ancient methods) applied to the various sites mentioned. These would of course give more accurate results.

Admittedly, if we do not connect figures from ancient sources to archaeologically dated baths, these calculations are not properly contextualized. Without it, we cannot identify which type of bath used up what kind of volume of fuel. The Achillean baths at Catania have been archaeologically attested, so these findings can be cross-checked with archaeological reconstruction and reconstructed fuel estimates. I am uncertain however to the degree to which this has been done. Checking Manderscheid's bibliography, which runs from 1988 to 2001, I have found only one archaeological report for this area.[33] Because we lack a specific archaeological context for the Catania inscription figures (though the complex reportedly was big), we do not know how many furnaces constituted these daily fuel-use. Similarly, the public baths at Misenum have also been archaeologically located.[34] Both the reports of Misenum and Catania however are only available in Italian, so they remain inaccessible to me. Lastly, as stated in the introduction to chapter 1 above, there are also fuel use

[30] Muys, B., et al. (2010), p 89

[31] IG XIV 455 = AE 1959, 26, see also Manganero 1958, pp 24ff

[32] In general there is an average difference in temperatures of at least 10°C between summer and winter temperatures in Sicily

[33] Wilson, R.J.A. (1996) "La topografia della Catania romana. Problemi e prospettive" in Gentili, B (ed) *Catania antica. Atti del Convegno, Catania 1992* (Quaderni Urbinati, Atti di Conveni 6; Pisa 1996) 149-173 as found in Manderscheid,H. (2004) in JRA SUPPL 55

[34] Cinque, A., Russo, F. and Pagano, M. (1991) "La successione dei terreni di eta post-romana delle Terme di Miseno (Napoli): nuovi dati per la storia a la stratigrafi del bradisisma puteolano", in *Bollettino della Societa Geologica Italiana* 110, pp 231-244 and Maniscalco (1997) *Ninfei ed edifici marittimi severiani del Palatium imperiale di Baia* (Studi di Storia e Topografia sulla Campania Romana, Napoli 1997), p 104, 106f. as found in Manderscheid, H. (2004) in JRA SUPPL 55

estimates based on benefactions or contracts expressed in financial terms, and not in volume. These require several different calculations however, so these will be treated in chapter 2 Bath operation and cost. Without using an archaeological context, it is impossible to extrapolate these figures to other baths. Similarly, based on these figures alone, it would be hasty to make conclusions about the sustainability, or the environmental impact of heating the baths. These figures do serve to express a possible range of fuel consumed, based on ancient sources. We can also compare these figures with the area required for sustainable exploitation, again giving a general idea what kind of area the ancients would exploit to provide for their local baths. These figures are rough estimates that we can use to compare with archaeological reconstructions (cfr section 1.3). However they already provide us with a more tangible idea why many have considered these baths as fuel-hungry, and a primary unit in transforming the environment into a more managed –or even denuded- landscape.

1.2 The Influence of the Hypocaust System, the Opening Hours and the Bath Temperatures

1.2.1 The Hypocaust system

For the reasons mentioned above, it seems that using archaeology as a basis for the study of fuel consumption has proven more popular. The reconstructions of Roman heated baths treated in the latter part of the chapter are rooted in (experimental) archaeology. In order to understand and interpret these reconstructions, we will swiftly introduce the basics of a hypocaust system, placing emphasis on where certain elements might relate to fuel consumption. The general principle behind a hypocaust system is usually the same (for an illustration of the system, see addendum 3 fig A). A furnace was stoked in a chamber on a lower level (the *praefurnium*), which was connected to a space underneath the heated rooms of the bathing complex. The hot air would flow underneath elevated floors (*suspensura*), eventually being drawn out via a flue or 'chimney' because of convection.[35] The fire burned directly on the floor of the tunnel that connected the *praefurnium* with the *suspensura*, without a grate.[36] Rook likens this process more to a bonfire than a modern fireplace.[37] He notes this has the advantage that the temperatures of the fire can be adjusted –or kept constant- by manipulating its size and geometry. A bonfire-type fire has the advantage of burning more slowly in comparison, because the air is drawn over the fire, rather than through as with modern grated fireplaces. As a result it can also be left burning unattended for long periods.

From the early empire onwards several additions to this system became common. These included spaced tiles or hollow tubes in the walls, and perhaps sometimes through hollow tubes in ceiling vaults.[38] With these innovations, the hot gas was also made to flow through the walls. This of course provided insulation and countered condensation.[39] At the same time, this warm air would turn the walls into an active heating agent.[40] As Seneca reports, an even heat was radiated throughout the heated room, even in "the lowest or highest areas of the room".[41] Heating the walls means a larger

[35] As far as we know, ancient Roman bathhouses did not resemble 'chimneys' as we know them. Instead they had vent openings or flues. See Rook, T. (1992) pp 30-33, citing among others evidence from the Simpelveldt Sarcophagus. Because these openings functioned as chimneys do, and for lack of a better word, the word 'chimney' and derivates will still be used (esp. in connection with 'chimney-sweeping')
[36] Rook, T. (1992), p 26
[37] Rook, T. (1992), p 26
[38] For a more comprehensive treatment of these heating systems (with tegulae mammatae, hammatae and tubuli), see Schiebold, H. (2006), pp 15-24
[39] Yegul, F. (2010), p 87
[40] See for example Yegül, F. (2010) pp 79-90, for walls as an active heating agent see pp 86-89
[41] Seneca, *Letters* 90.25 translation from Humphrey, J. W. (1998). *Greek and Roman technology : a sourcebook*, p275

surface area was transferring heat, in comparison to only heating the floors. According to Rook, the heat was also transferred to the heated room more easily as the tiles and plaster of the walls are much thinner in comparison to the concrete floors.[42] There is another interesting side effect for our purpose of studying fuel consumption. For its visitors, the heated walls would have provided the same heating effect but at a lower actual room temperature. As Rook notes, this is because humans respond more to radiant heat.[43] To use the example Rook gives: when a cloud passes over the sun, it might suddenly feel colder.[44] This is because the heat that was radiating from the sun has been cut off, even though the air temperature has not changed. The impact of this on heated baths is that the furnaces can operate at much lower temperatures while still providing the same warmth effect inside the heated rooms. So, for a similar outcome, this implies less fuel needed.

Another effect that would have influenced the fire in the stoke room is how fast the air flowed through the system, called the 'pull' of the air. A system where the tubes in the ceiling level were closed off, connected together and forming a single flue would provide a small draft. If not enough draft is present, there is a risk of carbon-monoxide (CO) being formed. If these were opened and the top level had many more connections to the chimney-flue[45] (see addendum 3, figure C), there would be much more draft and the fire would burn more intensely (See addendum 3, figure E for an illustration of the flow of air inside a heated wall, with an opened up top level). According to Yegül, a 'closed' system would probably be more slow-burning and economical.[46] Such a system would correspond to Statius' poetic account of a hypocausts 'slow burning fires' (*ignis languidus*).[47]

Often the heated rooms had heated pools. Ideally the water for these pools came in from pipes connected to the aqueduct, otherwise it was gathered from a well or a reservoir. Most hypocaust systems would use one or several boilers placed right over the fire in the stoke room, from which water could be used.[48] The pools were usually enclosed in thick masonry. Heating the water of these through the concrete floors would not have been swift, and maintaining a steady heat for long periods of time would have required oversight. That's why a lot of pools featured a metal 'box' (actually a half-cylinder), the *testudo*, usually made of copper, open on the end of the pool at the bottom, and connected to- but closed on the end of the fireplace. This closed end would have been exposed to the heat of the furnace and thus heating the water inside this part, moving it toward the open end at the bottom of the pool (called the *alveus*) and pushing the cool water toward the closed heated end (see addendum 3 fig B).[49] Bathhouses had many local adaptations to suit local needs and many different factors have to be reckoned with, such as the type of building, its size, the height its roof, the difference between outside and inside temperature, the types of walls in use (tegula mammata, tubuli, etc.), etc. In the northern part of the empire, to counter the colder temperatures, the baths could have had spaces for hot air to flow through the ceiling, its vaults and semi domes.[50] In the more arid regions the frigidarium and the pools (*natatio's*) would have featured more significantly.[51]

1.2.2 Opening Hours

[42] Rook, T. (1992), p14
[43] Rook, T. (1992, pp 14-15
[44] Rook, T. (1992, p15
[45] See footnote 34 on the use of the word 'chimney'
[46] Yegül, F. (2010), pp 87-88
[47] Statius, *Silvae* I, 5 "ubi languidus ignis inerrat aedibus et tenuem volvunt hypocausta vaporem?"
[48] See for example Rook, T. (1992), pp 28-29 or Blanco, A. and Pucci, M. (2012) "The boiler room of the Small Baths in Hadrian's villa" in Conference on Cultural Heritage and Technologies (CHNT) 17. There is also Vitruvius' account of how these boilers were supposed to work; *De Architectura* 5.1.1
[49] Famously, see for example the Stabian baths at Pompeii
[50] For example the baths at Aquae Sulis (Bath, England), see Rook, T. (1992), pp 33-34
[51] See for example Marechal (Sadi) ?

It is likely the opening hours had some influence on fuel consumption. Vitruvius states that bathing between midday and dusk was normal.[52]Martial indicates a somewhat similar timeframe (cfr infra).[53] Yegül argues that most people bathed in the afternoon, when the working day was done, and generally bathers wanted to bathe under copious daylight.[54] There are exceptions known where longer bathing hours were provided. Nielsen notes that sources like Martial or Vitruvius mostly consider men and a man's working day, or imply double bath facilities, with separate sections for men and women.[55] Especially during periods where mixed bathing was in disfavor, certain public facilities that lacked these facilities would have provided earlier opening hours to accommodate for women.[56] The baths from the Vipascenum inscription, for example continued operation from first light to the second hour of night, and the hours between first light and midday are especially reserved for women.[57] Nielsen reports that a graffiti from Arcades in Crete, early Imperial times, had similar hours for the baths, painted on the wall. [58] Other regulations showing that longer opening hours existed are also known.[59] Bathing at later hours might have been popular for some time. Nielsen points out that Alexander Severus donated lamps and oil to keep public baths opened at night.[60] As Merten points out however, the context of the inscription is to note the emperor's generosity and the largesse of his gift.[61] Some fifty years later, Emperor Tacitus however ordered the baths inside city walls to close at night.[62] On this basis, both Yegül, and Nielsen conclude that nightly bathing, when it occurred in the public baths (it was probably more frequent in private ones)[63], should be considered the exception that reinforces the rule.[64]

Most public baths were open every day, except possibly when maintenance was required. For the baths at Vipascenum this was once a month.[65] Nielsen shows, this is generally also true for private baths.[66] Kretzschmer states that after 5 days of continuous firing at an experimental furnace at Saalburg, only 3 to 4 handfuls of ash were found.[67] He found similar results for a firing in Xanten.[68] Though these tests were done with charcoal, which usually leaves very little ash. Nielsen similarly remarks that it is uncommon for much soot to be found in excavation layers, indicating little was produced in the firest place.[69] This makes it probable that shutting down the praefurnium/suspensura section for cleaning out soot would have been kept to a minimum (another look into the matter of maintenance will be given Chapter 2, in section 2.1.2 and 2.2). Though with different fuel types, there would have been different cleaning requirements, among others to avoid chimney fires, so we should not rely too much on the figures from Saalburg (cfr Chapter 3 Types of Fuel). For example, the walls

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[52] Vitruvius, *De Architectura*, 5.10.1
[53] Martial, *Epigrams*,10.48
[54] Yegül, F. (2010), pp11-12
[55] Nielsen, I. (1993), pp 135-136
[56] Nielsen, I. (1993), pp 135-136
[57] CIL II, 5181, l 18-21.
[58] Nielsen, I. (1993), p 135
[59] Cfr Nielsen, I. (1993), pp 135-138 cites, among others, the following sources: Emperor Tacitus is mentioned to have forbidden bathing when normal daylight had faded (S.H.A. Tacitus 10.2) and Hadrian decreed that no one but invalids were allowed to bathe before the 8th hour (Hadrian S.H.A. Hadr 22.7).
[60] Scriptores Historia Augustua, Alexander Severus. 24.6 as quoted in Nielsen (1993), p 136
[61] Merten, (1983), pp 77f. as quoted in Nielsen (1993), p 136
[62] Scriptores Historia Augusta, Tacitus 10.2
[63] Juvenal, *Satires*, 6.14.19 mentions the case of a woman bathing at night, in a private bath however.
[64] Yegül, F. (2010), p12; Nielsen (1993), p 136
[65] CIL II, 5181, l 24-27.
[66] See for example P.Flor III 384; an exception is the contract for the baths at Theogonis which requires opening every other day and on festival days, P.Mich. V 312 l 17, as quoted in Nielsen (1993), p 137
[67] Kretzschmer, F. (1953), p 27
[68] Kretzschmer, F. (1953), p 27
[69] Nielsen, I (1993), p 19; though see for example excavation of the baths of Bulla Regia, at the base of hypocaust site 24/16 for where it has been found, Broise, H. and Thébert, Y. (1993)

of the hypocaust in Thamusida were found to be coated in a resinous tar, indicating undried (soft) wood was burnt.[70] Similarly, a small layer of soot was found in the 4-5th century layers of the public baths at Bulla Regia.[71] The general lack of archaeologically attested ash can perhaps be reconciled with the passage of Pliny where he notes that enough soot was left in the hypocaust for the children of school to make ink out of.[72] To put this into context, Kretzschmer found that it took 12+ hours after the last fire was put out, for the suspensura temperature to sink below 40°C (from around 70°C), a point at which a person could enter without risking fainting and 24+ hours for it to drop below 30°C.[73] This means cleaning of the hypocaust/suspensura was a hot and arduous task if the baths only closed for one day (24 hours), as the Vipascenum contract explains. Nielsen notes other exceptions to daily opening when the emperor or one of his family died, or in the Christian period, on Sundays.[74]

However, it is not easy to translate opening hours into how much fuel was used. Rook has argued that not allowing the fires in the stoke room to die down completely would have been more efficient overall.[75] Yegül also estimates it would have probably taken a whole day or more to get unheated baths to the required temperature.[76] This means it is possible that the fuel consumption of baths was somewhat detached from their opening hours. As Nielsen notes, there are indications that people were called to the baths at the 'regular' times.[77] She shows Pliny mentioning a bell being rung when the water in the baths had achieved the right temperature.[78] Similarly, she finds Martial mentioning that the bell of the warm baths was rung at a certain point.[79] She argues that this was to warn people the heating of the pools was going to be stopped, and so they should hurry if they do not wish to bathe in cold water. It could however also mean the heated section of the baths closed before others (outdoors) sections did. It is possible the heated sections in certain baths could be closed off, where other (outdoors) sections remained open.[80] All the same, it is likely this account can be linked to a certain way of stoking in the furnace chamber.

To add to this speculation we find Martial mentioning that he prefers the eight hour for using the baths, as the seventh hour features 'an intolerable excess steam', and the sixth hour he considers the baths hot beyond measure.[81] Thought, it is prudent however to read Martial as high-society chitchat, accustomed to finer taste, it is possible though that Martial's account corresponds to a certain way in which the fires might have been stoked (cfr infra). We can imagine the furnaces being fed plentifully early in the morning to ensure that the building was again heated up to the required temperature in time. After a certain time then, a bell could have been rung to warn the visitors that the fire would as of then would be allowed to wither. From then on, it would have been kept smoldering for the night (we shall revisit the theme of how the fires were stoked again in chapter 2 Bath operation and cost). This does not mean that what Martial said was true to the full extent of what he implies; that nobody

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[70] Rebuffat, R. et al.(1972)
[71] Broise, H. and Thébert, Y. (1993), pp 132-134
[72] Pliny, Historia Naturalis 35.41
[73] Kretzschmer, F. (1953), p 27, fig 19
[74] For the closing on baths when someone from the imperial family had died, see for example Diod. Sic. 1.72.3, Suet. Calig 34.2; Euseb. Vit. Const. IV 69, and for closing of baths in Christian times see for example P.Flor. 384; as quoted in Nielsen (1993), p 137
[75] Rook, T. (1979), pp 277ff
[76] Yegül, F. (2010), p 82
[77] Nielsen, I. (1993), p 136
[78] Pliny, Letters 3.1.8 as quoted in Nielsen, I. (1993), p 136
[79] Martial, Epigrams, 14. 163 as quoted in Nielsen, I. (1993), p 136
[80] See for example the Center Baths at Pompeii, where the *palaestra* section is relatively open, and has many entrances, but the heated baths only really had one for non-staff.
[81] Martial, Epigrams,10.48

used the baths before the eighth hour. As seen above, there are sources that imply the baths were used before the 8th hour, as a special measure for certain groups.[82]

1.2.3 Bath Temperatures

The Romans had no scientific way of measuring temperature (or humidity for that matter, cfr infra). This means we have no sources that mention in objective terms what temperatures the furnace operated at, nor how hot the heated baths were. When Pliny recounts the attempted murder of Larcius Macedo by his slaves in his baths at his villa, he mentions they threw him onto the hot floor to see if he was feigning death.[83] Fronto describes being burnt when his knee was accidentally bumped into the wall of baths.[84] A mosaic from Sabratha depicts bathing sandals (*soleae balnares*) that could have been worn to withstand the hot floors in the caldarium (see figure 1 below). This is reportedly quite similar to what is worn in modern hammams, Yegül reports.[85] These also have an equivalent tepid room, and a hot room. However, their difference lies in not using heat from the walls, which is a key difference we shall return in the next section (cfr infra; The Nova baths experiment). Yegül states that modern Turkish baths, which use similar technology for heating floors, have minimal floor temperatures of 42-44°C, which is too hot to walk on barefoot, and that wooden clogs are normally worn. They produce ambient temperatures upwards of 37-38°C, which is the minimum to induce the sweating effect. This is because the human body operates at around 36°C. Rook explains that "the subjective assessment of ambient temperature depends upon the ease with which heat is lost by a person at this temperature by [radiation, convection and by evaporation of sweat]".[86] If the air temperature inside a heated chamber is above the heat of the body, then the body cannot lose heat through convection. If the walls are heated as well, this eliminates radiation by the body towards them, leaving only sweating and evaporation to control body temperature.[87] Finally, the degree of humidity determines whether the sweat will evaporate or run off, the latter being more difficult to tolerate than dry heat.

Figure 1 mosaic from Sabratha showing bathing sandals

Furthermore, as the bathing habit became ever more popular, it seems the hot- or coldness of the baths became a *topos* of conversation. An anonymous satirical poem states:

[82] Cfr footnote 49, Hadrian Scriptores Historia Augusta, Hadrianus, 22.7
[83] Pliny the Younger, *Letters* 3.14
[84] M. Cornelius Fronto, *Letters* 5.59
[85] Yegül,F (2010), p 83; see also Brödner, E. (1983) for an analysis and comparison of ancient baths with a medieval turkish bath "Incirli Hamam" from Bursa/Turkey
[86] Rook, T. (1978), p 272
[87] Rook, T. (1978), p 272; however it should be noted that the walls have to be heated to about room temperature, to eliminate the possibility of the human body radiating heat toward them. Conversely, when the walls are heated to a higher temperature than the room (air) temperature, the walls start to radiate heat.

"You should call this not a bath but rather a funeral pyre (...) [to the bathman] If it is your purpose to burn numbers of us alive, light a wooden pyre, executioner, and not a stone one."[88]

Martial of course features many jibes and jests in this respect.[89] He jokes:

"Faustinus, if you wish to temper these baths so blazing, that even Julianus would have trouble enduring, invite the orator Sabinus to bathe; his iciness chills the hot baths of Nero![90]

Seneca too, we can find nagging about the heat at which pools in the baths were heated in his day (as opposed to days of old).[91] Both accounts allude to the fact that temperatures among different baths might have varied, and competition probably arose between baths in a town or city, to cater to different tastes.

1.3 Archaeological Reconstruction, Thermal Analysis and Heat Transfer Studies

Several attempts have been to reconstruct hypocaust baths and learn from them. This involves seeing how the building is heated, how much heat was then required and thereby how much fuel was needed. Even though the discussion of these themes do have implications for fuel consumption, a comprehensive overview of the literature will not be given.[92] The limited review provided here is basic and non-specialist. The heating of the tepidarium in these cases will not be considered, as it is assumed to be secondary to the caldarium. From the early empire onwards baths usually featured large windows that were faced south to south-west. As Seneca laments, this allowed sunlight to enter more copiously and became quite popular (he, of course, appreciates the earlier, darker baths).[93] If these windows were (double) glazed, they provided a net benefit in heating, according to Ring.[94] However, the impact of using solar energy, and the heat loss resulting from the windows from the early empire onwards will not be featured here.[95] Similarly, the heating of the boiler and pools and the 'match' between the heating of the rooms will not be featured (though the energy required for their heating is included in the 'heat balances, cfr infra). Blyth states that because of differing outside temperatures, the water might be heated too much in winter, and not enough in summer.[96] This would require a review of how much heat goes to heating the water, and how much goes to heating the boiler, and would take us too far.

A few studies will be featured that took place in heated baths, either modern reconstructions, or archaeological reconstructions using estimates. 'Heat balances' will be used, where available, for a modest comparison between these cases. A full comparison would require an in depth look at the origin of these heat balances, which again is too ambitious for our purposes. These 'heat balances' depend in part on the view of the operating conditions of the baths, of which we know little. When measuring and comparing the operating conditions of a hypocaust, three aspects should always be

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[88] The Greek Anthology. XI 411; translation Paton, W. R. (1916). *The Greek anthology,* p 268 available online: Loeb Classics series <http://www.loebclassics.com/> last check 29/05/16

[89] Martial, 9.75. Tucca had built wooden *balneum* and marble *thermae.* Martial noted the lack of fuel in the latter and suggested the balneum be put to good use. Yegül's interpretation is found in Yegül, F. (2010), p 48

[90] Martial, Epigrams 3.25, my translation

[91] Seneca, Epistulae, 86.10

[92] For that see either Schiebold, H. (2006), pp 66-93, Grassmann, H-C. (2011), pp 8-15; or Miliaresis, I. (forthcoming)

[93] Seneca, Epistulae 86.8

[94] Ring, J.W. (1996), pp 717-724, in the case of the Forum Baths at Ostia, a net inflow of 340 000 BTU/hour, see Table 1, p 722

[95] An early example of this technology is the Center Baths at Pompeii

[96] Blyth, P.H. (1999), p 89

accounted for: air temperature, the temperature of the floors, walls and ceilings and the humidity (cfr supra section 2 The Hypocaust system). However detailing these aspects, along with room volume, outside temperature, heat losses, fuel consumption etc., would take us too far. To properly compare the heated baths featured below, the studies in question (referenced) simply need to be consulted. The aim is to take estimates of fuel consumption, and expand -where necessary- on some basic elements to give the reader a general idea on the matter. This will allow a modest comparison to the ancient sources dealt with in the first section (cfr supra section 1.1). It will be concluded by pointing to newer, promising research that claims to be able to reduce the element of guesswork in modern estimates.

1.3.1 The Saalburg baths

In 1952 Kretzschmer was the first to undertake an academic study of a small reconstructed room in Saalburg, fitted with suspensura and tubuli.[97] For the first time, this included a temperature study inside the room and a flow model of the hot gas. These are the basic necessities that allow heat transfer calculations.[98] The hot room measured 5.14x4.42x3m and its volume is around 68m^3. An average room temperature of ca 25°C was achieved with a floor temperature of ca 26-27°C, with outside temperatures varying between -2 and 5°C. The temperature in the furnace itself fluctuated between 45-110°C. Firing was done from 8 o' clock in the morning till 8 in the evening. After an initial period of heating up, about 7,5 kg of charcoal was added to the fire every four hours. About 150 kg of charcoal was used over a 5 day period.[99] The work claimed however that the *tubuli* walls were 'not active', merely serving as insulation. Even though temperatures somewhat lower than room temperature were measured inside the *tubuli*, it was thought they provided no additional heating to the room. This would make it a 'passive heating' system.

Later analysis of the same establishment with more advanced tools (e.g. thermal imaging) by Hüser showed that *tubuli* did actively heat up the room.[100] Roughly every two *tubuli* columns were filled with heated gas, alternating with two colder *tubuli*. Research that was done later by Grassmann, in the 'Herbergsthermen' in Xanten in '93-94, generally supports Hüser's analysis and show that the tubuli walls did have an active part to play in heating the room.[101] Nonetheless, some controversy remains surrounding details of the heating system, and how to reconstruct it.. Grassmann's model of the gas flow based on Hüser's measurements is rejected by Schiebold, on the grounds that 'it goes against modern knowledge about behavior of gasses'.[102] For his part, Schiebold accepts a flow model where the sideways openings in the tubuli are to equilibrate pressure, nonetheless resulting in an ever upward movement of the hot air (Reichel's flow model, see addendum 3: fig F).[103] Whereas Grassmann compares his model to that of the behavior of warm water according to gravity (both gas and water behave as fluids; see addendum 3, fig B and E).[104] A higher temperature allows for a less dense concentration (and lower pressure), so the warm elements rise. By heating the *tubuli* and the bath walls, the gas gives off heat and will then descend, resulting in a higher density (and higher pressure). It is then more susceptible to gravity and will descend again. He counters that the standard flow model would suck in so much air that the hot gas from the praefurnium would be cooled off.[105] To counter

[97] Kretzschmer, F. (1953), pp 7-41, with also a later reanalysis: Kretzschmer, F. (1961) "Die Entwicklungsgeschichte des antiken Bades und das Bad auf dem Magdalensberg; see also Schiebold, H. (2006), pp 81-89 for a more detailed analysis
[98] Grassmann, H-C. (2011), p 9
[99] Kretzschmer, F. (1953), pp 24-25, figs 15-18, also p 27, fig 19
[100] Hüser, H. (1979), pp 12-30
[101] See for example Grassmann, H-C. (2011), pp 12-31
[102] Schiebold, H. (2006), pp 89-91
[103] Schiebold, H. (2006), p 91; and Reichel, W. (2007), p 79 and fig 2
[104] Grassmann, H-C.(2011), p 32
[105] Grassmann, H-C. (2011), p 12

this a very strong burn would have been necessary. Grassmann however supposes that a slower burn would have been desired (cfr supra '*ignis languidus*'), as it is more fuel efficient. Research featured below, by Yegül, seems to agree with Grassmann's model.[106]

1.3.2 The Herbergsthermen

In the early 90's Grassmann ran several measurements at the 'Herbergsthermen' in Xanten.[107] The 'Herbergsthermen' caldarium has a volume of 142m^3. It has an alveus capable of containing 4200l, and the furnace also features a boiler (capacity 1000l). Newer technology allowed Grassmann to measure and calculate various sources of heat loss, meaning 'heat balances' could now be made accurately. These balance the input of energy and its loss, and allow for detailed comparison of different bath installations. As mentioned above, we shall not use these to compare in detail the different baths featured (though their summary is added in addendum 4), as this would take us too far from our intension and would make an analysis more specialized. Grassmann measured that in winter initially 120 kg was stoked. While maintaining a steady heating of the baths at 31°C, this amount could be lowered to 100 kg a day (24h) after 6 days. The heat loss in winter was calculated to be around 12,01 kilowatt (later kW), which means an hourly input of this much energy was needed to maintain steady temperatures. In summer, initial usage was 150 kg, which then dropped to 100 kg after 7 days, and from the 11th day onward around 65 kg's of wood fuel was used each day to maintain a steady 37°C. Here the heat requirement was 7,73kW. He claims the latter was 'overheated', and a 31°C average in summer would only take 50kg's. The air humidity in the caldarium for both seasons was between 60-70%.[108] The water in the boiler started at 10°C. It was found that during the opening hours of the baths (an estimated 16 hours) around 80 liters of water at 40°C could be used every hour.[109] Similarly, the alveus was heated from 15°C to 30°C in winter and around 40°C in summer.[110] Grassmann made the remarkable conclusion to his fuel report by stating that the heat retaining capacity of the hypocaust system ensured that even though outside temperatures fluctuated widely in both seasons (winter from 0-10°C, summer from 16-22°C), steady average temperatures could be achieved after a few days, with a steady daily fuel input.[111] This heat conservation, against daily fluctuations, has implications for fuel delivery (cfr Chapter 2, section fuel contracts). This means that to gauge average fuel consumption, tests preferably should run for a long enough period. The Kretzschmer tests for example only stoked for 5 days.

1.3.3 The Nova Baths

The Nova bath experiment at Sardis, by Yegül et al. shows the importance of the tubuli element. This was a small 3 chambered bath (frigidarium, tepidarium and caldarium) that was reconstructed near modern day Sart, Turkey for the NOVA television-series by the American Public Broadcasting Station (PBS). The caldarium had a total volume of 37,6m^3, an alveus with a capacity of 1700l and a boiler that contained ca 520l. It was calculated that to achieve a warm enough room temperature without the use of heated walls, the floors would have to have been warmed to 62°C, described by Yegül as an 'impractical' and 'dangerous' temperature.[112] Instead, with active wall-heating a 'regular' 42-43°C was enough to produce the effect desired by Yegül, which was inspired by the experience in a modern-

[106] Yegül, F. and Couch, T. (2003), pp 171-2, fig 26
[107] Grassmann, H-C. (2011)
[108] Grassmann, H-C. (2011), p 19 section V2 and fig 13
[109] Grassmann, H-C. (2011), p 19 section V3
[110] Grassmann, H-C. (2011), pp 19-20 section V4
[111] Grassmann, H-C. (2011), p 26 section V9
[112] Yegül, F. (2010), p89

day hammam.[113] The construction was one with active tubuli, but low draft (every fifth row of tubuli was opened toward a chimney), with the intent of creating a 'slow burn'.

The effects of other configurations are mentioned in the report. These explore briefly what would happen by blocking off more tubuli, creating a more 'passive system'.[114] Generally the more 'active' a role the tubuli are thought to have played, the more of them are connected to the 'chimney', to create draughts. The more draughts, the more fuel would have been used.[115] The high floor temperature means that sandals had to be worn to tolerate walking about (cfr supra; an illustration can be found in the NOVA documentary at 51'30", where Fagan experiences the floor's heat directly, almost burning his feet).[116] However, Grassmann's research pointed out that the floor temperature is linked to the thickness of the suspensura.[117] In other words, thickening the suspensura floors enough could eliminate the need for wearing sandals (cfr supra), other than perhaps for countering slipperiness. Grassmann recorded that the system can make up for this loss with a suspensura thickness up to ca. 60cm, lowering the temperature of the floors (in his case) from 27,5°C to 22°C.[118] The thickness of the floors in the NOVA baths was 22cm.[119] The fuel use was around 15 kg of oak wood per hour. It was found that 4,7 kW was needed per hour to maintain the baths at the desired temperature. The furnace was stoked every two hours, around the clock. Heating experiments were conducted for ten days (between 31 Oct- 9 Nov 1998), and the average outside temperature was 15°C. With further additions to the system (which time and budget constraints prevented) and properly dried wood (cfr infra), Yegül estimates this figure could sink to 6 kg per hour.[120]

Several other baths have been submitted to heat analyses. The figure of the Nova baths reportedly corresponds somewhat to Joria's calculation for the similarly sized Welwyn Villa baths, where 7kg's of firewood was burned per hour.[121] For these same baths, Rook once calculated much higher figures (13 kg's), but these were based on room temperatures of 60°C. Because these failed to take into account the effect of humidity, Rook later repudiated them.[122] Correcting his earlier estimations, Rook described a room temperature of 40°C at 100% humidity (which means sweat forms and does not evaporate cfr supra) as 'devastating'.[123] Basaran and Ilken report similar results to Yegül in their thermal analysis of the small baths in ancient Phaselis.[124] These baths have two tepidaria, one caldarium and one sudatorium. The caldarium measures 11m x 5,5m, though decreases in width in the North West section to 4,4m. The sudatorium measures 2,4m x 4m. No figures for volume are given, however a heat analysis of the entire building was added (see addendum 4). Their calculations were made assuming the caldarium was heated to 43.3°C, and the sudatorium to 48.9°C. However, the total heat requirement of these baths was calculated to be 66,5 kW, which is about 14 times more than the NOVA baths and 9 times more than the 'Herbergsthermen'. Using an estimated heating value of 15492 kJ/kg, or 4,303 kWh/kg for the fuelwood, they calculated that around 15 kg of wood fuel would have been needed hourly.[125]

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[113] Yegül, F. (2010), p89
[114] Yegül, F. and Couch, T. (2003), pp 171-172
[115] Yegül, F. and Couch, T. (2003), p 163
[116] NOVA/WGBH, 1998-99 Program *ROMAN BATH* aired on national PBS Television, February 22, 2000; available online at <https://youtu.be/FKBc3_fKHtA?t=51m30s> last check 30/03/16
[117] Grassmann, H. (2011), p 39, section IX
[118] Grassmann, H. (2011), p 31 and fig 26
[119] Yegül, F. and Couch, F. (2003), p 176; though p 162, fig 14 shows the schematics of the floor and there the thickness of the floor is a total of 26 cm
[120] Yegül, F. and Couch, F. (2003),
[121] See Rook, T. (1993)
[122] Rook, T. (1978); Rook (1993) as quoted in McParland, L. (2009), pp 176-77
[123] Rook, T. (1993) as quoted in McParland, L. (2009), pp 176-77
[124] Basaran, T. and Ilken, Z. (1998), p 5
[125] Basaran, T. and Ilken, Z. (1998), p 5

1.3.4 Discussion and Comparison of the Archaeological Reconstructions

Several conditions differ in the thermal studies featured above. Grassmann calculates fuel consumption on the basis of the Herbergsthermen, which were heated to ~31°C (inside temperature in winter) and ~37 °c (inside temperature in summer). The heat requirements for winter and summer were 12,01 kW and 7,73 kW per hour respectively for a room that has a volume of 142 m^2. For the NOVA baths at Sardes, Yegül based his calculations on 42°C. Here the heat requirement was lower, 4.7 kW per hour for a room the volume of 37,6 m^2. The baths were also operating at different levels of humidity, and as we learned from Rook, this would have an impact on the bathing experience. The average humidity for the Herbergsthermen was between 60-70%, for the NOVA baths, it was between 25-35% in the caldarium. Grassmann showed that the interplay between temperature and humidity provides a 'spectrum of enjoyment', which could reduce guesswork.[126] The fuel input of the NOVA baths were estimated at 6kg per hour, or 144 kg each day. The fuel input of the Herbergsthermen roughly translates to 4kg's per hour in winter, and 2.7 in summer, or a daily use (/24h) of 102 kg in winter and 62.7 kg in summer.

The low fuel use of the Herbergsthermen is remarkable, considering the volume of the caldarium is four times that of the Nova baths. Several explanations for this can be provided. Firstly, it is possible this variety in relative use existed in ancient times as well. Secondly, the total volume of fuel needed, depends on its calorific value. The calorific value is the measure for the amount of energy a fuel will give off in a fire. This can be expressed in calories or in joule, or in kilowatts per hour. As Yegül and Grassmann note, the moisture content in (wood-) fuel plays a significant role in a fuel's calorific value, and burn efficiency.[127] Both cases did not measure moisture content in the wood provided, which Grassmann shows is vital.[128] Grassmann calculated with values for firewood of 2,832 kWh/kg. Yegül calculated using gross figures of 18,123 MJ/kg, or 5,034 kWh/kg, and factored in an estimated 25.4% moisture content, meaning 3.755 kW/kg. The longer fuelwood is dried, and the lower its moisture content, the higher its calorific value. Moisture content can vary between 50-60% in green, undried wood, to 25-35% after being dried one summer, to as low as 15-25% after drying for several years. Thus much less fuel has to be used when it is properly dried. Lastly, another factor might contribute to different fuel volumes consumed. As McParland et al. state, we do not know at what temperature the furnace was stoked, so either modern conditions or experimental reconstruction have to be relied upon.[129]

This means estimates or comparisons must be used. For the Yegül reconstruction for example, the hammam provided inspiration. These inferences could contribute to the relative differences in fuel consumption between the various tests mentioned above. To reduce the 'guesswork' in this respect, reflectance microscopy might provide us with new primary evidence. By analyzing charred remains for their reflectance, the temperature the material sustained can be reconstructed. These temperatures that the material sustained then become a proxy to actual operating conditions for the hypocaust system. Another supposed possibility of reflectance microscopy is seeing if the charred wood in question was charcoal or wood when it was burned. This has implications for fuel consumption, because for one batch of charcoal, roughly seven to eight times that amount of wood was needed to produce it.[130] Though experiments by Kretzschmer and Hüser used charcoal, newer studies generally prefer using raw wood. We shall treat this matter, and reflectance microscopy and its criticism, more in depth in chapter 3 on types of fuel, section 3.1.3.

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[126] Grassmann, H-C. (2011), p 40, fig 36
[127] Yegül, F. and Couch, T. (2003), p 175; Grassmann, H-C. (2011), p 29 section V.12
[128] Grassmann, H-C. (2011), p 29
[129] McParland, L. et al (2009), p 181
[130] Veal, R. (2013), pp47-48, Olsen, S.D. (1991), p 412

1.3.5 Areas needed for sustainable exploitation

The fuel use estimates from these various baths above can be used to see what area of land they imply for sustainable fueling. Grassmann argued the Herbergsthermen would have stoked about 100 kg daily in winter and 50 kg in summer. Assuming three months of summer, 6 months of 'intermediate temperatures' (with fuel use halfway between winter and summer) and 3 months of winter, we would calculate total fuel use a year to be 27 375 kg.[131] Given the location, the figures for oak and chestnut will be used, provided by Blyth (cfr supra). If only oak were used this would mean around 15,6 ha was needed for sustainable exploitation.[132] If only chestnut were used, this would mean around 11,9 ha. Though an 'all chestnut' firing is unlikely for the time period, the figures for chestnut will represent a more fast growing species than oak (cfr infra). If a mix of 70% oak and 30% chestnut were used, this would mean 14,52 ha. This 'mix' represents an environment where chestnut has been introduced following Roman occupation, and the environment has become more 'cultivated'.[133] The results are summed up in table 1.

	Area needed for sustainable exploitation (27 375 kg)
100% oak	15,6 ha
100% chestnut	11,9 ha
70% oak, 30% chestnut	14,52 ha

Table 3 Area needed for sustainable exploitation of the Xanten 'Herbergsthermen'

It is likely that various other tree species could have been used in this type of location as well. Birch (betula) and ash (fraxinus) spring to mind, as they burn easily and have a high calorific content. However non-wood fuel like peat, or perhaps even animal bones or dung cannot be excluded from use (cfr Chapter 3).

The NOVA baths at Sardes used up 15 kg of oak wood per hour, but that figure could have been lower according to Yegül, down to 6 kg per hour. Yegül points out that a large part of this inefficiency was due to inefficient burning of wood, which was improperly dried.[134] This means a daily use of either 144 kg or 360 kg. Yearly use, using these figures all year round, would mean a use between 52 560kg - 131 400 kg. Again, using Blyth's figures, this would mean an area of 30 ha – 75 ha. Given this bath was located in Turkey, firing with maquis and pine (pinus negrus) will also be considered. Figures from Grove and Rackham, and the Xylarch project will be used (cfr supra section 1.1).[135] If nothing but maquis vegetation was used, 52,5 ha – 131 ha would be needed. If all pine were to be used instead, the area needed for sustainable use would be between 13,7 – 34,2 ha. We shall note that the Xylarch figures also account for moisture content in the wood, so that in this case, the 'low' estimate is probably more accurate (cfr supra). Archaeology however makes it clear that a mix of fuel sources was usually used

[131] Summer and winter counting 92 days each, a year counting 365 would make (92*100kg)+(92*50kg)+(181*75kg) = 27 375 kg

[132] Blyth, P.H. (1999), p 88; Blyth supposes oak can deliver 1.75 ton/ha sustainably. Daily winter use would need 5,7 are, and in summer 2,9 are. Simplified (cfr footnote 23-27 in section 1.1) this means an area of 75m x 75m (winter) and 38m x 38m (summer) had to be harvested from daily.

[133] See for example: Conedera, M., Krebs, P., et al. (2004). The cultivation of Castanea sativa (Mill.) in Europe, from its origin to its diffusion on a continental scale. *Vegetation History and Archaeobotany*, *13*(3), pp 161-179

[134] Yegül, F. and Couch, T. (2003), p 175

[135] Grove, A.T., and Rackham, O. (2001) suppose maquis can deliver 1 ton/ha sustainably. The Xylarch project considers 414 kg/m^3 to be the oven dry density of pinewood, so around 30% moisture content will be accounted for. The average Pinus nigra growth rate is estimated at 6.5 m^3/ha/year

(cfr chapter 3). If we suppose a mix of all three sources (Mix A: 70% oak, 20% pine, 10% maquis) the area needed would be, for the higher estimate (131400kg/year): 72,6 ha; for the lower estimate (52560 kg/year): 27,4 ha. If we suppose another mix (Mix B: 20% oak, 60% pine and 20% maquis), the area needed would be, for the higher estimate: 61,8 ha; for the lower estimate: 24,7 ha. These results are summed up in table 2.

	High estimate (131 400 kg)	Low estimate (52 560 kg)
100% oak	75,1 ha	30 ha
100% pine	34, 2 ha	13,7 ha
100% maquis	131 ha	52,5 ha
70% oak, 20% pine, 10% maquis	72,6 ha	27,4 ha
20% oak, 60% pine, 20% maquis	61,8 ha	24,7 ha

Table 4 Area needed for sustainable exploitation of the Sardes 'NOVA baths'

This changing mix of tree species in the Mediterranean is typical for the classical period (though in some places it might have already taken place in the Bronze Age).[136] The first mix (mix A) proportions represent a Mediterranean environment that has experienced relatively little pressure from human occupation. The latter fuel mix (mix B) represents a Mediterranean environment with prolonged human pressure, where deciduous trees have largely been replaced by evergreens. We can see that the different mixes produce roughly the same required area, because the 'gains' (in area) from more productive pine tree is offset by the increase in use of maquis. This does not mean that a change to a landscape that has more evergreens and maquis (mix B) would not have an (environmental) impact. A drying up microclimate might pose serious issues for local land use regimes.

It is these land use regimes that should be considered when interpreting fuel consumption. On its own, the use of maquis vegetation would of course decrease pressure on forests. The situation is different if maquis vegetation is used because the pressure on forests is already at its limit. Secondly, when added together small differences might produce an overall great effect. If the baths, local industry and fuel for personal use all require a small percent more area, because of using a less productive fuel source, shortages would be inevitable. Sadly, the limited data used for these calculations and their generality make it so that we cannot really substantiate any claims.

A local analysis that identifies species through palynology or anthracology (which is what the archaeological reports in Chapter 3 will be based on), and considers local land use, soil conditions and climate is vital in reducing guesswork in this respect. We can look forward to such analyses of Miliaresis (forthcoming) insights on the matter of fuel consumption of the Forum Baths at Ostia Antica, and to Veal (forthcoming) for a general overview of the fuel consumption of Pompeii. The former's work completes the trend toward modelling and digitalization of the study of Roman baths.[137] Using computers, calculations can be made consistently and with much more physical data (properties of building materials, solar radiation, variations in temperature, type of fuel...). Changes made over time to the building or the heating system can easily be added. Miliaresis also developed a user-friendly database program to accompany the study will no doubt greatly ease future thermal studies of ancient baths.[138]

[136] Hughes, D. (2011), p 49

[137] See for example Basaran and Ilken (1998) or Grassmann (2011) for examples of computer models for heat transfer between 1994 and 2004

[138] Miliaresis, I. (forthcoming) Doctoral Dissertation. From its introduction, p 25, freely available on Academia.edu <https://missouri.academia.edu/IsminiMiliaresis> last check 11/04/16

1.3.6 Discussion and Comparison to Ancient Sources

The figures calculated above (the area needed to exploit sustainably) might be biased in some way, because of the limitedness of the sample data. They require a localized study (as for example Miliaresis has done, cfr supra). The same was argued about the ancient sources featured in section 1.1. A short comparison might provide a few insights or at least allow us to provide more context to the ancient sources. The 'Herbergsthermen' in Xanten required an estimated 27 375 kg of wood fuel yearly, and compared to the NOVA baths, have low fuel consumption for their size (caldarium: 142m²). The NOVA baths required between 52 560 kg and 131 400 kg yearly, which is at least double, for a size that is much more modest (caldarium: 37,6 m²). The small baths at Phaselis, studied by Basaran and Ilken, required as much fuel as the high estimate of the NOVA baths (131 400 kg). According to what can be deduced from their description, the surface-size of the caldarium would have been less than 60m².

The amount the NOVA baths required is somewhat comparable to the donation by the duumvir of Misenum, who donated 400 cartloads of hardwood (157 200kg), to be given each year. The same can be said of the benefaction from Aurgi. In the Aurgi benefaction 300 agnua of woodland was donated which converts to 36 ha and between 65 625 – 130 500kg yield. Though both ancient sources and archaeological calculations have limitations, they do seem to point in similar directions for these smaller (provincial) baths. They can be contrasted to the much higher number seen in the inscription from Catania, where daily fuel use dropped from 4960 kg to 2790. This amounts to a yearly use of 1 785 600 kg to 1 018 350 kg. The figure is about ten times that of the baths at Misenum or Phaselis. The Achillean baths (to which the inscription is linked) are reportedly quite big, so perhaps these figures represent the fuel use of more opulent imperial establishments. To supply the original amount, depending on which fuel source we use, we get an area needed between on average 600 ha for lower estimates to about 1000 ha for higher estimates. The inscription at Catania links to an imperial architect who caused the drop in fuel use. Likely some alterations to the heating system were carried out, so that the baths retained heat more. Finding out what exactly took place would advance not only our understanding of how the ancient baths worked, but also how much ancient Romans knew about the thermal aspects of their buildings.

Below is a visual representation (figure 2) that uses Google Earth to demonstrate the areas calculated in comparison to modern Catania (urban area to the east) and Mount Etna (to the north). The frame goes about 40 km inland and represents what could be considered as Catania's immediate hinterland. The yellow area's dimensions are 5 km – 2 km, meaning the yellow square has a surface area of about 1000ha –the high estimate for the original amount in the inscription. The smaller red area's dimensions are 3km – 2km, and has a surface area of about 600 ha –the low estimate of area needed to sustainably provide the original amount in the inscription. Coincidentally, the gain in efficiency noted in the inscription, from 1 785 600 kg to 1 018 350 kg, when using the high estimate, is a drop from 1000 ha to somewhat less than 600 ha, so the figure can also represent how much area was gained.

Figure 2 Modern Catania and estimated area needed to supply 1 785 600 kg of wood

1.4 Summary and Intermediary Conclusion

We have seen that ancient sources allow us to approximate roughly the fuel use of the ancient baths. These calculations are based upon benefactions, contracts and official correspondence and so provide a reliable basis to build upon. These calculations sidestep important several factors. These are the particulars of an idealized hypocaust system, the influence of the opening hours and the bath temperatures. These factors provided some context for our engagement with the archaeological reconstructions. These reconstructions try to reliable reconstruct the function of a hypocaust and its corresponding fuel use. Currently however, these still require some guesswork as to the several factors in its operation (such as inside temperature or humidity), that would influence the bathing experience. These reconstructions do allow for a spectrum of fuel use to be established, which in turn can be used to guesstimate the area needed for a sustainable exploitation (using only wood fuel, which probably over-estimates the area needed cfr section 3, especially section 3.2 on the use of non-wood fuels). Lastly, these reconstructions compare well to the fuel use we calculated from ancient sources, strengthening the reliability of both in approaching the amount of fuel consumed. These provide a solid foundation toward quantifying and modelling the Roman fuel economy of the baths. It seems likely that the impact of a smaller and medium sized bath would not have greatly impacted the hinterland, each requiring between 15 to 30 ha of forest (low estimate) or 50-70 ha of forest (high estimate). Even using all maquis the guesstimates run from 50 ha to at most 130 ha of maquis wasteland. It is quite likely however that the larger (imperial) establishments would have required specifically designated forests of a respectable size in order to provide adequate fuel sustainably. In the next section we'll explore the supply chain that made this consumption possible.

2. Bath Operation and Cost. Bath Management and Supplying its Fuel.

As seen in the previous chapter, high local officials (duumviri) both in the Misenum and Aurgi donated tracts of land specifically to supply the public baths. These sources, along with archaeological research, have been pressed to provide guesstimates of fuel consumption. However, the amount of sources that feature a donation of fuel in a physical, non-monetary sense or the donation of land to provide fuel is rather rare. A great deal of sources can still be explored and their interpretation benefits from being put into an economic supply chain.

Entrance fees can inform us on cost- and revenue streams of these baths and so provide clues for fuel expenses. Additionally, there is a large group of non-constructional, monetary donations to the baths. Furthermore, the city administration provided financing and citizens were also required to help out financially and physically via the liturgy/munus system. Lastly, tracts of land were usually dedicated and reserved exclusively for public purposes.

This way a variety of people would have been involved in the fuel supply. A hierarchy of command developed for the baths, with municipal control on its public services. The stokers themselves were probably at the lowest rung in this system, yet still had to control the fires in the *praefurnium* and could likely influence the amount of fuel needed for a properly heated bath. It might benefit the interpretation of many of these sources if we could find out how fuel was priced. For that we need to be able to factor in the cost of transportation, account for maintenance in the baths, etc. To add to the previous chapter, which dealt with raw fuel estimates and the surface area needed for a sustainable exploitation, we need to provide more economic context. Our sources for the cost of fuel however are very meagre and little has been written specifically with respect to these economic aspects of the fuel economy of the Roman baths.

In this section and section 3 we shall assume that the fuel economy of the baths was a somewhat separate sphere, and not feature fuel markets in the larger sense. This is first of all because very little information exists on fuel markets, and secondly, because what information exists relates only marginally to the fuel economy of the baths.[139] Both in this section and section 3, we shall thus try to form some coherent foundations for later research. In the first section we shall first analyze where the money for running the baths came from, with of course an emphasis on the aspect of providing fuel. Then we will see who actually ran the bath's operation and how this can inform us about fuel consumption. This leads us into the actual supplying of fuel and its conditions. From there, we shall explore considerations to what extent we can integrate this into a price of fuel, and if this price was relevant for the supply of the public baths. We will conclude this chapter with a short summary and an intermediary conclusion.

2.1 Funding the Baths

The following sections pertain specifically to the sources of revenue the baths could count on. There are two remarks to be made however. Firstly, we shall forgo discussing in depth where the larger imperial baths got their funds. It will be assumed that they either received support from the emperor or received income from imperial lands.[140] It is possible their funding could additionally have included funding similar to that of the municipal baths, if that was necessary. Secondly, because we are dealing with public baths, owned by the municipality or the emperor, this topic could cross into a discussion on the nature of public revenue. We shall analyze the funding of the baths from the perspective that

[139] See for example Meiggs, R. (1982), De Ligt, L. (1993)
[140] See for example Nielsen, I. (1993), p 124-125

the municipal government was a force in public spending, could levy taxes and could spend money on sustaining public buildings. This is based somewhat on a reading of Zuiderhoek, who in turn follows Schwartz.[141] This view is based on the situation in Asia Minor. By the time of the Roman Empire, the cities in Asia Minor would have had a long institutional tradition of that of the classical poleis. It is quite possible this would not be representative of the whole Roman Empire. The Vipasca lease in particular might be used as a counter-example. Furthermore, the evidence from late-Antiquity does hint that elite contributions to the municipal coffers were more than welcome. However, to explore that discussion in depth would be beyond the scope of our work. If any conclusion is to be drawn, it is that our sources come from a variety of places with different institutional contexts. Therefore, a plethora of ways of the funding of the baths could have been possible. We shall present here an ideal-type municipal bathhouse and therefore include the full range of its possible income streams.

The Municipal public baths could receive revenue from four sources: entrance fees and rents, private benefactions, the (local) public treasury and through use of public lands.

2.1.1. Entrance Fees, Benefactions of Free Bathing and Rents

Baths usually demanded an entrance fee, called the 'balneaticum'.[142] Several authors report that the balneaticum in Rome traditionally was one quadrans for men.[143] Women usually also had to pay entry fees; in Vipasca this was double (1 as) of what men paid (half an as).[144] Children were probably exempt from fees, though exceptions exist (cfr infra).[145] It is possible that by the time of Diocletian, some standardization of entrance fees had occurred.[146] Sometimes several groups of people were exempt from paying entrance fees, and individuals could be rewarded with free bathing.[147]

It became a quite popular benefaction to ensure free bathing.[148] Several bath tokens (tesserae) have been attested that might have served this purpose.[149] Local elites or patrons often ensured free bathing to certain groups for certain periods.[150] Many of these benefactions are limited in time however, and coincide with a political office, or some festival or celebration.[151] Not only private citizens, but the emperor or the city administration could also foresee donations for free bathing. Augustus donated property at the death of Agrippa to his baths, 'so that (the people) might bathe free of cost'.[152] By the 2nd century CE use of the public baths in all Rome was free.[153] Other cases are known: A bath in Hispellum (Umbra) and one in Neapolis (Gallia Cisalpina) offered free bathing at public

[141] Zuiderhoek, A. (2009), pp 37-53 and Schwarz, H. (2001).
[142] Meusel, H. (1960), p 102
[143] Horatius, Satirae 1,3,137; Martial Epigrams. 3,30,4 and 8,42; Seneca, Epistulae, 86,9
[144] CIL II, 5181
[145] CIL II, 5181 for an example, the exception being Bononia CIL XI, 720 where free a benefaction was made in order to provide free bathing to "men, and children of both sexes"
[146] CIL III, p 1936; 7.75-66; see also Fagan, G. (1999) p 327
[147] CIL II, 5181 mentions that imperial freedmen and slaves in the service of the procurator were exempt from entrance fees; CIL XII 3179 mentions a legionnaire being awarded free bathing for life
[148] Meusel (1960), p 107 details emperors, senators, equites, municipal officials, well-off citizens and freedmen
[149] See for example Rostoffzeff, Sylloge 85 ff and 103 for nineteen lead *tesserae* either bearing the names of their baths or of the *balneator*
[150] Ten out of thirteen of the inscriptions featured in this section are from local elites and patrons who had held offices. CIL XI.6167 gives free bathing in perpetuity to all citizens; CIL XIV. 2979 gives free bathing to all inhabitants of the town in perpetuity
[151] AE 1989.420; CIL XI.3811
[152] Cassius Dio 54 29 4
[153] Meusel, H. (1960), p 104

expense.[154] An inscription from Histria mentions free bathing for foreigners at public expense.[155] The exact amount donated for this purpose is often omitted. There are exceptions: A benefaction from Bononia, 1st or early-2nd century, informs us that a sum of 400 000 *sesterci* (~~HS~~) was donated, so that its proceeds might serve to provide free bathing to men and children of both sexes in perpetuity. At 5% interest this means 20 000 ~~HS~~, or 80 000 *asses*.[156] Divided by the number of days in a years (365), this means the donation covered the revenue of 219 *asses* each day. If we suppose half an *as* was paid by the men, and one *as* by the women and children, the benefactor might have estimated his donation provided free entry for about 328 visitors each day.[157] This number seems comparatively little for an imperial establishment open all day. Blyth makes the same calculations but uses one *quadrans* (one tenth of a *sestercius*) as income fee.[158] He also only accounts one tariff for every person. This way he reckons there could have been up to 240 000 paying customers each year, which he converts to about 110 bathers per hour. The donation makes clear this establishment was built by Augustus. This means the baths at Bononia might have been more spacious than most and might have allowed such a capacity. Because the number of bathers seem reasonable to Blyth, he argues that income from entrance fees would likely have been enough to cover the running costs of the baths.[159] Therefore having heated baths might not have strained a municipality with a large financial burden. This would be substantiated by the Vipasca lease, where the leaseholder had to pay most expenses by himself, including heating.[160] This of course presupposes that these leases were bought for profit, not out of other concerns, such as social status or prestige. We shall revisit the contention of self-sufficient baths in section 2.1.3.

Another source of income was the leasing of stalls for food vendors, street traders etc. or even several tasks in the baths could be leased out (e.g. masseur, epilator, prostitutes, etc.).[161] The example from the Zeuxippos bathing complex at Constantinople, where the emperor instructs that the bath porticos be rented out for additional revenue, illustrates this.[162] Though the Zeuxippos case is from a relatively late date, it is similar to earlier sources showing the municipality derived income from shops leased out publicly.[163] Similarly, it is possible that smaller communities helped out larger cities, perhaps as a form of tribute. Symmachus notes for example that the city of Terracina donated wood to aid Rome in its supply of firewood.[164] Merten notes this might have been as part of the *annonae*.[165] This tax *in natura* to the city of Rome was made compulsory for the Italian districts by the age of Diocletian.[166] Strabo notes a similar situation for Nemausus (modern Nîmes), where the city taxed 24 surrounding communities.[167] In Egypt a general bath tax (probably *in natura*, cfr section 3.2.2) replaced entrance fees.[168] Though the evidence is scarce for other parts of the Roman Empire, it is likely that various forms of municipal revenue contributed toward the heating of the baths. This would be similar to the

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[154] Plinius, Epistulae, 8,8,6 and CIL V.376
[155] CIL V. 376
[156] Following Augustus' monetary reform, the as was devalued to ¼ of a sestertius
[157] Assuming half of the amount came from men and the other half from children 219 men and 109 children can be admitted freely
[158] Blyth, P.H. (1999), p 88
[159] Blyth, P.H. (1999), pp 80, 90
[160] CIL II, 5181
[161] Nielsen, I (1991), p 128, 145
[162] Codex. Theodosianus. 15.1.52
[163] Zuiderhoek, A. (2009), p 40 footnote 8 lists an inscription from Aphrodisias published by Reynolds (1996), p 123-124
[164] Symm. Ep. 10.40.3
[165] Merten, E. (1983), p 58
[166] Merten, E. (1983), p 58
[167] Strabo IV, 1.12
[168] Johnson, A.C. and Tenney, F. (ed) (1975), p 547; See also Wilcken, U. (1899) *Ostraka* I 169ff.

trend described by Fagan, where the municipality often took care of maintaining and repairing public baths (cfr section 2.1.3).[169]

2.1.2 Other Types of Benefaction and Benefactions 'in tutelam'

Aside from benefactions of free entrée, other benefactions were given to the baths. These benefactions could specify that a sum of money, oils, water, fuel, etc., was donated. The *Digesta* makes it clear that legacies of wood for heating the baths were possible.[170] As featured above, the inscription from Aurgi donated 300 agnua of woodland and a water supply.[171] Another example we find in the Misenum inscription, made by a former duumvir, who featured a donation of 400 cartloads of fuel, and noted the administration of his estate passed over to the city's magistrates.[172] This suggests a close connection between benefactors and the city administration.

Most benefactions though feature monetary donations. We shall feature a benefaction featuring a monetary donation meant to supply fuel in section 2.3.4.

Most benefactions however do not feature a specific mention of providing fuel, instead they donate a sum of money '*in tutelam*' (lit: 'for care'). This would have the added benefit of flexibility in its allocation. The interest on these sums probably served for upkeep and maintenance, though different opinions on their exact nature exist.[173] Nielsen and Merten argue that *tutela,* aside from upkeep and maintenance, could also include fuel and even water. This is largely on the basis of the occasional magnitude of these donated sums.[174] It is tempting to interpret several donations this way if they feature baths being built along with a sum of money given '*in tutelam'* and no mention is made of separate money for fuel or repairs (a 'total package' is being donated).[175] Furthermore, a parallel can be made with the use of '*tutela'* with respect to publicly designated forests (cfr section 2.1.4). It is likely however that this '*tutela'* money simply meant maintenance, and that providing fuel or water supply was left up to the city or the bath's leaseholder.

Contrary to Nielsen and Merten, Fagan takes '*tutela'* to mean general maintenance, such as cleaning, chimney-sweeping, and so forth.[176] Similarly, Blyth reckons *tutela* money served as payment for staff.[177] He calculates using the Altinum inscription as follows: at 6% interest each baths would spend 6000 HS yearly on staffing (and 12000 on heating). He reckons that if maintaining a slave cost 40 HS per month, this would have allowed 12 slaves for each bath.[178] Blyth supposes a profit margin was taken, so assumes only 8 slaves would have been employed. Because little else is known about these baths, he assumes this means the baths were of medium size and reckons they are comparable to the Stabian Baths at Pompei. Reservations could be made about this calculation, which we shall address in section 2.2.

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169 Fagan, G. (1999) chapter 6, *passim,* especially pp 133-34 and 143-146
170 Dig 32.55.3
171 CIL II.3361
172 CIL X, 3678
173 Nielsen, I. (1991), p 122; Duncan-Jones (1982), pp 362-63
174 Nielsen, I. (1991), p 123; Merten (1983), pp 48 ff; though see CIL II 5489 = ILER 2045 for an example of a smaller donation (each year 150 den = 600 HS)
175 AE 1979.353; AE 1961.109 = SuppItal 3 (1987): 144-145 (no. 8); CIL XIII 3162.I = ILTG 341; IGRR 4.1302 = IK 5 (Kyme) 19
176 Fagan, G. (1999), p 313. See footnote 45 for detail on the use of the word 'chimney' in connection to the Roman baths; cfr Meusel (1960), pp 132-33
177 Jones, R.D. (1974) pp17ff, and Blyth, P.H. (1999), pp 87
178 Blyth, P.H. (1999), p 87 quoting Sen. Ep. 80,7 and Jones , R.D. (1974) The Economy of the Roman Empire, 12

The view that '*tutela'* covers more than just maintenance and upkeep needs to be reconciled with, for example, the Altinum inscription.[179] Here separate mention is made of funds serving for *tutela,* for repairs, and for heating. Because of the popularity of heated baths, it is understandable that a benefactor would stress his efforts, rather than hiding it behind the wording 'tutela'. Because of these considerations, and because separating the cost of maintenance from the cost of fuel would not be easy, we shall not consider benefactions 'in tutelam' for our calculations later on in section 2.3.4).

2.1.3. Liturgies, Civic Duty and Public Funds

In the previous section we noted that, according to Blyth entrance fees could have covered most running costs for the baths. This argument needs to be reconciled with evidence for municipal intervention that will be featured in this section. Blyth's view can be contrasted with that of Nielsen; she argues that the local public treasury probably paid for most of the bath's expenses.[180] Though most of the evidence for this view comes from legal documents from late-Antiquity.[181] It is quite possible that providing fuel for the baths was handled differently in the early Empire than in late Antiquity Even then we cannot be sure of a homogenous situation across the empire. It is quite likely the situation in the mining town of Vipasca was different from the Eastern cities. In Vipasca, the baths were leased out and the leaseholder was himself responsible for all of the heating expenses.[182] The Eastern cities on the other hand would have had a long institutional tradition. An ostracon from 3rd century CE Herakleopolis or Memphis shows that it is quite possible a tax in kind (probably of chaff, cfr. section 3.2) existed in Egypt so as to provide fuel for the public baths.[183] It is difficult to deduce whether time period or location is more important in accounting for possible differences.

The evidence in the early Empire for the funding of the baths is often scanty. A municipal law from Andania (near Messenia) regarding a religious festival from the 1st century BCE specifies that the ἀγορανόμος (from here on: market supervisor) was to oversee the baths only charged 2 copper coins, and that the fuel contractor provided enough fuel to the stoker.[184] It is unclear whether these baths were privately owned or whether they belonged to the municipality. It is plausible, as Blyth proposes, that the entrance fees for these baths would have covered running costs. The fuel for the baths then again was to be made available from a forest sanctuary (cfr section 2.1.4). Nowhere also is it stated who paid for the services of the fuel contractor however, so perhaps these could be included in the running costs. At the same time the involvement of the market supervisor might indicate a part of the funding came from indirect taxation; the various levies on market activity and import taxes.

Another source of income for these expenses was through the contributions of a 'munus' in the West or a λειτουργία (from here on: 'liturgy') in the East, two related concepts. Both 'munus' and 'liturgy' can be defined as a system of social obligation where individuals are expected to contribute to their municipality either financially or physically, dependent on their status.[185] The purchase of fuel for the local municipal baths was usually reserved for local elites. This system could also cover expenses for

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[179] Nsc 1928, p283 as quoted in Nielsen, I. (1991), p 123 and Fagan, G. (1999), p 313 nr 240; Blyth, P.H. (1999), pp87f; and Meusel, H. (1960), p 130
[180] Nielsen, I. (1991), pp 122-123; for a similar view, see Meyer, B. (1989), p 569
[181] Merten, E. (1983), pp 50-51
[182] CIL II 5181
[183] O.mich.1.221 reads "Phamenoth 4. Aeion, son of Atesios: 4 baskets (σαρ(γάνας)), for the bath."
[184] IG V 1390
[185] Corbier, Mireille (Paris); Hönle, Augusta (Rottweil). "Munus, Munera." Brill's New Pauly. Antiquity volumes edited by: Hubert Cancik and , Helmuth Schneider. Brill Online, 2016. Reference. University of Gent. 24 May 2016 <http://referenceworks.brillonline.com/entries/brill-s-new-pauly/munus-munera-e812060>

water, if these occurred.[186] A papyrus from 2nd century CE Arsinoe features its *πρεσβύτεροι* (from here on: presbyters) making a monthly delivery of the chaff to the gymnasiarch for the heating of the big gymnasium.[187] The papyrus, a receipt of delivery, mentions no sum of money charged. Meyer speculates that in this case the chaff was not bought and was given free of charge.[188] Quite possibly this chaff was a waste product from the village threshing floor, and so was put to use again for the benefit of the municipality. An oration by Libanius for example shows that in the 4th century CE the liturgy of fuel supply befell members of city council in Antioch (similar to other Syrian cities).[189] Lastly, a contract for fuel supply from Hermopolis from the early 1st century CE shows that the 'gymnasiarch soon to be elected' personally hired fuel contractors to heat the municipal baths and paid for fuel.[190]

Merten argues that neither law nor custom dictated that the amount of fuel was determined, nor was the temperature of the baths set. These would have been left up to the discretion of the liturgate (cfr section 2.2). An example can possibly be found in the benefaction from Tenos, from the 1st/2nd century CE. Here a bequest of 5000 denarii (=20 000 ~~HS~~) from the people and council of Tenos was to be used for heating the bath.[191] If 5% revenue was taken from this yearly, that would mean 1000 HS per annum. If we take Blyth's estimates of the cost of fuel transport, at 30 HS per cartload of fuel delivered (cfr section 2.3.4), then 13102 kg of fuel could have yearly been bought.[192] This is about half of the amount of what was needed for the Herbergsthermen, according to Grassmann. This is almost four times less than what was needed for the NOVA baths (lower estimate 52 560 kg). It is probable that the bequest from Tenos did not fully cover what was needed, and perhaps served complementary to other income. Meaning it is possible here that the city paid for what expenses remained. This can be contrasted with the Hermopolis lease, where the price for fuel is agreed upon between the liturgate and the fuel suppliers under the conditions he specifies, namely of continuous supply to the stoker. This coincides with a view of competitive gifting by local elites to attain status, and the view that the city itself covered the day-to-day running costs of the baths.

Citizens were also expected to help their town out in non-monetary ways. In the *Digestae*, Hermogenianus mentions that there are *munera* (duties) bestowed upon private citizens (*munus personale*), which among others include the *'calefactiones thermarum'* (heating of the baths).[193] The subset of the *munus personale* in general involved taking on management or perhaps providing the personal labor. In the case of management, we can refer to the donation made by the duumvir from Misenum featured above, who passed administrative duties of his benefaction to the city's magistrates. The personal labor involved with heating the baths, was likely the transport of fuel as the stoking itself was usually performed by slaves (cfr section 2.2). A passage from Arcadius Charisius elaborates that the *munus personale* involved no personal expense.[194] Merten follows Meusel in speculating that where expenses were to be made, the municipality would have intervened.[195] This view is based upon a passage from Arcadius Charisius.[196] It states that in some cities the heating of the baths was considered a civil employment (*munus personale*) 'when the revenue is received from the municipality'. It is clear the law relates to a situation similar to that of duumvir's donation at

186 CIL XVI 3013; P. Oxy 2569 l.17f as quoted in Nielsen (1991), p 124
187 BGU.3.760
188 Meyer, B. (1989), p 570
189 Libanius, oration 26,6; this oration has not yet been properly published and translated (along with or. 27-29) and the use of it here is based solely on Merten's paraphrase, see Merten, E.W. (1983), p 53
190 P.Lond. III, 1166
191 IG XII 5, 946
192 See Blyth, P.H. (1999), pp 92-95
193 Dig. 50,4,1,2
194 Merten, E.W. (1983), p 52; Meusel, H. (1960), p 126; and Dig. 50,4,18,1
195 Dig 50.4.18.5
196 Dig 50.4.18.5

Misenum (who gave 400 cartloads of fuel), which would have to be managed by the city's magistrates, who'd then be tasked with a *munus personale*. A similar situation can be found with the gymnasiarch-elect in Hermopolis inscription. The fuel contractors in this inscription might have then received the '*munus'* of *'calefactiones thermarum'*. Contributing in this way might have raised the status of associate members (cfr section 2.3.1). An imperial edict under Caracalla shows that those who supplied fuel (reeds) to the baths of Alexandria were exempt from expulsion from the city.[197] This exemption also held for the swine merchants and the boatmen, two other important corporations. As Meyer believes, having such an honor bestowed upon the guild denotes their privilege and status.[198]

This system came under pressure by Late Antiquity, yet problematically this time period is where most of our sources come from. This was a time when the civic administration changed. The liturgical council was weakened in favor of the imperial administration.[199] It is possible municipal treasuries everywhere took a big hit as elites ceased their competitive gift giving and entered a salaried post in the imperial administration. In response extra taxes were sometimes levied illegally, for example, to cover municipal expenses, including heating of the baths.[200] This discussion is beyond the scope of our work however, and we shall try to make sense of these sources, yet remember they belong in a specific context.

In the late 4th century, the citizens of Antioch complained to the governor of the Eastern provinces (comes Orientis) that under his supervision the baths and pools were not heated properly. In this discussion Libanius stepped in, countering that this task did not befell the *Comes Orientis*. It had probably long been a municipal task that befell the city's finances. Usually the gymnasiarch or the market supervisor had final-responsibility. Libanius continues that the small wealth of the person designated to perform this liturgy did not allow opulent heating.[201] This could mean, according to Merten, that liturgies could be enforced upon a person regardless of the wealth of the candidate.[202] They could then be read as an indication that liturgical beneficence was a necessary addition to the city's revenue. However the complaint fits the period's trend where the central administration coerced the city councils into fulfilling their duties.[203] The complaints of the time might simply be the result of a) the disintegration of the council system, and b) the large hit many municipal funds took at this time due, a.o. frequent wars and the Antonine Plague. Furthermore, Merten points out that Libanius' claim in this oration conflicts with another of his orations, where he suggests that the Comes does in fact care for the wellbeing of the city.[204] This fits the general picture of citizens trying to escape contributing to the community on the basis of their erstwhile civic position. Libanius mentions that the liturgy of fuel supply for the baths was considered heavy and many supplicants that pleaded with

[197] P. Giss 40 II 18

[198] Meyer (1989), p 567; It should be noted that Merten reads this edict differently. She states that the guilds of the swine merchants and boat builders were the associations who supplied fuel to the baths, and were given the task of supplying fuel to the baths (Merten 1983), p 52. The translation by Winter does not agree with this interpretation however, and sees the phrase "ἐκεῖνοί τε οἵτινες κάλαμον πρὸς τὸ ὑποκαίειν τὰ βαλα[νεῖ]ạ καταφέρουσι" not referring to the preceding "ọ[ὐχ]ịμ[έν]τọι γẹ χοιρέμπορọι κ̣αὶ ναῦται ποτά[μ]ιοι,", but with as a separate group, similar to Meyer, translating the whole piece as: "(...) except for the swine merchants, the boatmen and those who bring reeds for the heating of the baths."- Winter (1933), p 21

[199] Liebeschuetz, J.H.W.G. (2001),

[200] Cod. Theod. 7.11.2. See also Nielsen, I. (1991), p 123

[201] Libanius, oration 28.3

[202] Merten, E. (1983), p 53

[203] Liebeschuetz, J.H.W.G. (2001), p 121

[204] Merten, E. (1983), p 53 referencing Petit, P. (1955) *Libanius et la vie municipale à Antioche au Ive siècle après J-C;* and Liebeschuetz, J.H.W.G. (1972) *Antioch. City and Imperial Administration in the Later Roman Empire*

him for help in removing them from this task.[205] We should note that the pleading for exemptions from liturgical duty was however a practice long established.[206]

Imperial exemptions could have been bestowed on higher status and more well-off individuals, meaning they no longer contributed toward the duties the guild was tasked.[207] It is possible this led to some guilds as a whole no longer fulfilling their duties. On the other hand, these exemptions could have been made for the least fortunate guild members, so that the burden of fuel supply fell more frequently on those who were still well off. Complaining that many of the munera obligations are not carried out, Libanius clamors that many of the *curiales* (the city councilors) have to combine several duties in his corner of the Eastern Empire.[208] In this case he provides a (probably) mock example where those who levy taxes also heat the baths and even 'get hold of the bucket (of water)'.[209] So with Libanius we at least find the fear that in certain cities members of the elite dirtied their hands with tasks meant for *plebei* or *tenuiores*. Somewhat more likely, we find non-elite groups funding and providing fuel for the baths in late-Antiquity.

Professional associations at this time were involved in supplying fuel. According to Merten they were traditionally charged with transport and exploiting and maintaining the baths.[210] It is likely they contributed financially due to the decline in municipal support, perhaps resulting in heavy losses. As we've noted, the liturgical duty sometimes devolved to more modest members of society, who then also contributed minimally. As a result some guilds burdened with this liturgy saw their members decline.[211] Emperor Constantine for example signed the order that sixty members of the corporation of the shippers (*navicularii*) be transferred to the organization that saw to the '*necessitas lavacrorum*' (needs of the baths).[212] The persons who were transferred were checked for their wealth, to see that they would carry this burden and not flee. Another transfer was ratified forty years later under Valentinian and Valens. Several years later, orator Quintus Aurelius Symmachus, when he was urban prefect of Rome (384-85 CE), related to emperor Valentinian II that the contractors of the salt works (cfr *mancipes salinarum / thermarum*)[213] were again in need of help.[214] The *mancipes thermarum* petitioned Symmachus, and the emperor, that they be merged with the shippers. Rugini sees this as a way to relieve financial pressure, so that they might collectively guarantee the burdensome operations of the public baths.[215] While this may be true, it could also be seen from a different perspective; Barrow implies that this desire for merger could have originated from self-interest.[216] This could be as the *naviculari* imported wood to Rome and might have, as a result of now having to supply the baths, then lowered the price of fuel (cfr section 2.1.4) or provided better access to cheaply imported fuel. This is probably also why the *naviculari* refused a merger and in the end, several of their members instead were transferred.[217]

[205] Libanius, oration 49.10
[206] See Phaenippus' example from Classical Athens in Demosthenes, Against Phaenippus 42.7
[207] Liebeschuetz, J.H.W.G. (2001), p 178
[208] Libanius, oration 2.
[209] This bucket of water to pour over the bathers; a duty often rendered by the balneator, or a bath attendant
[210] Merten (1983), pp 54-55
[211] Codex. Iust. 11,15,1 and Cod Theod. 14,2,4 reaffirm the 'privileges' of the corporations and instruct those who have run 'to foreign lands', to return and fulfill their duties
[212] Codex. Theodosianus. 13.5.13
[213] Codex. Theodosianus. 14.15.1
[214] Symmachus, Relationes 44
[215] Late Antiq, p 480
[216] Symmachus, Q. Aurelius, & Barrow, R. H. (1973). Prefect and emperor : the Relationes of Symmachus A.D. 384., p 221
[217] Symmachus. Relations. 44.2

2.1.4. Public Domains: Loca Publica.

Numerous sources indicate the fuel for the baths came from certain designated tracts of public land. An example can be found in the 1st century BCE municipal law of Andania regarding a religious festival.[218] Here the fuel contractors were permitted to chop wood from the sanctuary in order to provide fuel for the festival's baths.[219] Frontinus noted that "there are woods from which firewood is cut for the public baths".[220] Not only could these woods be used for firewood for the baths, but often they served a general public function; Hyginus states:

> *Assignatae sunt silvae, de quibus ligna in reparationem publicorum munerum traherentur. Hoc genus agri tutelatum dicitur.*[221]

These woods were publicly owned lands, as we can tell from Agennius: On the subject of the two types of public lands (loca publica), Agennius explains that there are forests and pastures called 'fundus septicianus coloniae agustae concordiae'.[222] These are given to a colony itself and 'cannot be taken away from the republic'. He continues that these are assigned '*in tutelam*' to the public temples and the baths and 'no one may remove anything' from them.[223] Agennius puts these in contrast to the other type of public lands, Augustus' public forests and pastures, who are given names and can be sold off. Hyginus gives a similar explanation for what 'tutela' means with respect to public lands.

> *Aeque territorio si quid erit adsignatum, id ad ipsam urbem pertinebit nec venire aut abalienari a public licebit. Id "datum in tutelam territorio" adscrebimus, sicut silvas et pascua publica.*[224]

The Historia Augusta notes that Severus Alexander "allotted forests for the heating of the public baths".[225] Merten interprets this such that by late antiquity, it became necessary for the emperor to intervene in the heating of the baths.[226] These interventions have oft been interpreted as a sign that by late antiquity the Mediterranean forests were thinned out or depleted.[227] Fagan shows that roughly one third of benefactions were the building or donating of baths.[228] It is possible that the enthusiastic construction of the baths put a strain upon existing designated forests, so that new ones had to be allocated. In this case, the assumption could be made that many baths could not cover the costs of supplying themselves anymore. The emperor donating extra land might have helped providing fuel or lowered the price of fuel, so that more could be bought.

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[218] IG V 1390

[219] IG V 1390, l 109

[220] Frontinus De Controversiis. Agrorum. 55.4 "sunt silvae de quibus lignorum cremia in lavacra publica ministranda caeduntur"

[221] Hyginus. De Condicionibus Agrorum 114.3 "There are designated forests, whose firewood is used for sustaining public services. These types of lands are called 'tutelatum' (tutela = care)

[222] Aggenn Urbicus on Frontinus. De Controversiis. Agrorum; 18

[223] This was probably supervised by the saltuari, see Nenninger (2001), p 60; or Meiggs (1982), p330

[224] "Similarly, all (lands) that are assigned to a territory, are part of a village proper, and it is forbidden from sale or any other way in which it might be removed from public domain. We call this "given to a territory for its care", as with public forests or pastures" translation from: Pseudo-Hyginus, P., Frontinus, S. Julius, & Guillaumin, J. (2005). *Les arpenteurs romains,* p112

[225] Historia Augusta, 24.5-6

[226] Merten, E. (1983) , p 49

[227] See for example Hughes, D. (1994), passim chapter 7, especially p 239

[228] See Fagan (1999), G. pp 104-175

Two remarks should be made toward this interpretation.

Firstly, we are as of yet unsure to what extent the Mediterranean forests suffered because of the Roman Empire.[229] Cassiodorus for example does not seem to mention any problems for Theodoric when he instructed 1000 ships built in 6th century Italy.[230]

Secondly, as Nenninger argues, by late antiquity many of the –originally- public forests came to be in private hands.[231] Liebeschuetz points toward a system of imperial grants, which he likens to a form of corruption.[232] These land owners might have seen these forests as safe long term investments.[233] Therefore they might have been reluctant to contribute or might not have cared for selling below a certain price. Those that could not escape obligations would petition for exceptions (cfr supra section 2.1.3). The system of exceptions is noted in complaints by Symmachus and Libanius. [234] Furthermore, Nenninger argues, the system of granting exceptions from supplying wood for high ranking officials only makes sense if they had large private estates (with forests) to begin with. In this context Nenninger places the frequent complaints of wood and fuel shortages in late Antiquity. Similarly, this would explain the transport of fuelwood in late-Antiquity from North Africa to Rome, even though North Africa probably was not more forested than Italy.[235] In this case, the assumption is that many forests were once public, and were used to supply the baths. At some point these were appropriated by the elite who saw these as long term investments and petitioned against providing for the public benefit through exceptions.[236] Depending on how effective coercion and imperial power was, the exceptions that were granted could be revoked and landowners could have been made to contribute perhaps at fixed prices with low profits.[237] The emperor might have eased prices or provided a precedent by donating forests himself.

2.2 Bath Management and Personnel, Monitoring and Heating the Baths

Though private bath owners might have formed into professional associations to defend their interests, as an inscription from Ephesus in the early 3rd century CE records,[238] the owners of the baths, be it the emperor, the town or a private person, were rarely active in running the baths.[239] Executive duties usually were relegated to an official, a salaried manager or a leaseholder.[240] In the Eastern part of the empire, management of the baths could have been the responsibility of the *γυμνασιαρχος* (from here on: gymnasiarch).[241] These officials were usually of high rank. In the West, Nielsen argues it was more common for baths to be leased out, usually to a *conductor*, who in turn was subject to municipal

229 See for example Grove, A.T., Rackham, O. (2001); Williams (2003), Butzer, K.W. (2005). For a counterperspective see Hughes, D. (2011)
230 Cassiodorus 5.441-5
231 Nenninger, M. (2001), p 59
232 Liebeschuetz, J.H.W.G. (2001), p 178
233 Liebeschuetz, J.H.W.G. (2001), p 59
234 Libanius, oration 49.10; Symmachus, Q. Aurelius, & Barrow, R. H. (1973). Prefect and emperor : the Relationes of Symmachus A.D. 384., p 221
235 Nenninger, M. (2001), p 81
236 Nenninger, M. (2001), p 81
237 Cod. Theod. 11.16.15 and 11.16.18; see also Fagan, G. (1999), p 144 for a speculation of a decline in civic duty to explain these phenomena
238 IK Ephesos VI 2078
239 See for example P.Mich 5 312 which features two Romans of equestrian rank owning a bathhouse in Telei, Arsinoe leasing it out to two other individuals for the price of 265 artabai of wheat
240 Nielsen, I. (1991), p 125
241 Nielsen, I. (1991), p 125; P.Lond. 3 1166; P. Oxy. 3173; also known as an 'επιμελητής'

supervision, this was for example the case in Vipasca.[242] Whether a leaseholder or a member of the city council was in charge, these men were usually freeborn and well-off. Juvenal notes that in exceptional cases they might have been of modest means.[243] According to the Codex Theodosianus in Rome the public baths were taken care of by the *mancipes thermarum*, a professional association:

Quidquid erga mancipes, qui thermarum exhibitionem Romae curant, in exercitio compendiisque salinarum scitis priorum principum cautum est, aeterna sanctione firmamus. (my emphasis) [244]

Meusel considers this to mean they were only in charge of providing the fuely supply (cfr supra section 2.1.3; and infra section 2.3.1).[245] This is based on the heading of this law, which reads *"De mancipibus thermarum urbis et subvectione lignorum*".[246] Merten on the other hand argues in favor of including management as a task that was to be carried out by the *manicpes thermarum*.[247] This fits with the narrative of the law, which reaffirms their principal right to exploit the salt pans,[248] probably in order to cover the costs of leasing the baths, or perhaps as compensation for management of the baths.[249]

Customarily a baths leaseholder (or public official, or manager) was supervised by the municipality. This supervision was to see that the baths did not overcharge entrée money,[250] that the baths were being heated enough[251], that they were clean[252], that the right kind of fuel was used[253], and that fuel was not resold illegally[254], etc. In the east, this was the duty of the market supervisor or a gymnasiarch.[255] In the West the *aediles* performed a similar role according to Seneca.[256] At some point however special functions were created for this purpose. Later inscriptions feature a '*curator balneum*' or a '*curator operis thermarum*'.[257] Seeing as these people are also mentioned holding municipal posts, such as aedile, flamen and duovir,[258] it is likely their task was to supervise the correct working of the baths in a manner similar to the aediles and the market supervisor before them. The existence of this function explains why it is Symmachus (cfr supra), as an urban prefect, who petitions the emperor in the matter of the *mancipes thermarum*. Obviously the smooth functioning of the system was threatened and an imperial intervention was needed.

It was probably a matter of good business and reputation that the baths be heated warm enough. It seems the leaseholder or a supervisor in charge (such as the *balneator*) were held responsible for this quality of the baths. An anonymous satirical poem complains to the βαλανευ (*balneator*) about the pool being too cold.[259] Similarly, the anonymous satirical poem featured at the end of section 1.1.2 (cfr

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[242] Nielsen, I. (1991), p 125; CIL II 5181
[243] Juvenalis. Satirae. 7.4, see Nielsen, I. (1991), p 126
[244] Cod. Theod. 14.15.1; "We reaffirm the eternal privilege for the manceps, who take care of the maintenance of the baths of Rome, that their traditional and principal concern is the exploitation of the salt pans"
[245] Meusel, H. (1960), p 127
[246] "On the bath contractors and the fuel supply"
[247] Merten, E. (1983), p 55
[248] Meusel, H. (1960), p 127 and Merten, E. (1983), p 56 argue that as a reward for the munus of provisioning the baths, they were given the monopoly on the trade in salt in Rome
[249] Meusel, H. (1960), p 127
[250] IG V 1390
[251] IG V 1390
[252] CIL II, 5181, l 21
[253] Sen. Ep. 86.8-9
[254] CIL II, 5181, l 31
[255] IG V 1390;
[256] For aediles see Sen. Dial. 7,7,3 or Ep. 86.8-9
[257] Nielsen, I. (1993), p 126
[258] CIL IX. 1419 = ILS 6489 (dated to Hadrian); CIL II.4610 (sin datum)
[259] The Greek Anthology IX 617

supra) blames the balneator for overheating the baths.[260] According to Yegül, the book of a Roman schoolboy instructs the youth to give thanks to the *balneator* as a form of courtesy. The acknowledgement is phrased as 'your baths were warm'.[261] Martial uses bath benefactor Tucca as the butt of a joke that centers on his stinginess. Tucca had built wooden balneum and marble thermae. It seems the latter was not heated properly, according to Martial, upon which he suggests putting the wooden one to good use.[262] The joke works because it centers on portraying Tucca as status-seeking by building expensive baths, yet stingy enough to cut expenses on ensuring its actual running. This would indicate that the viability of large baths was accounted for by those who built it and that baths could have needed additional funding aside from entrée fees (contra Blyth section 2.1.1). Seeing as the Romans had no device to measure temperatures, leasing contracts usually had a clause whereby the lessee is to make sure the baths are heated 'enough'. This means up to the standard of either the lessor, or a government official.[263] Perhaps this is why the Vipasca inscription features a clause that wood cannot be sold by the conductor. The conductor was fined 100 ~~HS~~ per cartload of fuel, to be paid to the fiscus.[264] Fagan speculates this was to counter corruption and insufficiently heated baths, and its mention does hint that the practice of selling fuel might have been widespread.[265]

Citizens could complain to the municipal supervisor if the baths were not heated enough. As featured above (section 2.1.3), evidence for this comes from Antioch where Libanius had to show support for both the municipal official who was in charge of fueling the baths, and the governor of the Eastern provinces (Comes Orientis). Libanius, having grown up in a family of city administrators, could counter that the task of heating the baths did not befell the Comes. As we have seen, it was the municipality who was to provide oversight and maybe step in when things went awry. Libanius coming up with an excuse for the municipal official, might also shed light on why the complaint was in fact filed with the Comes Orientis. As a supervisory organ, the municipality too could be faulted if the liturgist could not really afford to heat the baths. The plaintiffs would have to go higher up (to the *Comes Orientis*) to make sure their complaint was taken serious. On the other hand, it is quite possible this was a political move to discredit members of the political elite.

The term '*exhibitio*' from the Codex Theodosianus section featured above should be understood as 'managing' the baths, as opposed to actually being present on site. The leaseholders for these large public baths would have had a whole host of people under them, to see to the actual running of the baths and stoking (e.g. a balneator, or a vilicus). Large imperial baths were normally operated by imperial slaves or freedmen; a *vilicus*, *exactor*, or an *actor*.[266] The most frequently used term to refer to bath personnel is as *balneator* (or Greek βαλανεύς). Nielsen typifies this person as a Jack-of-all-trades, who could also serve as a bath superintendent or the person for the day to day running of the baths.[267] It is likely this word took on a general meaning.

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[260] The Greek Anthology. XI 411

[261] Loewe, G., & Goetz, G. (1892). *Corpus glossariorum latinorum.* Lipsiae: Teubneri. "Hermeneumata pseudoDositheana", pp 22f as found in Yegül, F. (2010), p 12. His reference however is not precise, and we have not found the passage to which Yegül refers. We believe we have located the passage, which corresponds to what we believe is the text to which Yegül refers, mentions the phrase "bene lavasti" and can be found at: Loewe, G., & Goetz, G. (1892) *Corpus glossariorum latinorum.* Lipsiae: Teubneri. "Hermeneumata pseudoDositheana", Colloquia Monacensia part 10. The phrase 'bene lavasti' is similar to the mosaic at Sabrantha (cfr supra, chapter 1 "Hypocaust systems, opening hours and operating temperatures")

[262] Martial, 9.75. Tucca had built wooden *balneum* and marble *thermae.* Martial noted the lack of fuel in the latter and suggested the balneum be put to good use. Yegül's interpretation is found in Yegül, F. (2010), p 48

[263] See for example P.Lond. III, 1166; P. Mich. V. 312; CIL II, 5181

[264] CIL II, 5181 l 28-29

[265] Fagan, G. (1999), p 326, nr 282

[266] Nielsen (1991), p 126 citing a.o. CIL VI 8676; CIL VI 8679; CIL VI 8677

[267] Nielsen, I. (1991), p 127; see also Meusel (1960), pp 138-141

There are some inscriptions known where a balneator was a freedmen, though usually the social status of the balneator was quite low.[268] In the *Digesta* a balneator is regarded as part of the inventory of the baths (an instrumentum), indicating slave-status.[269] This also indicates that the leaseholders would not only lease the bathing complex itself, but also the balneator and other staff who belonged and probably lived in or near the baths (cfr infra).[270] In similar positions we should perhaps see the 'vilicus *thermarum*', usually an imperial slave or freedman.[271]

A stoker was called a *fornacator* or a ὑποκαυστήριον, and was usually a slave.[272] Two mosaics from North Africa support this assertion. Both feature naked men carrying a basket with fuel. The one from Bir-Shana Moghane (see fig 3, left hand side) shows this fuel alight to emphasize the connection with the praefurnium, and also features a poker in the person's other hand. The poker could symbolize that the stoker's task was also to oversee a burn, correct where necessary, and ensure enough air got to the burning fuel. This might indicate that there was some skill involved in balancing air flow, burn temperature, fuel efficiency and the conditions inside the baths.

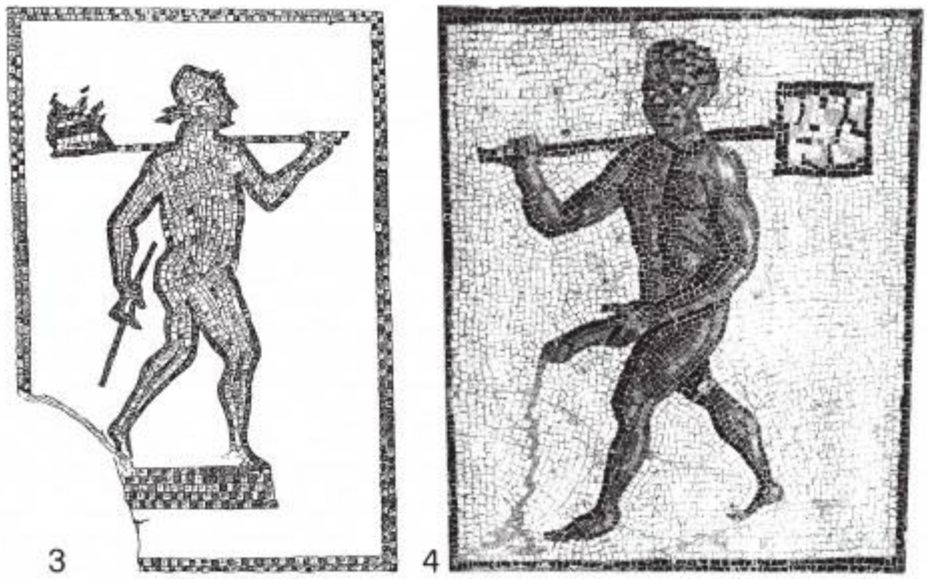

Figure 3 Mosciacs of slave stokers from Bir-Shana Moghane, and Thamugadi, see Thebert (2003), figure 173

The start-up firing of an unheated hypocaust, and usually took a long time and was costly in terms of fuel (cfr section 1.1.3). In one of his letters boasting about his villa, Pliny points out that the village nearby had several bathing facilities in the event an unforeseen guest would visit, implying the baths in his villa would not be ready at short notice.[273] Similarly, an Egyptian papyrus from the 3rd Century has a man requesting a bath be heated before his arrival, so that it would be ready in time.[274] Because of this, several instances of nightly firing are known. The advantage to this would be double: firstly it is more fuel efficient to not let the fire die down completely during the night.[275] Secondly, starting up the ovens early enough ensure the baths would be warm enough by the time visitors arrived. Again here we have a papyrus from the 3rd century alluding to the supply of oil for the lamps for those who

[268] CIL VI, 9395/96 = ILS 7718a (sin data)
[269] Dig. 33.7.13.1; Though in some cases the balneator was also a leaseholder. In Egypt the balneator was usually a freeborn receiving wages, see Nielsen, I. (1991), pp 127-128
[270] Making running the baths somewhat similar to running a household.
[271] CIL VI.8676, CIL VI.8679, see Fagan, G. (1999), p 321, note to nr 268
[272] Dig 33.7.14
[273] Plin. Min. Ep. II.17.26
[274] P. Flor. II, 127 (= Sel. Pap. 140)
[275] See for example Rook, T. (1978), p 277 and Rook, T. (1992) , p 26

were to prepare the chalkeia of the baths.[276] Similarly, Martial complains that the sixth and seventh hour of the day the baths were too hot for his liking.[277] This is probably another indication that the baths were stoked early, so that the rooms would be hot enough by the time the bathers arrived.

As several baths had extensive service quarters it is likely these had live-in slaves working in shifts. These were seen as part of the *instrumentum* of the baths, so they could be bought and sold along with the baths.[278] Seen through this logic we could expect these slaves to stay on site and tend to the hypocaust, even at night. However Kretzschmer, in the Saalburg trials in 1953, notes that after attending to the (charcoal) fire for 2 hours and 20 minutes, the furnace door could be shut closed, and the fire left to run its course, requiring feeding and attendance only twice or thrice daily.[279] This has been reaffirmed in later tests.[280] On the other hand, as is evident from these tests, this caused fluctuations in temperatures, both in the suspensura system and the inside of the caldarium itself (see Addendum 3, figure G). It is possible less fuel would have been needed if the temperatures were not allowed to drop significantly (cfr Yegül and Grassmann's experimental tests, section 1.3). Statius in his laudations also alludes to the 'slow burning fires', conforming to a view of a slow and steady fire.[281] The report by Hüser features a full report by the stoker during testing.[282] Here it was noted that the conditions of stoking were not (physically) demanding. The scent of wood tar was pervasive throughout the duration of the test, but very little carbon-monoxide was measured in the stoke room or the suspensura. This conditions are contrary to what was expected, yet it seems optimistic to think the stoke room would not have been dirty and dusty. Pliny the Younger notes that slaves could be punished by having them serve in the baths.[283] Nielsen interpreted this as being forced to help out with stoking on account of the arduousness of this task. If Hüser is correct, there is no reason to believe these slaves were not made to clean or do other menial tasks. If such a penal system was in place however, it would seem logical to limit movement, and to have live-in slaves. It is far more likely however that this 'community service' did not involve stoking, but instead cleaning and maintenance.

2.3 Fuel Contractors and Fuel Transport and the Price of Fuel.

The fuel contractors are the next-to-last step in the fuel supply chain, the last being those who produce fuel (cfr section 3). For the fuel supply of the public baths several contracts are known to us. These can help us interpret how the baths were fueled. Equally their social status can aid in the reconstruction of this part of the fuel economy. It is likely fuel organization and status would have influenced the cost of fuel. The payment these suppliers received can be cross-checked with sources for the funding of the baths. Several difficulties arise however.

First of all, the cost of transport would have differed widely depending on local terrain. The various modes of transport would have all impacted cost; via mule, by cart, via river or import via sea. These would all have been affected by seasonal differences: Mountainous regions could become impassable in bad weather, in dry periods local rivers might have become too shallow to navigate, and the sailing season might have affected sea imports.

[276] P. Col. Zen. I, 37 (= P. Col. III,37)
[277] Martial, Epigrams,10.48
[278] Dig. 33.7.14
[279] Kretzschmer (1953), pp 26-27
[280] Grassmann (2011) stoked every four hours; as did Yegül, F. and Couch, T. (2003)
[281] Statius, *Silvae* I, 5 "ubi languidus ignis inerrat aedibus et tenuem volvunt hypocausta vaporem?"
[282] See Hüser (1979), p29 section 13
[283] Plinius, Epistulae, 10.32

Veal argues that this could have led to price fluctuations and, to ensure the everyday supply of the baths, storage somewhere near the city might have been an option. Sadly, evidence for storage spaces is usually speculative.

Our sources on the price of fuel are very meagre. They consist largely of the Price Edict of Diocletian. We will follow Blyth's argument that the prices listed in the *Edict* were not retail prices but forests prices, meaning the prices fuel transporters would have paid the producers of fuel wood. To what extent this price was applicable to the fuel supply of Roman public baths is uncertain. As seen in section 2.1.4 public forests might have been specifically designated to serve public functions, such as supplying the baths. We'll with section 2.3.4 where we'll crosscheck some calculations for the price of fuel and cost of transport with monetary benefactions. In section 3 then, we'll explore the context of fuel production and other types of fuel besides wood.

2.3.1 Contracts and Social Status

As with the bath managers, the fuel contractors were kept under the supervision and regulation of the local government (cfr. section 2.2). As we have seen in section 2.1.3, certain individuals or groups could be charged with the provision of fuel for the baths. Though often seen as civic duty, this system would still have been organized through contracts, given out by the government official in charge or the bath leaseholders.[284]

A religious law from the 1st century BC pertaining to the sanctuary of Andania, near Messenia, mentions fuel suppliers as contractors.[285] The rulings of the sanctuary specify the proceedings of a religious festival, the Mysteries of Andania, which was revived by a local benefactor. Though it is not explicitly stated whether the baths were owned by the sanctuary or the city, or were owned privately, it is implied that they were leased out.[286] Presumably the baths' leaseholder had to hire fuel contractors, similar to the Vipasca inscription (cfr infra), though this is not stated. The service of the fuel contractors were regulated however in this law, and its compliance was charged upon the market supervisor. The law stipulates the market supervisor had to make sure that the suppliers of fuel provide 'enough' dry wood every day, 'from the fourth hour to the seventh'.[287] This type of delivery, from morning till noon, essentially conforms to the view on stoking as featured in the previous section (cfr. section 2.2). Stoking could have started early in the morning, and the fire would have been allowed to linger for the afternoon (cfr 'slow burning fire'), making use of the baths' heat retaining capacity.[288]

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284 CIL II, 5181

285 IG V 1390, lines 106-111. The text and translation consulted was by Meyer, found in Meyer, M.W. (1987) The Ancient Mysteries, a Sourcebook on Sacred Texts, p 58; see also Bowden, H. (2010) Mystery Cults in the Ancient World, pp 68-71

286 IG V 1390 Line 107 reads "Regarding the annointing and bathing. The supervisor of the market is to be careful that those who wish [to provide public baths] in the sacred area not charge the bathers more than two copper coins"; translation by

287 It should be noted here that Greek and Roman hours do not correspond with our measurement of time. The Greek and Roman day at this time period (1st century BCE) was divided into twelve hours on the basis of sunlight, with the first starting at dawn and the day ending at the twelfth hour, which would correspond with sunset. This means these twelve hours are uneven and constantly changing because days are shorter during winter. At the winter solstice, the fourth hour would have begun roughly at9.45AM, whereas at the summer solstice it would have corresponded with 8.15 AM. The seventh hour corresponds with noon (the word 'noon' –ironically- is derived from the ninth hour). For further information see Hannah, R. (2009) *Time in Antiquity*, especially pp 6-8 (Introductory chapter: "Time in Antiquity"), 73-75 (chapter "Telling Time")

288 For the possibility of hypocaust-like baths at this early period in Greece, or at least heating methods more advanced than braziers, see also Fournet and Redon (2013) in Trümper, M. (ed), Greek Baths and Bathing Cultures, pp 239-265

Regulations however could vary from place to place. The Hermopolis inscription features a clause that 'sufficient' fuel should be supplied 'up until the bathers leave'.[289] Similar to Andania, the future gymnasiarch of Hermopolis oversees and regulates the baths' operation with regards to their heating (cfr section 2.2). Yet another type of stipulation can be found in the laws of Vipasca.[290] Here the conductor of the baths is to provide, at his own expense, enough fuel 'in order to warrant continued operation from first light to the second hour of night'.[291] The stipulation for the openings hours is noted to have been made in conjunction with the procurator of the mines, similar to regulation by market overseer in Andania and the gymnasiarch of Hermopolis (cfr section 2.2).[292]

Where these suppliers got their wood fuel from however, is rarely stated. Though we've stated there were often designated public forests in section 2.1.4, it is possible wood fuel could also have been bought at the fuel market, or with nearby private suppliers. Cato describes a type of farm close to the city, called a *fundus suburbanus,* which would produce perishable goods, such as fruits and vegetables, but also firewood for the city.[293] It is possible this type of farms supplied the market with enough fuel to also supply the baths. In fact, Veal sees a connection between this type of farm and fragments of vine trimmings, fruit- and nut trees usually found in the charcoal assembly inside the city.[294] An early example can perhaps be found in Demosthenes' speech against Phaenippus from that same period, features landowner who had been given a liturgy, but tried to transfer the burden to a richer man on the grounds that he was not rich enough (cfr section 2.1.3 and 2.1.4).[295] Though Phaenippus's estate main crop was barley, Demosthenes mentions Phaenippus plenty of money by selling fuel (cfr supra *fundus suburbanus*). Meiggs, and Olson point out however, that as Demosthenes' intent is to portray Phaenippus as wealthy, the figures given (12 drachmas a day) might have been revenue and not profit.[296] In any case, they point out that fuel suppliers could be vertically integrated by a landowner like Phaenippus, thereby providing a valuable asset for his estate. A similar assessment can be made for the baths (cfr section 3.1.1 and 3.1.2).

It is likely however that in most cases the fuel contractors provisioned the baths directly from the producer (there are exceptions, cfr infra). As the baths posed a large enough demand, this might have offered a more secure supply. A year's contract might have escaped price fluctuations inside the city throughout the season (cfr section 2.3.2 and 2.3.3). However, a system with such a contract might also tempt a bath's leaseholder to sell this fuel at such times when the price of fuel was high, which would explain why this practice was explicitly mentioned and forbidden in the Vipasca lease.[297] The benefaction from Misenum made in the late 2nd/early 3rd century featured a duovir supplying 400 cartloads of hardwood each year from his estate for the heating of the baths.[298] This indicates that wealthy benefactors could have supplied fuel from their estates directly to the baths.[299]

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289 See for example Nielsen, I. (1993), pp 135-138 for an account of baths being open until late at night for certain busy people or conversely in order to cater toward those who favored a bathing at a time more conductive toward licentiousness

290 CIL II, 5181, see for example Fagan, G. (1999) p 325, nr 282

291 CIL II, 5181, l 18-21.

292 Line 19 reads "arbitratu proc(uratoris) qui metallis praeerit"

293 Cato De Agri Cultura 7.1

294 Veal, R. (forthcoming), p 191

295 Demosthenes, Against Phaenippus 42.7

296 Olson, D. (1991), p 417; Meiggs, R. (1982), pp 205-206

297 CIL II, 5181, l

298 CIL X,3678

299 See also Poehler, E. (2011), pp 194-215

Olson argues - for classical Athens- that fuel suppliers would usually have quite a low status, as gathering and transport of fuel was seen as hard work.[300] Near late Antiquity, Diocletian's Price Edict too lists the maximum payment for a mule driver as 25 denarii.[301] By comparison the same wage was given for an unskilled farmhand, with a skilled worker receiving double.[302] An account from a private estate in Memphis, Egypt from the middle of the 3rd century CE for example shows twelve donkeys being hired along with 24 donkey drivers, each being given a day's wage of 4 obols, for carrying chaff from the village threshing floor to the estate's baths.[303]

Mule drivers and woodcutters who performed the actual labor would have had a low status, yet there are some indications that was not the case for all involved in the fuel industry. Strabo mentions a contemporary from Mylasa called Hybreas, whose original possessions were a 'wood-carrying mule' and a mule-driver, and who worked his way up. He later became a market supervisor and later an orator, eventually becoming one of the most powerful men in his city.[304] Pompeian *programmata* (graffiti for local elections) provide a small insight into the possible diversity of organization of a city's fuel supply. They hint at professional organisations of lignari plostari, lignari universi and muliones.[305] According to Meiggs the 'lignari plostari' carried wood in wagons, probably from the forest to the town.[306] The 'lignari universi' would then have included all those who handled wood, including fellers, carters and retailers. Veal believes these lignari universi might also have been shopkeepers who sold wood.[307] The muliones, or mule drivers, could have transported all kinds of goods, but that could have included wood and charcoal.

The professional associations these men formed could also have been well regarded. We have seen Caracalla's imperial edict calling for the expulsion of 'Egyptians' from Alexandria, save for the pork-dealers, boatmakers and the "reedcutters who bring fuel for the baths."[308] This would indicate that contributing to heating the municipal baths had an impact on social status. In Rome a professional organization was charged with the munus of both the running of the baths and the transport of fuel to the public baths (cfr. section 2.1.3).[309] In the Codex Theodosianus we find a law concerning "the bath contractors and the fuel supply".[310] Meusel argues this duty befell the *mancipes thermarum* (cfr supra section 2.1.3).[311] Yet it is apparent that the shippers (navicularii) were also involved in the supplying, or transporting of fuel. This is evident from the arguments put forth by Symmachus, which probably echo those put forth by the *mancipes thermarum*.[312] The *mancipes* argued that their duty (munus) of caring for the baths and that of the shippers are actually the same, and so their organizations should be joined. Their involvement in the fuel supply could be seen confirmed in a floor mosaic from Ostia, where *navicularii* and *lignarii* share an office and are pictured together as if they are a whole (see figure 4, p.t.o.). The situation in Rome, due to its size, might have been exceptional compared to the rest of the empire. As we have argued in section 2.1.4, by late Antiquity

300 Olson, D. (1991), pp 415-416
301 Edictum de pretiis rerum venalium (Diocletian's price edict), section VII
302 Edictum de pretiis rerum venalium (Diocletian's price edict), section VII
303 BGU 14 III, line 18 and P. Lond. 131V
304 Strabo 14.2.24
305 CIL IV, 485; CIL IV 960; CIL IV 97, 113, 134
306 Meiggs, R. (1982), p 359
307 Veal, R. (forthcoming), p 226
308 P. Giss. 40 col 2
309 Symmachus Relationes, 14.3
310 Cod. Theod. 14.15 "De mancipibus thermarum urbis et subvectione lignorum"
311 Meusel, H. (1960), p 127
312 Symmachus Relationes, 44.2 "tunc urgente defectu navicularios aeque lignorum obnoxios functioni ad parem sollicitudinem vocare coeperunt, ut utriusque corporis cura coniuncta indiscretum munus agnosceret." (my emphasis)

fuel was imported to Rome not only from the Italian countryside, but also from North Africa as well.[313] This might explain the shippers' involvement in the fuel supply of the baths and the arguments put forth by the *mancipes*.

Figure 4 Floor Mosaic from Ostia (CIL XIV 4549, 03)

As we've stated in this section, most of the fuel that would've provided the baths was likely from a city's immediate hinterland, for which there are several reasons (these shall be dealt with in section 3). As seen above, Rome is somewhat of an exception to this (see also section 2.1.4). There are some indications however that short- to more long distance-trade existed for fuel. Veal argues that short-distance overseas trade in fuel was likely economically viable for supplying Pompeii.[314] Furthermore, the evidence is mounting for a trade in coal for Roman Britain (cfr section 3.2.5). As Dearne, and Branigan pointed out, the use of coal was as frequently attested in a civic context as a military one. There is an ample set of baths with documented use of coal, where in the vicinity no coal occurred. While it is possible this trade occurred as a subset of other trade (using coal, or wood fuel as ballast on a return trip), too little research has been done at the moment to offer more than speculation. We shall revisit this problem in section 3.3 and in section 4.

2.3.2 Transport and Storage [315]

There was a variety of transportation methods for transporting fuel. Aside from oxen, donkeys were quite popular beasts of burden, and several have been attested as transporting fuel.[316] Donkeys or mules were probably most used in transportation by track or road. Mules could have formed mule trains with filled side bags, or could pull wagons or carts. These sturdy and sure-footed beasts would have been the only option available in a steep, hilly or muddy environment. Veal notes that the use of carts implies at least a firm road, most often paved.[317] How many donkeys, mules or oxen or what

[313] Symmachus Epistulae, 10.40.3 and Nenninger, M. (2001), p 81
[314] Veal, R. (forthcoming), p 222
[315] Several of the considerations on transport, especially river transport, are indebted to Veal, R. (forthcoming) pp 210-223
[316] BGU 14 III, line 18 and P.Lond. 1 131 V specify donkeys or mules, as does the story of Hybreas in Strabo 14.2.24, or that of Phaenippus in Dem. Against Phaenippus 42.7
[317] Veal, R. (forthcoming), p 211; The Digesta note that a road, or *via*, is defined by the ability of a vehicle to move along it, Dig 8.1.13

size or type of cart were used (two wheels or four) probably depended on the situation.[318] Mules can pull a wagon individually or in pairs. Depending on how the carts are attached, how well the harness is made, and how much a cart weighs a single mule could pull a cart with a 400-500 kg load on flat terrain.[319] Laurence uses comparative evidence from the American Mid-West to suggest a mule could pull a total load of 400 kg for a distance of 50 miles (or about 80 km).[320] The roads used by these mule carts would have been constructed by the state/military, the local authorities or in some cases by rich landowners (usually for private use).[321]

These roads could vary in width and were defined by law, though many have been found quite narrow.[322] In some cases these were just enough for one cart to pass, perhaps requiring to maneuver the outer wheels onto the roadside shoulder.[323] Furthermore, there were no general traffic laws to follow in the Roman Empire, instead rules and regulations could vary from town to town and changed over time.[324] Generally speaking, local administrators accounted for the size of the streets, their capacity, and even safety and technical aspects (size of the carts, direction of traffic).[325] In Rome, Julius Caesar forbade loaded carts from entering the city during the day.[326] This stipulation was renewed several times during the empire.[327] This regulation did not hold for beasts of burden or porters and would have made donkey trains a more interesting method of transport rather than using carts. Equally it is possible some fuel suppliers delivered at night or near morning, a period which could coincide with the start of stoking (cfr section 2.2).[328]

River transport would oft have been a viable alternative. Pliny asking the emperor for funds to build a canal in Bithynia, mentions that firewood was traded via river and a local lake, and that this was at a low cost compared to over land.[329]. Several flat-bottomed river boats have recently been uncovered in the Netherlands that likely travelled frequently along the Moselle, from what is now Saarland to the Netherlands.[330] As indicated by Pliny's request to Trajan for a canal, river transport in most areas of the Mediterranean is dependent on several factors. Firstly the course of its stream toward the intended destination; a strong current might have deterred transport going upriver. Secondly the depth and level of the river, as too much cargo might have run a boat aground in more shallow areas.

[318] For a more detailed analysis of different features and profitability of transport, see Poehler, E. (2011), pp 194-215; also P. Lond. 1 131 V where a slave leases a wagon from another estate and uses several donkey's for various purposes, including transporting wheat to the estate-baths. See also Phaenippus who made money using 6 donkeys to transport firewood to Athens, according to Dem, 42.7

[319] Dibbits, H. (1995), pp62-74; especially pp 71-72; also from recommendations from "Donkey Cart Considerations", Donkey Power: Facilitation and Consultancy, P.O. Box 414, Makhado/Tshitandani, 0920 South Africa, pp 3-5

[320] Laurence, R. (1999), pp 125-126 as quoted in Veal, R. (forthcoming), p 212

[321] Chevallier, R. (1976), pp 65-66

[322] See Laurence, R. (1999), pp 58-59; the Twelve Tables mention roads had a minimum width of 8 feet, allowing two vehicles to pass, Twelve Tables 7; Dig 8.3.8

[323] See Tilburg, C. R. (2005), pp 60-65, 142-143; and Veal, R. (forthcoming), p 223

[324] These were differentiated by law as a 'track' (actus) instead of a 'road' (via), See Tilburg, C. R. (2005), pp 60-65, 102, 135-43; and Laurence, R. (1999), p 59

[325] Tilburg, C. R. (2005), p 102, pp 142-43

[326] See Tilburg, C. R. (2005), p 135 and CIL I², 593, 56-67

[327] Tilburg, C. R. (2005), p 135, and and CIL I² 78&104

[328] P. Col. Zen. I, 37 (= P. Col. III,37) (254-250 BCE) refers to the supply of oil for lamps for those who were to prepare the chalkeia of a bath, indicating nightly heating
And P. Flor. II, 127 (= Sel. Pap. 140) (266 CE)

[329] Plinius Minor. Letters to Emperor Trajan, 50

[330] See Visser, R. (2010) and De Groot, T., & Morel, J. M. A. W. (2007). Het schip uit de Romeinse tijd De Meern 4 nabij boerderij de Balije, Leidsche Rijn, gemeente Utrecht. *Waardestellend onderzoek naar de kwaliteit van het schip en het conserverend vermogen van het bodemmilieu. RAM-rapport*, *147*

Lastly, the permanence of its flow; a lot of rivers run dry in the dry season, or have levels too shallow for transport.

In the Mediterranean, these factors are often influenced by the season and by rainfall. According to Pliny the Younger, even the Tiber was not navigable from his property in Tifernum in the summer months.[331] The advantage of using mules and/or carts would have been a greater independence from this seasonality. Secondly, river transport might require several changes in transport method, switching from mules or carts to river transport, and back again at its destination.[332] This might have been arduous and time consuming, as Pliny's request indicated.[333]

A final possibility of transport is that of coastal sea transport, for coastal towns. This would have been dependent on the sailing season. Duncan-Jones finds the following ratios for cost of transport from Diocletian's Price Edict:[334] sea: river: land = 1: 4.9: 28

Laurence maintains the advantage of sea over land has been overstated, as both sea and river transport in practice always imply some overland transport.[335] Greene on the other hand notes that the efficiency of river transport might have been smaller, on account of the costs involved in the change of transport mode (noted above), and the supposed lack of efficient river boats before the empire.[336] Still this would indicate a large preference for sea and river transport past certain distances, especially for bulky goods like wood.

Veal, using Duncan-Jones' ratios, calculated several of these scenarios for the fuel supply of Pompeii.[337] Excluding seagoing charges (such as harbor taxes), she found that sea-transport from Surrentum or Positano, up to 50 km away (and 2 final km overland), could have been cheaper than overland transport.[338] Riverine transport was equally practical from the Appenines along the Sarno (25km river and 1-2 km of track). Overland transport would mainly have been advantageous for shorter distances (up to 8.5 km) coming from the midpoint of the Sarno plain, halfway between Nuceria and Pompeii. Veal notes another advantage is that mule-transport could have avoided all extra costs (market fees, etc.) by providing direct delivery. For our purposes though, delivery to public baths, these fees might not have applied, though we cannot be sure (cfr section 2.3.3). Furthermore, these figures should best serve as guidelines for interpretation, rather than as the basis of a cost-benefit analysis. The latter type of rationality would have probably been foreign to the Ancient world.[339]

Direct, almost day-to-day fuel delivery might have been viable if fuel could be brought in overland from short distances. This would perhaps be limited to a mule being able to manage a trip in a single day (up to 80 km with a load of 400 km, cfr. supra). If the logistics of fuel supply fell within these limits, then perhaps ample fuel storage on-site at the baths would not have been necessary. Several contracts, such as the inscription from Hermopolis, or the laws from Andania suggest fuel delivery every day.[340] The benefaction from the duumvir from Misenum gave 400 cartloads each year.[341] This could mean one cartload every couple days during normal periods, and perhaps two cartloads each

[331] Plinius Minor. Letters 5.6 11-13, as quoted in Veal (forthcoming), p 214
[332] Veal, R. (forthcoming), pp 219-220
[333] Plinius. Minor. Letters to Emperor Trajan, 50
[334] Jones, R.D. (1974), pp 366-369
[335] Laurence, R. (1999), Chapter 7, pp 95-108; and pp 121-122
[336] Greene (1986), p 40 as quoted in Laurence, R. (1999)
[337] Veal, R. (forthcoming), pp 217-220
[338] Veal, R. (forthcoming), table 16 and p 219
[339] Laurence, R. (1999), p 99
[340] P. Lond. 3. 1166; IG V 1390
[341] CIL X 3678

day for the coldest months (cfr. section 1.3 winter vs summer usage in the Herbergsthermen and NOVA baths).

On the other hand, the laws of Vipasca mention the conductor should have a stock of wood plenty enough to last a certain number of days.[342] This could be seen as a policy to prevent shortages or improper heating from occurring, perhaps even as a measure to counter corruption (cfr. Fagan, section 2.2). Nielsen states that Ulpian mentions it to be a requirement, a general bath policy, of keeping enough fuel stocked and ready, but the source quoted does not indicate this conclusion.[343] The Vipasca lease contains the only mention, to my knowledge, of the requirement of keeping a stock of fuel ready. It is possible Vipasca might be an exception, as the mining operation implies a different context than an urban setting. An urban setting could have more organized services present (such as a market), or could collect waste products from the city. Perhaps the stock of fuel had some connection to the mining facility in case of a shortage.

Nevertheless, the existence of storage spaces for fuel stocks has generally been assumed.[344] If the service quarters of a bath site had ample storage space, then fuel delivery would probably not be expected to involve direct day to day, ad-hoc delivery. A papyrus contract from 34 CE from Talei, Arsinoe for example mentions a private bath featuring an adjoining chaff storage bin.[345] An archaeological study trying to locate and determine these spaces of storage could further our understanding of fuel delivery practices. How accommodating bathing sites were to large storage spaces might provide another cross-check for our fuel-use estimates and fuel delivery practices.

We should note however, that if day-by-day transport was practiced, not much storage space would have been needed. After all, for the NOVA baths or the Herbergsthermen (who are albeit of the smaller variety compared to large imperial baths), this would imply possibly as little as 100-150 kg of wood each day (cfr section 1.3). This amounts to around 1/4th of a stère of wood,[346] hardly noticeable in most establishments. For the Achillean baths in Catania, which the inscription noted using 3000-5000 kg of wood daily, this would imply at least 10 stère needed for storage, assuming the same dried weight. It is quite possible larger baths then did require storage space, perhaps even a stock of fuel as part of a policy (see Vipasca lease supra). In that case, one would expect not only storage space but also offloading sites with ramps leading out to the street, if carts were used as stated in the benefaction from Misenum (cfr supra).[347] A compilation of bathhouses such as Nielsen's at first glance shows that most baths' service corridors opened out onto the street and many public baths were usually close to one of the city's major roads.[348] Perhaps delivery could be made by the roadside. Especially if done in the morning or at night, this might have caused little hindrance.

[342] CIL II 5181

[343] Nielsen (1993), p 123 footnote 4, and Dig. 32.55.3. The discussion of Title 55 clearly centers on bequeathing or inheritances. In discussing which part of a bequeathing belongs to whom the distinction is made between timber and fuelwood. In the third segment it is made clear what a gift of land for fuel means and to what purposes it can be legally made.

[344] See for example Pasquinucci, M. (1987) *Terme romane e vita quotidiana*, p 45, fig 33 or Schiebold, H. (2006), p 38

[345] P. Mich. 5 312

[346] A 'stere' is a unit of volume for wood stacked into a 1 cubic metre space. This is different from 1 cubic metre of wood, which does not account for the spaces in between the cut logs and the irregularities in stacking. Depending on the type of wood and its dried weight, the weight of a stère can vary. From personal correspondence with wood dealers, they suggested the 'average' the weight of a stère would be between 400-500 kg

[347] CIL X, 3678

[348] Nielsen, I. (1993), part II

2.3.3 The Cost of Fuel and Cost of Transport

Our information on the price of fuel is quite meagre and is spread across vast time periods. Woods suitable for fuel are usually only mentioned in passing as to their burning quality and hardly any information is available on the economics of fuel itself.[349] The temple commissioners' accounts from Eleusis and Delos provide some information.

Accounts from Eleusis (329 BCE) note the purchase of 67 talents of wood and 60 bundles of vine trimmings for fuel for the Haloia festival brought in by sea at '2 obols each'.[350] The wood used for burning was not specified, so Meiggs concludes this must have been a mixed lot, as another entry for burning did declare the type as 4 talents of olivewood and 4 bundles of vine prunings. A mixed-lot of fuel where no preference is indicated what type of wood it contained could be presumed to be expected as most hardwood and dried softwoods have about the same calorific value (cfr section 1.3). We shall revisit this claim again in section 3.1. The fuelwood in the Eleusian account for the Haloia festival was brought in from the sea, and seven drachmae and 3 obols were given to the ferryman, a fee of 7% of the cost of the wood. The early date of these accounts require figures on inflation and conversion to be compatible with later Roman prices, and for this reason shall not be attempted here.

Similarly, the Delian accounts reach far closer to the period of the Roman Empire, some 300 years' worth of purchases have been found. Yet these have problems of their own. Most wood on the island was imported and its scarcity meant that its prices on Delos were high.[351] As Veal notes, wood's great scarcity on the island meant the temple priests meticulously recorded the information, and so the very reason we have this information is the same that rules out anything but the broadest inferences.[352] It seems though that these prices did wax and wane according to the season.[353] Ancient authors mention that the recommended time for cutting wood was autumn/winter.[354] Nenninger notes this could be due to the wood being more resistant to rotting than had it been cut in summer.[355] This seasonality could perhaps be exacerbated by consumption patterns and by transport considerations (cfr section 2.3.2). Columella notes that an Italian landlord would be doing well if his wood brought in 100 ~~HS~~ for a single iugerum~~.~~[356] Blyth uses this figure to calculate the cost of one cartload of fuel (30-33 ~~HS~~), an estimate we have used throughout this text (cfr. section 1.2 and 2.1.1).[357] As Veal notes however, we cannot be certain this income was on an annual basis (as Blyth), rather than per cut or harvest.[358]

The most obvious source to find information on the price of fuel would be Diocletian's Edict. Though there are problems using this document. At the outset, the *Edict* was made to secure provisions for

[349] Cato De Agri Cult. I.2 and V.8; Varro De R.R. I.6.2 and V.6.4; Col De R. R. I.2.3; Vitr De Arch. 2.9.5-6
[350] Meiggs, R. (1982)
[351] Reger, G. (1994)
[352] Veal, R. (forthcoming), p 208
[353] Reger, G. (1994)
[354] Among others Vitr. II.9.1-3; Varro de R.R. I.27.3; Cato De Agr Cult XXXI.2; Colum. De R. R. XI.2.11; Plin. Hist Nat XVI.188-192
[355] Nenninger, M. (2001), pp 38-41
[356] Col. Res Rustica 3.3.3
[357] Blyth, P. H. (1991), p 87
[358] Veal, R. (forthcoming), p 208

the supplying of the Roman military.[359] Additionally, according to the (hostile) account of Lactantius it affected trade negatively and had to be withdrawn.[360]

The first complication is that it is possible the prices might not have accounted for local fuel economies.
This means first of all that, depending on the location, vastly different determinants for the price of fuel might have applied, which might not have been considered. This argument however then leaves us with no immediate sources and no foreseeable way of pursuing a more quantitative path. It is possible –and perhaps not unreasonable to assume- that prices did not alter much geographically, corresponding everywhere to some basic price level, derivative perhaps of the price of grain. This would perhaps be necessary in order for fuel to be purchased by urban dwellers living not much above subsistence. Alternatively, it might not have interested those who made up the *Edict* to preserve the workings of local economies, instead focusing on stabilizing the empire with the military complex at the forefront. It might then be the relevant price for all official transactions, perhaps including the baths.
Secondly, the *Edict* for example considers firewood (in various loads), plant stakes and bundles of twigs 'for use in ovens'. As we shall see, various locations across the empire resorted to other fuel sources as well (cfr chapter 3). These are not mentioned in the *Edict* as they might not have mattered toward its goal, which is securing the supplies for the military. The use of olive pits and dried olive pressings (formed into cakes cfr section 3.2) was a local or regional phenomenon where olive cultivation and olive presses were plentiful. To what degree these had a price, rather than being given freely remains uncertain (cfr section 3.2). Egyptian sources hint that chaff and other harvest by-products from the village threshing floor might have been given freely for public purposes.[361] On the other hand, the lightweight and transportable nature of olive pits and dried pressing might have encouraged commercialization. This might be why coal was traded in Roman Britain. No price information for our period survives for these alternate sources as far as we know.

The second complication the *Edict* poses is that the document is from 301 CE, a time where inflation was high. It is therefore debatable whether we can use these prices for earlier time periods. There have been estimates of the inflationary factor toward the early empire (which resulted in a factor 70 in comparison to the 1st century CE).[362] Yet these are again open to doubt as we do not know how the price of firewood, or the cost of transport would have moved in relation to other prices. A common practice is to transpose monetary prices to prices in wheat. In this manner Blyth compares the prices of 329 BCE Eleusis, 310-169 BCE Delos, 1663 CE London, and 1800 CE Rostock, Germany.[363]

This way he found that the cost of fuel in wheat of the *Edict* are at smaller than those of London and Rostock by a factor of 2 (so the Edict is at least a half cheaper). In comparison to the cost at Eleusis in Delos by a factor of 8. The later could be nuanced, as above, by pointing out the special circumstances (cfr supra). Additionally Blyth points out that both Eleusis and Delos were for use at religious ceremonies, could have been of special quality or were regulated in the interest of selling small quantities for visitors.[364] Converting prices into equivalent quantities of wheat however is not without its own problems; prices of wheat of course fluctuate themselves. They are also influenced by the

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[359] Noethlichs, Karl Leo (Aachen), "Edictum Diocletiani", in: Brill's New Pauly, Antiquity volumes edited by: Hubert Cancik and , Helmuth Schneider. Consulted online on 14 June 2016 http://dx.doi.org/10.1163/1574-9347_bnp_e326230; see also Meissner, B. (2000), "Ueber Zweck und Anlass von Diokletians Preisedikt" in Chamber, M., Heinen, H., et al (eds) *Historia* 49, pp 79-100
[360] Lactantius, De Mortibus Persecutorum 7.6-7.7
[361] BGU.3.760
[362] Veal, R. (forthcoming), p 221 notes Wassingk (1991), p 466 and Duncan-Jones (1982), pp 374-75
[363] See for example Blyth, P.H. (1999), pp 92-93, Table 1
[364] Blyth, P.H. (1999), p 92, Table 1

success of the harvest, and the cost of transport and accessibility. Yet, the prices in the *Edict* are all that is really available, so they will be discussed.

The four prices for firewood are quoted in Chapter 14 of the *Edict* as follows:[365]

Wagonload of firewood	1.200 librae	150 denarii
Camel load of firewood	400 lb	50 den
Mule load of firewood	300 lb	30 den
Donkey load of firewood	200 lb	…

According to Blyth these prices differ from other prices in the edict in several key ways. First of all the price per unit weight is quoted according to the mode of carriage instead of the dimensions of the wood, as is the case for building timber. As stated before, this is to be expected as transport costs probably made up a large portion of the price (cfr. section 2.3.2).

The quantities are also larger than those found at Delos and Eleusis and the prices are much lower than most comparative historical prices (cfr supra).[366] For this reason Blyth argues they are not retail prices but 'forest prices'; the prices a trader would pay at the production site (the forest).

Two further arguments support this. Firstly, the price of fuel wood at –or near- the felling location in the forest would have been far easier to compile for the bureaucrats who made the *Edict* because the different aspects of transport costs did not need to be reckoned with.[367] The price was intended for those who would have bought fuel at the production site (the forest) to transport it to the city. The treatment of the prices for fuel in this manner in the *Edict* implies, according to Blyth, that a system of specialist wood-sellers had spread throughout the Roman world by this time. These would have purchased fuel wood where it was produced, stored and dried, and then would have transported it to sell in the city. The problem with this argument is that such a system of course would run counter to a model where large *latifunda* produce firewood for the city.[368] Another problem is that prices might be set at such a low bar, because they were intended to serve the Roman military. The army could have enforced and demanded them without thinking of the consequences, as Lactantius indicates (cfr supra). The loads of firewood furthermore are beyond what might be needed for personal use, so they would imply some larger purpose, such as a public function. This might justify the comparatively lower price. We have already noted the financing problems the municipal authorities faced in heating the baths by late Antiquity (cfr. the *mancipes thermarum* and Libanius' complaints in Antioch section 2.1.3, 2.1.4 and 2.2).

365 From Kropff, A. (2016) An English translation of the Edict on Maximum Prices, also known as the Price Edict of Diocletian. Published on Academia.edu 27/04/16 and available at <<https://www.academia.edu/23644199/New_English_translation_of_the_Price_Edict_of_Diocletianus>> last check 07/06/16

366 See Meiggs, R. (1982), appendix 4, for among others, a treatment of the Delian and Eleusian accounts

367 Blyth, P.H. (1999), appendix 1 pp 95-97

368 Veal, R. (forthcoming), pp 191-193

There is however a second argument that would support Blyth's interpretation. According to Blyth the maximum price of a wagonload of fuel (forest price) can be related to the transport charges also mentioned in the *Edict*:[369]

Charge for a wagon (four wheeled mule-cart, or *raeda*), with customary load (= 1200 librae?)	Per Roman mile (= 1.479 km)	12 denarii
Freight charge for a 1200 librae wagonload (two wheeled ox-cart, or *carrus*)	Per Roman mile (= 1.479 km)	20 den
Freight charge for a donkey, with load 200 librae (65.4 kg)	Per Roman mile (= 1.479 km)	4 den

The 'forest price' of a wagonload (carrus) of firewood would be the equivalent of the cost of transport of 7,5 Roman miles (+- 12 km) overland, and that of a mule-cart (raeda) at 12.5 Roman miles (+- 18.5 km). These distances Blyth argues were the likely distances fuel would have travelled overland.

These distances Blyth assumes do coincide somewhat with those proposed by Veal for the fuel supply of Pompeii.[370] Using the transport costs (shown above) in addition to the cost of a wagon of wood, in the fuel supply from Campania to Pompeii, Veal found that transport usually accounted for 50% of the final cost of supplying fuel.[371] This coincides with Blyth's historical comparison of the *Edict*'s fuel at half the cost of fuel in1663 CE London, and 1800 CE Rostock, Germany (cfr supra). This same relation (1/2) would be explained by arguing, as Blyth does, that the *Edict*'s prices are 'forest prices', without cost of transport. Lastly, these distances travelled, the local-ness of the fuel supply, are substantiated by anthracological and archaeological research of fuel deposits as far as we know, both for baths and in general (cfr section 3).

Spurr is critical however of the use of transport costs from Diocletian's edict on account of that these prices are based on hired transport.[372] It is possible, he argues, that agricultural producers (including those of fuel) could have used slaves, thereby reducing costs (cfr supra section 2.3.1, Phaenippus and *fundus suburbanus*). One could presume this might apply with benefactions of fuel made to the public baths. The benefaction made by the duumvir from Misenum (400 cartloads of hardwood donated in perpetuum) notes however that the administrative costs of this donation befell the municipality. Presumably the duumvir gave 400 cartloads, and the municipality had to arrange (and pay) for its transport, meaning the *Edicti*'s price might apply (cfr supra section 2.1.3).

2.3.4 Calculations and comparison

Suppose we take these considerations toward the inscription from Altinum (dated to the 1st century CE), which records a donation of 400 000 ~~HS~~ for heating two baths.[373] At an interest of 6% that means 12 000 ~~HS~~ was available for each bath. In contrast to Blyth, we shall allow that half of this amount went toward additional transport costs. This assumes the fuel came from a distance of 18.5 km (cfr supra),[374] which is somewhat less, but similar to what Veal thought was the case for Pompeii.[375] Then

369 Veal, R. (forthcoming), pp 191-93
370 Veal, R. (forthcoming), p 219 Table 16
371 Veal, R. (forthcoming), p 222 Table 18
372 Spurr, S. (1986), pp 144-6 as quoted in Laurence, R. (1999), p 99
373 Nsc 1928 p283 Altinum
374 Assuming the price of 150 den covers 18.5 km, multiplied by 2
375 Veal, R. (forthcoming), p 222 Table 18

we factor in the inflation between the date of the inscription and Diocletian's *Edict*. The inflation from the 1st century CE to the 4th century CE is a factor of 70, based on the figure Veal uses, which in turn is based on Duncan-Jones.[376] This amount would have purchased 700 cartloads for the baths.[377] These amount to 275 100 kg of wood fuel, which is about double that of the Phaselis baths, as estimated by Basaran and Ilken (cfr section 1.3.4).

The difference between this estimate and that made by Blyth for the same inscription (cfr section 2.1.1) however is off by a factor of 2. Blyth estimated one cartload of fuel at this time would've cost 30-33 ~~HS~~, and is based Columella's remark on the expected revenue for a landlord's coppiced woodland, whereas ours is based on the *Edict*. Yet, by accounting for Blyth's remark that these are forest prices, we've doubled the price to account for transport costs. This way our estimate is more similar to historical comparison, whereas Blyth's estimates are slightly higher (cfr supra).

These calculations also allow us to monetize for example the benefaction made by the duumvir at Misenum, who donated 400 cartloads, which would have been the equivalent of donating 3428 ~~HS~~ each year.[378] Assuming this was the 5% revenue of a lot, this piece of land would have been worth the equivalent of a trust sum of 68 560 ~~HS~~.

Using Blyth's price of a cartload of fuel (30 ~~HS~~), this would be donating 12 000 HS yearly, and be the equivalent of a 240 000 ~~HS~~ piece of land. Blyth's estimate corresponds far more to the Altinum inscription (which donated 200 000 ~~HS~~ for heating). Similarly, Blyth's estimate is that it bought between 360-400 cartloads, which is similar to the amount the Misenum inscription donated. Also, the donation of 150 iugera of land by the official at Aurgi converts roughly to a yield of about 350 cartloads of fuel (cfr supra section 1.1). [379]

The convergence of these three benefactions assumes these donations were meant to cover the entire expense of heating the baths, which -it is also assumed- are similar for the same size baths throughout the empire. This could be substantiated by the correspondence with fuel use estimates of the Nova baths by Yegül (low estimate: 52 560kg – high estimate: 131400 kg), and the Phaselis baths by Basaran and Ilken (also estimated at 131 400 kg). This makes Blyth's reconstructed price somewhat more believable than ours. While it is very likely these donations covered most of the heating expenses, there is no reason to assume these were the same all over the empire. As we've copiously seen, different patrons had different standards for the heated bathing experience (cfr section 1.2.3, 2.2), which probably translated into fuel use.

Another angle into this matter could be the The Vipasca inscription, which notes that a conductor will be fined 100 ~~HS~~ per (re)sold cartload of wood.[380] In all likelihood this fine exceeded the cost of one cartload of fuel, though by how much is uncertain. A lease from Hermopolis from the same time period states that a breach of contract by fuel suppliers means they shall be fined double of what they were paid.[381] If this was double its cost that would bring the cost of one cart to 50 ~~HS~~. However there is really nothing to indicate the fine couldn't be three times the original amount either, which would bring us to Blyth's estimate. The fine would have to be ten times the price of a cartload for a correspondence with our estimate

[376] Veal, R. (forthcoming), p 221; Jones, R.D. (1982), p 374-375
[377] 150 den = 600 ~~HS~~. Factoring in inflation of 70 means 8.57 ~~HS~~ cost per cartload. 6000 ~~HS~~ / 8.57 ~~HS~~ per cartload = 700 cartloads
[378] CIL X.3678; 8.57 HS / cartload * 400 cartloads = 3428
[379] CIL II.3361
[380] CIL II, 5181 l 27-28
[381] P.Lond. 3 1166

2.4 Summary and Intermediary Conclusion

In section 1 we provided estimates for the extent of the fuel consumption of the baths. In section 2 we've shown its economic context; its funding, management and suppliers.

The baths were funded either through entrance fees, benefactions, municipal funds, or through a system of civic duty. It is quite likely forests were dedicated especially for the purpose of heating the baths, perhaps avoiding commercialization and the relevance of a price tag on the fuel itself altogether. The baths were managed by a local official, a salaried manager or a leaseholder who in turn were subject to municipal supervision. Both running a bathhouse and providing it with fuel would've been an asset to prestige. The Bath's management didn't actually run the baths, instead there was staff for that purpose, usually in the form of slaves attached to the baths. These probably lived on-site. It is quite likely stokers were specialized slaves who might have had some training.

We've mostly found the fuel suppliers for the baths as contractors for municipal officials. The fuel suppliers' contracts often reflect the patron's desire to gain status by providing properly heated baths. They usually emphasize 'enough' fuel should be delivered, or requested a 'continuous' supply. It is quite likely the fuel suppliers had access to designated forests for this purpose. Other possibilities are purchase at the fuel market, or perhaps it was gathered from regular fuel producers. Though fuel suppliers themselves likely had a low status, contributing toward supplying the baths improved social status. Despite the idea that the fuel for the baths mostly would have been supplied locally, there is some evidence that the fuel supply in the larger sense could have involved interregional trade. For Roman Britain at least we have evidence this trade supplied several baths (cfr section 3.2.5). We shall see in section 4.2 how this can be explained by Erdkamp's 'consumer economy' model.

There are several ways fuel transport could have been organized; overland, via river or overseas. Most would have been affected somewhat by seasonal differences inherent in- and around the Mediterranean. The ease of transport might have affected its cost and in turn this might affect whether much fuel was stored on-site of the baths or not. We've seen the example of overland transport for Pompeii by Veal, which concluded this was the most viable option, though short-distance overseas transport cannot be ruled out. These considerations in part depend on the price of fuel and the cost of transport, for which we have but few sources. The most rewarding for our purposes is the *Edict*, though it is not without its problems. The prices though are likely internally consistent, as the price of a cart of fuel somewhat corresponds to the transport costs of a likely destination. Calculations based upon them also correspond somewhat to later historical examples.

Lastly, it should be mentioned that these kind of calculations (e.g. cost-benefit analysis in transporting fuel, cfr Veal section 2.3.2) assume some type of 'rational economic' price behavior, which might not have applied to the ancient world. It is quite possible the fuel supply of the baths were embedded in relations of civic duty and beneficence, which might be priced differently or escape a monetary expression altogether. We hope however that, as the second, or third attempt (that we know of) at modelling the fuel economy of the baths, that these calculations might contribute either way. As Veal notes; "We still lack the data to make more than an educated guess, but nothing will be lost if we attempt to qualify and quantify the Roman fuel economy".[382]

There may be some rationality present in the fuel supply however. In the next section we'll argue there are some indications for a rationally managed environment. Different types of fuel were selected from a perspective that made the most out of what was available, perhaps using waste products that weren't otherwise commercialized. This is 'rationally managed' in the sense that it was sustainable and its production was regular. These shall be addressed in the following chapter.

[382] Veal, R. (2013), p 40

3. Types of fuel

As part of this thesis, a limited 'survey' of twenty-four archaeological studies was conducted. A focus was placed on the anthracological and carpological remains found in the sediment layers of Roman baths (specifically hypocausts). The expectation was that this would provide the basis for an analysis of the fuel supply chain and so provide a novel way of approaching the economy of the public baths.

There are several drawbacks to this method.

Firstly, the study of charred remains is still new. Especially in the past charcoal remains were not collected for reasons of cost or because their use was poorly understood, often being ignored in favor of larger finds.[383] This means many excavated baths lack a proper analysis of the sediment layers in the hypocaust room.

Secondly, I know of no heuristic tool that would allow a search of published archaeological digs involving anthracological or carpological remains, specifically those found in sediment layers pertaining to Roman baths. It would be greatly helpful if a database of some sort was constructed for this purpose, as it has been created for the study of pollen.[384] Ideally, these could even be coupled to geographical information software. This way fuel data can be checked for geographical and spatial relationships. Stanford's ORBIS could for example be used to check different possible transport routes for different varieties of fuel.

To compile this survey, it was necessary to sieve through as much relevant literature that references these types of archaeological studies as possible. This of course resulted in a limited number of studies being used. These are, moreover, skewed toward the Roman East, thirteen of them taking place in Syria or the Levant. Five of them were in Morocco, Algeria and Tunisia, two in Roman Britain, three of them in Italy and one in Ummendorf, Germany.

Thirdly the small amount of studies means that research from widely different contexts are being compared, from Wiltshire in the UK to Bosra, Syria, as noted above. This of course renders deep analysis difficult. Furthermore, the studies featured not only vary in geographical space, but also in time period. The short survey includes research from the 2nd century CE up to the 8th century, far beyond the Roman imperial timeframe. Especially in these later periods, many baths would not be comparable to the erstwhile grand public establishments, both in technology as in size, though others still were.[385]

Lastly, it may not be wise to focus on sediment layers in hypocausts alone. These would only indicate the last (last few) burn episode(s), which according to Veal means only a restricted number of wood types will be identified.[386] To properly get a view of the fuel economy Veal recommends random sampling over all context types as it would provide a greater view of the wood diversity, and ultimately the fuel economy.

However our purpose is specifically related to the fuel economy of the baths. While a general view based on random samples found in a city can complete our view of the fuel sources used in the baths, there is value in the specific character of our survey.

383 Veal, R. (2013), p 50

384 The European Pollen Database was established in 2007 by Nicholas Garnier and tries to record the many pollen studies carried out over space and time within what is now Europe. It was however developed however in close cooperation with the African Pollen Database. Available at <www.europeanpollendatabase.net> last check 30/06/15

385 For example the Center Baths in Bosra, still active in the 5th century, see Fournet, T. and Lepetz, S. (2014)

386 Veal, R. (2013), p 51

First of all, general city-wide surveys other than for Pompeii are rare.[387] Focusing on the fuels used in the baths are an efficient shorthand for general fuel use in an urban context. The result of such a survey will probably show specifically selected fuels. This, as we shall see, included waste products from artisans and obsolete building timbers and so our survey can also serve a wider purpose. Furthermore, a problem often encountered when trying to determine the fuel economy of a city is the factor of demographics. As Veal notes, demographics and fuel consumption levels are key to subsequent quantitative modeling.[388] By analyzing the fuel consumption of the public baths, this problem is sidestepped, as calculations for their fuel consumption have become more quantifiable (cfr section 1.3), and should contribute to the picture of a city's fuel economy.

Additionally, this way, fuel sources which would otherwise be considered 'exceptional' or 'alternate' fuel sources, can demonstrably be shown to have been used in bathing establishments. Unless under special circumstances, the (charred) remains found in the hypocaust were likely used there. As evidenced in our survey, chaff, reeds, olive pits, dung and even bones were used for heating the public baths. Furthermore chaff and agricultural products were found to be used *outside* of Egypt, where their use is accepted and attested in written sources. Egypt is usually considered a special case. The use of chaff and harvest by-products might in other places otherwise never have been connected to baths or large scale public use. Yet we shall feature several sites where such '*briquets*' were used, as they have been in more recent time periods.[389]

Secondly, the vast time-frame present in our survey, though unfortunate, does not preclude all analysis. In order to demonstrate the variety in the usage of fuel, a general perspective was chosen over a smaller 'area study'. Firstly, this was to provide overlap with as many ancient sources as possible. These often provide valuable extra information allowing us to interpret the archaeological finds differently. Secondly, this more abstract perspective is intended to add towards a framework that can be tested locally, yet is not skewed toward any locality (cfr section 3.3, section 4). We shall try to make sense of several paradoxes that come from these widely different contexts. Lastly, considering the former two arguments, within the space of this work, a general overview allows the flexibility needed, while perhaps forgiving the lack of detail that would be required of an area study. Even so, except for specific cases, pollen records show no drastic changes in forest cover for our time period.[390] Aside from an erosion period roughly in the early medieval period, the same can be said of the topography for the duration of our survey (2nd century CE- 8th century CE) .[391] The dramatic changes in the socio-politico-economic spheres, might not have impacted traditional land use regimes as drastically in certain parts of the Mediterranean (for example the Eastern parts in the 6th century). Though it is very likely these changes occurred, often we don't know about them yet. The short term historical periods are not easily captured in the long scale pollen studies, which usually run over thousands of years.[392] Trees still have the same physical requirements as they did two thousand years ago, so even when information on forest management is lacking, we can use modern scientific studies to complement our ancient historical information.[393]

This is why before we discuss the results of the survey pertaining to wood section 3.1.2, we will first sketch the silvicultural systems and agro-forestry that would have been existent in the Roman period

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387 Veal, R. (2013), p 49

388 Veal, R. (2013), p 43

389 Panckoucke, C.F.L. (1823) Description de l'Égypte: ou, Recueil des observations et des recherches qui ont été faites en Égypte pendant l'expédition de l'armée française, Volume 13, p 8

390 Veal, R. (2013), p 42

391 This erosion period has been labelled the 'Younger Fill' by Vita-Finzi, C. (1969); the exact timing of this erosion period differs with location, though can roughly be situated in the early medieval period, for an overview see Bintliff, J. (2002)

392 Veal, R. (2013), p 42

393 Veal, R. (2013), p 44

in section 3.1.1. Seen from this lens, we can deduce several trends appear concerning the use of wood fuel.

It should be noted that our survey includes several private baths, some in a rural setting or pertaining to a villa complex. These privately owned establishments could have had vastly different fuel supplies, either supplying themselves, trading amongst themselves, and in rare cases perhaps importing fuel. According to the Justinian Code (cfr section 2.1.4) they would not have had access to designated forests, reserved specifically for public purposes, and so might have explored alternate fuel sources. On the other hand, where such designated forests did not exist for the large public establishments, private rural baths might show a bias toward using *more* wood. Rural villas could in some cases conceivably have had more wood resources than large urban public establishments in the form of orchard trimmings, brushwood and maquis or desert vegetation. Our dearth of sources forces us to use these sources nonetheless, which is especially unfortunate for the section on wood. These can be used to prove certain points, however cautiously. To improve upon this weakness, urban random sampling for Pompeii and Bosra from Veal and Bouchaud (resp.) shall be used.

After discussing the results of our survey pertaining to wood, we shall discuss briefly why we believe charcoal was less commonly used than raw wood, and which problems might arise with the identification of burnt charcoal versus burnt raw wood. As one portion of charcoal requires at least four times that amount of raw wood (up to a factor of 10 or 15), the result of this discussion can seriously impact our view on the pressure the ancients put on their forest resources.[394]

The second section (section 3.2) discusses various other types of fuel sources used and encountered in our survey. These sections aim to show that use of wood was not a *condicio sine qua non* for fueling the baths. In fact, our preference to see wood as the main fuel may not have been rational in certain parts of the empire. A short conclusion (section 3.3) will summarize the arguments from the different sections this chapter and point out their relevance for the overall picture of the fuel economy of the baths.

3.1. The use of wood and the use of charcoal

3.1.1 The use of wood and silvicultural systems

The Roman Empire stretched a number of vastly different landscapes. In the Mediterranean alone there can be found over forty species of tree with as many sub-variants.[395] Increasingly, various regional studies are becoming available that try to map which species grew where and at what time through palynology and anthracology.[396]

This diversity renders a general approach quite difficult, though there are some things which have become clear. There was a general tendency of broadleaf deciduous woodlands being replaced by evergreens across the Mediterranean in our time period, though in plenty of areas this had already happened during the Bronze Age.[397] To what extent this was due to desiccation of the climate or human pressure, is still being studied.[398] Though there is a growing body of evidence to support that ancient societies impacted the composition of Mediterranean woodlands over time.[399]

394 Veal, R. (2013), pp 47-48
395 Williams, M. (2006), pp 76-77
396 See for example Frenzel, B. (1994); Grove, A. and Rackham, O. (2001); Thommen, L. (2012); and Hughes, D. (2014)
397 Grove, A. and Rackham, O (2001) pp 161-3, 169-71, 290-302; also Whyte, I. (2008) pp 96-100
398 See Grove, A. and Rackham, O (2001) for the desiccation hypothesis, and see Jaillette, P. (2005) for criticism
399 See for example Hughes, D. (2011) pp 47-9 en Chabal, L (2001) pp 93-110

Interpreting the different kinds of wood used in the baths would normally require a deep understanding of local ecology. Viewing the use of fuel through Roman land use schemes (including possible silvicultural systems) can enable more general statements. This way statements can be made and trends spotted that require far less detail, yet still are meaningful. We can presume that in response to different needs, different land use schemes were developed.[400] In fact, as early as Plato we find an account of this realization.[401] Though Plato puts a negative value judgement on the Athenian landscape in his age, linking it to the moral decay of its people, he did understand that different landscapes imply different land use, and that both are linked to each other.

Different aspects of land use schemes were analyzed and weighted by the Romans. Roman agronomists, writing for audiences in Italy, usually recommended that a domain contain a tract of forest.[402] This was to provide building material, stakes and poles for agricultural tools, fodder for animals and likely also fuel. Cato considers:

"*Praedium quod primum siet, si me rogabis, sic dicam: de omnibus agris optimoque loco iugera agri centum, vinea est prima, si vino bono et multo est, secundo loco hortus inriguus, tertio salictum, quarto oletum, quinto pratum, sexto campus frumentarius, septimo silva caedua, octavo arbustum, nono glandaria silva.*"[403]

"If you ask me what is the best kind of farm, I'll say: One hundred iugera's worth of all types of land, ideally located, first there's the vineyard, if the wine produced is good and if there can be plenty of it, secondly, a watered garden, thirdly a willow-grove, fourthly an olive grove, fifth is a meadow, sixth a cornfield, seventh a coppice-wood, eight an orchard and ninth a wood-pasture" (translation by the author).[404]

In general Cato does not value the orchard as high as, say, the vineyard or the olive grove. In special circumstances however, he does. Later in the text he recommends it thoroughly as part of a type of farm near to a city, called a *fundus suburbanus*, which grows fruits, perishable goods and sells firewood to the city.[405] This firewood also found its way to the baths. This is evidenced by the charred remains of wood from orchards were found in the hypocaust of a Roman villa in Farangola.[406] Though from a rural context and not an urban one, they indicate that, increasingly from the 3rd century onwards, orchards provided the necessary fuel. Their incidence in the 3rd century is mainly in the form of mastic (Pistacea lentiscus; 12% of total sample) and sorbus (Sorbus sp.; 4% of total sample). Their number increases however and by the 5th century the sample consists almost half out of mastic (Pistacea lentiscus; 47% of total sample), and includes fragments of wood from the pomegranate (Punica granatum), prunes (Prunus sp.), olivewood (Olea europaea). In the urban context of Bosra, Syria the hypocaust of the baths near the amphitheater section contained wood from the grapevine (Vitis vinifera), the juniper (Juniperus sp.) and the olive (Olea europaea).[407] Furthermore, in Bulla Regia, Tunisia, deposition layers from the 3d and 4th century in the hypocaust room of the public baths were

[400] See for example Hughes, D. (2011) for an account that links classical Mediterranean societies to deforestation and erosion

[401] Plato, Critias 111 b-c; see Meiggs, R. (1982), p 188-190 arguing that competition from vineyard and olive groves meant that a lot of oak, poplar and elm stands were replaced, which were previously used for timber and fodder

[402] Columella, De Re Rustica. I.2.3-4; Cato De Agri Cultura XIV 1-3; Plinius Minor Epistulae, III.19.5; II.17.3,26; V.6.8

[403] Cato De Agri Cultura 1.7

[404] 'Silva glandaria' litteraly means a wood producing acorns, likely as fodder for pigs, cows, etc. Hence the term 'wood-pasture' was chosen.

[405] Cato De Agri Cultura. 7.1

[406] Caracuta, V. and Fiorentino, G. (2012)

[407] Bouchaud, C. (2009)

found to contain wood from strawberry (Arbutus unedo), mastic (Pistacea lentiscus), fig (Ficus carica), and olive (Olea Europea).[408]

The use of olive wood is generally advised against by ancient authors, except for use in open fires, because it could damage the foundations of the baths.[409] However numerous archaeological studies confirm its use regardless. As noted, the hypocaust room of a late-Roman villa in Farangola contained olivewood. Same for the hypocaust room of a public baths in 3-4th century Bulla Regia, Tunisia. The practice continued to late Antiquity (6th century) Bosra and Jordan (Kirbat al-Dharih) and the Byzantine baths at Um Qeis, and beyond with Al-Bakri noting that 11th century Cairo 'had no other wood to burn but olivewood' to fuel its baths.[410] His perspective implies that for him, given a choice, it would not have been his first. Aside using it out of necessity or for lack of a better alternative, it is quite possible the use of olivewood as fuel for the baths across the empire is due to its proximity or low cost. Furthermore this does indicate that specifically assigned forests (cfr section 2.1.4 loca publica) were not the only source of fuel for the baths, instead perhaps relying on local land owners, and these *fundi suburbani* to fuel the municipal baths. A corollary to this is of course that baths could have been built without a specific designated fuel source in mind, the expectation perhaps being that entrée fees could cover the costs of purchasing fuel (cfr section 2, especially section 2.1.1 and 2.1.3).

The use of wood from orchards and olive groves, etc. indicates that the production of wood and the supply of fuel could have featured as part of the agricultural system. Cato (cfr supra) in fact names a type of agro-forestry called a *silva glandaria*, or wood-pasture (though the term 'savannah', or 'mastwood' are equally appropriate).[411] This refers to oak woods ('*glans*' means acorn), but according to Meiggs this could also mean beech woods.[412] This connection is based on the beechnuts being used to feed the animals pastured in the woods, which would mainly be pigs.[413] Visser argues that further evidence for this can be found in Pliny where he describes the beechnuts being a favorite of pigs, further linking beech to the *silva glandaria*.[414] Though a silva glandaria is featured last in Cato's list, Meiggs notes this is because Cato has a type of mixed farm in mind, with little cattle. Based on Strabo's account, Meiggs notes the *silva glandaria* was far more popular in Gallia, supplying a large part of the pork for Rome.[415]

In Pompeii Veal found that the main taxon used (50-75% depending in the time period) was beech.[416] It could be argued that this beech came from these *silva glandaria*, but it is far more likely most of the fuel wood came from primary fuel woods. By 'primary fuel woods' is meant woods with the primary focus of supplying wood. This is because of the sheer quantity needed (13 000 up to 200 000 tons of fuel), which could not only be supplied by the – essentially - savannah type landscape of the *silva glandaria*.[417] The use of fuel from primary fuel woods could be understood through several other silvicultural systems which could have been existent during the Roman Empire.

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[408] Broise, H. and Thébert, Y. (1993)
[409] Plutarchus. Quaest. Conv. 3.658E
[410] For Bosra, see Bouchaud, C. (2009); for Jordan see Bouchaud, C. (2014); for Um Qeis Holm-Nielsen, S., Nielsen, I., & Andersen, F. G. (1986).; For the account of Al Bakri, see Description de l'Afrique septentrionale (rev Ed..) par El-Bekri ; translated by Mac Guckin de Slane (1913), p 61
[411] See for example Grove, A. and Rackham (2001), chapter 12, pp 190-216; in the Digesta the term 'silva pascua' probably refers tot he same, Dig 50.16.30
[412] Meiggs, R. (1982), p 263
[413] See for example Grove, A. and Rackham, O. (2001) pp 190-195
[414] Visser, R. (2010), p 19 citing Pliny Nat. Hist. XVI.15-34
[415] Meiggs, R. (1982), p 263 quoting Strabo 218 (or IV.1.12); see also Nenninger, M. (2001), pp 46-47
[416] Veal, R. (forthcoming), pp 104-105; sampling 7 different areas, see pp 82-84
[417] Veal, R. (forthcoming), p 203; see also addendum 2 Quantitative Model, table 'Model of Wood Fuel Supply'

Clear felling is usually regarded as the oldest and most basic way of exploiting a woodland, and was very likely practiced in Roman times.[418] This is when an area woodland is felled completely. After felling the area is left to regenerate for several decades. This way a rotation system can be devised, whereby each part is only revisited every so many years. It is quite possible this method was applied to the public forests and domains of the emperor for the purpose of fueling the baths, requiring the least effort in comparison to other silvicultural system. Furthermore, supposing the jurisdiction of the Digesta was followed in practice, lands dedicated specifically to the baths were inalienable and off limits to regular usage (cfr section 2.1.4). This exclusivity would have facilitated the required forest regeneration. If this system was practiced we might expect different types of wood to show up in the charcoal record that correspond to the varieties found in the area's pollen records.

Ancient forestry however might have also included more active management and selection of trees to be felled.[419] The uses of different types of wood are usually mentioned in passing by ancient authors.[420] Vitruvius for example mentions that fir burned quickly and violently, whereas larch ignites with difficulty yet has a slow burn.[421] This selection could be based on species, or on other characteristics to maintain a certain silvicultural system. This could be to favor a certain species over others, as certain species grow faster than others, something the ancients already knew.[422] Furthermore, it should be noted that deciduous forests usually recover quite spontaneously, while conifer forests might require replanting seed.[423] Visser suggests this selection was overseen by *saltuarii*, who are attested as stewards on imperial estates (cfr Addendum 3, figure), or perhaps imperial forests (cfr section 2.1.4).[424] The depiction of a *saltuarius* on a grave stone near Heidelsburg (Germany) with a *securis* would further underline this function. This *securis* is a type of axe that resembles a 'loogaxt', used from the Middle Ages until the 18th century to mark trees that should be felled.[425] It should be noted that the term *saltus* does not usually denote a forest, often appearing in the context of pastures as well as trees. It is quite tempting however to fit this into savannah-like wood pastures (known in Spanish as *dehesas*).[426] Furthermore, the Digestae indicate a saltuarius' function primarily was to oversee boundaries and to look after crops.[427] On the other hand, the prevention of devaluation through overcutting a forest is equally indicated as a cause for dispute between a leaseholder and an owner.[428]

Another type of forest management is through coppicing. Coppicing is where trees are felled near the ground (or somewhat above ground in the case of 'pollarding') and allowed to shoot up again. This way every couple of years the stems are harvested. Most trees that grow around the Mediterranean and contemporary Europe can be coppiced, aside from pine (Pinus sp.) and fir (Abies sp.). Some pines, like Pinus brutia, can however be pollarded.[429] The type of trees coppiced could vary depending on their purpose and the rate of growth.[430] Coppice wood is particularly interesting when producing firewood because the shoots are of course smaller than a fully grown tree, thus producing smaller and more manageable wood that requires less preparation. It is however more labor intensive than clear

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418 Visser, R. (2010), pp 13-14
419 Visser, R. (2010), pp 15-17 argues that a.o. dendrochronological evidence indicates a Roman bridge near Ciujk and water wells near Gennep were constructed in the 4th century AD using wood specifically selected from nearby woodlands
420 See for example Nenninger, M. (2001), pp 38-41
421 Vitruvius De Architectura 2.9.5-6
422 Varro Re Rustica I. 41.4
423 Veal, R. (2013), p 43
424 Visser, R. (2010), p 15; though the same idea can be found in Hughes (1994) and Meiggs (1982)
425 Visser, R. (2010), p 15
426 Grove and Rackham p 194
427 Dig 33.7.8 (1); 33.7.12.4
428 Dig 32.55
429 Rackham, O. and Moody, J. (1996), p 63
430 Nenninger, M. (2001), p 47 note 286 lists over a dozen types referenced by ancient authors

felling, requiring attention every couple of years. Detecting whether or not wood fuel, when it's been burnt, came from coppicing rather than clear felling is impossible.[431] Though as we shall see, many of the species found in hypocaust sediment layers would have allowed coppicing. Both Columella and Pliny reference the practice and the Digesta in fact defines such a coppicewood as a '*silva caedua*':[432]

> *Silva caedua est, ut quidam putant, quae in hoc habetur, ut caederetur. Servius eam esse, quae succisa rursus ex stirpibus aut radicibus renascitur.*

"Some authorities hold that coppice wood is such as is set apart for that purpose. Servius says that this also applies to trees which have once been cut, but have grown again from sprouts or roots." Translation by Scott, S. (1932)

3.1.2 Comparison with the results from our short survey and discussion

From our short survey, it seems that baths usually were fueled by a designated main fuelwood, which could usually be coppiced. Oak (78%) and poplar (11%) were the dominant species of the anthracological remains found in the hypocaust of the 2-3rd century Roman villa at Groundwell Ridge[433] Likewise the hypocaust room of the villa in Farangola, North Eastern Apulia contained predominantly oak (quercus pubescens) (74% of the anthracological remains) in the layers of the 2-3rd century.[434] This stands in contrast to the absence of local riparian types of vegetation, which are less suitable for burning. As Caracuta and Fiorentino inferred for Farangola, this provides clear evidence for fuel selection.[435] It seems likely these villas had a tract of forest to supply wood. Towards the 5th century however a tendency to use cultivated species, and orchard trimmings comes forth (cfr infra).

Similarly, from a general assembly at Pompeii, Veal found that in the early Empire beech (Fagus sylvatica) was the dominant fuelwood species (51.7%), followed by oaks (Quercus robur/petrea), maples (Acer sp.) and hornbeams (Carpinus sp) (32.5%).[436] As Veal notes however, the percentage frequencies of taxa found in a context cannot be said to be directly in proportion to that of the wood chosen for burning. This is because woods are differentially preserved, which depends on a number of factors: fire burning conditions (temperature, intensity, fragment position in the fire) and wood properties (water content, size, taxon characteristics), among other influences.[437] In particular, wood from orchards and softwoods preserve worse than hardwoods, which leads to the latter being overrepresented. Regretfully, this bias is often little examined because it is usually estimated that the general trend in these studies is still anyhow correct.[438] For the purposes of demonstrating selection however, this method used above should still suffice.

Many of the species found in our short survey can be coppiced. Pine, which cannot be coppiced and so requires clear felling, was found less commonly in the West. It was present though in the more eastern, arid regions surveyed. In Bosra, pine was attested from the 2nd to the 4th century CE in baths from the amphitheater section in Bosra, and in the 8th century CE in the 'Palace of Trajan' baths.[439] Bouchaud speculates that the use of conifers could also represent the waste products of scaffolding

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[431] Though it can be done for timber, see Haneca, K. et al (2005) and Bernard, V. (2003))
[432] Col. Re Rust. IV. 33.1; Pliny Hist. Nat. XVI. 60 (141-142); Dig. 50.16.30
[433] McParland, L.C., Hazell, Z. et al (2009), p 178
[434] Caracuta, V. and Fiorentino, G. (2012), p 168
[435] Caracuta, V. and Fiorentino, G. (2012), p 168
[436] Veal, R. (forthcoming), p 135 table 9
[437] Veal, R. (forthcoming), p 6
[438] See for example Veal, R. (forthcoming), p 160
[439] Bouchaud, C. (2009), and Bouchaud, C, (2014)

or other building tools.[440] This would be similar to the use of leftover timber in the small baths at Karanis, as Maréchal believes.[441] Similarly, in the 6th century, in the baths of Placcus in Jerash, Jordan, pine made up a little over one third of all anthracological samples (36%).[442] In these same locations other conifers were used, such as cypress (Cupressus sp.) and juniper (Juniperus sp.). It is of interest then that in the public baths of Thamusida, Morocco, dated to the 1st -3rd century CE, Rebuffat found a coating of tar or resinous remains on the hypocaust walls of the baths.[443] These indicate green or undried wood, possibly a soft green wood being burnt.

It could be argued that this absence of pines, or conifers in general, in the Western part of the Empire corresponds to its bad reputation as fuel. Vitruvius for example did note some of the burning properties of conifers; of the fir he says that it burns violently, and of larch that it ignites with some difficulty and does not produce charcoal.[444] The wood of conifers is indeed known to burn at high temperature. Furthermore its high resin count and moisture can cause creosote problems (leading to chimney fires).[445] This occurs mainly when the wood is burnt slowly or at a smolder (cfr section 1.2.1 '*ignis languidus*') or if the wood is burnt when insufficiently dried. Their drawbacks however should not be overstated. Seasoned pine (2years) burns fast, but when mixed with a more slowly burning fuel (such as hardwood) it produces a more even fire, which can be left alone to burn and smolder.[446] Still, the absence of pines in the West might further substantiate that species to be used as fuel were selected and woods might have been managed to serve a productive purpose.

Even though there usually was a dominant species of fuelwood, it was not used exclusively and a variety of other fuelwoods accompany it. Many of these secondary fuelwood come from what is considered to be more 'wild' vegetation. 'Wild' is put in parenthesis because these are relatively uncultivated yet productive lands, which Forbes refers to as 'the waste'.[447]. They fit into an extensive exploitation of more peripheral land. In the 5th century, in the Hypocaust of Farangola 8 to 12 different types of species could be identified, several among them macchia type shrubs such as mastic (Pistacia lentiscus), and buckthorn/mock privet (Rhamnus/Phillyrea sp.). Similarly, the Eastern baths did not only contain wood from conifers, but usually also macchian type woods such as Acacia, Ziziphus, Grewia and Pistacea. At Bulla Regia, Broise and Thébert found olive trimmings, both wild and cultivated (cfr section 3.2.3), mastic (Pistacia lentiscus) and strawberry (Arbutus unedo). A local vegetation map confirmed these species could represent more 'wild' vegetation, though from an environment modified by human activity.[448]

Some baths similarly contained wood from desert-vegetation. The military baths at Gemellae contained tamarisk (Tamarix sp.). So too for the 8th century private baths in the 'Palace of Trajan', which contained tamarisk (Tamarix sp.) and box-thorn (Lycium sp.). A similar situation can be found for the public baths associated with the pilgrimage site of Umm 'al Amr. The 1.4l sediment sample from the *praefurnium* pertaining to its last firing in the 6th century yielded 200 anthracological remains, of which 56% were of tamarisk.[449] Lastly, a similar case can be found in the rural context of Kirbat al Dharih, with 60% of the samples belonging to the tamarisk. These baths also contained olive wood (Olea europaea, 15%), juniper (Juniperus sp., 14%) and Christ-thorn Jujube (Ziziphus

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[440] Bouchaud, C, (2014), p 606
[441] Maréchal, S. (2016), p 493
[442] Bouchaud, C. (2014)
[443] Rebuffat, R. et al. (1977), p 103, 174
[444] Vitrivius De Architectura. 2.9.5-6
[445] From personal correspondance with Appalachian wood burners; often this area leaves no choice but to burn pinewood or other coniferous wood.
[446] ibid
[447] Forbes, H. (1994)
[448] Broise, H. and Thébert, Y. (1993), p 132-134; vegetation map by H. Gaussen (1958) Carte Internationale du Tapis Vegetal, f. Tunis-Sfax
[449] Bouchaud, C. (2014), pp 601-602

spinachristi, trace amounts), though no identification as to whether these are cultivated or 'wild' variants is further given.

The use of 'wild' vegetation, desert vegetation, or the use of pine in the more arid regions, would indicate that the local environment played an important part in providing fuel for the baths.[450] Because of the aforementioned high transportation costs (cfr section 2.3.2) this intuitively makes sense. It has been called the principle of least effort (PLE). This can also be deduced from several sources. As we have seen, the law of Misenum stipulated that for a religious festival the 'holy men' of the sanctuary must 'allow the suppliers the furnishing of wood' (cfr section 2.1.4).[451] Pliny too makes a point to explicitly mention that all of the fuel for the baths in his villa came from a nearby forest.[452] This trend can also be found in ethnographic research. An overwhelming majority of pre-industrial communities of South and Central America, and of Niger used resources within a 7km radius, most within 1-3km for fueling their pottery-production.[453] Veal concluded that most of the wood used (beech) in Pompeii likely would have come from its hinterland 15-25 km's away.[454] A counterexample, that the transport of fuel from North-Africa to Rome, is considered to be more of an exception pertaining to Rome, than evidence of a general trade in fuel (cfr Nenninger section 2.1.4).[455]

Yet, Veal also warns against this PLE, keeping in mind the small sample of our survey, and the lack of substantiated environment analysis. For Pompeii, she showed that import by the sea from 50km was reasonable an alternate option (cfr section 2.3.2).[456] Similarly, for the Bosra site survey, Bouchaud notes that currently in this area these conifers appear only in a cultivated form.[457] This could mean either a more widespread distribution in ancient times, or an import of these species as fuel. The former is quite likely however, as conifers like pine and cypress characteristically have a circum-Mediterranean distribution. They require little water and are efficient in their use of available water.[458] So local conditions at least do not hamper the spread of these species in this area. Bouchaud also notes that these conifers could have been used in construction and the waste products thereof burnt. A good conclusion would be that either the factor 'local' played a part in fuel selection, or the factor 'availability' played a role. By this is meant the recycling and using available resources optimally, for example construction waste. We shall see in section 3.2 and 3.3 that the recycling of by- and waste products is not uncommon.

3.1.3 The Use of Charcoal

Ancient sources provide little information on how frequently charcoal was used to heat the baths. From Lucretius we can find a warning against using charcoal (*charbo*) in the baths but this probably stems from a time when braziers were used inside to heat up the room, and could be seen as a warning

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450 See for example; Bouchaud, C. (2014), p 596; Broise, H. and Thébert, Y. (1993), pp 132-34 and 339; Smith, W. (2001) pp 420-41

451 Hughes (1994), p5 and Hughes, J.D. and Thirgood, J.V. (1982), pp 71-73

452 Pliny Epist 2.17.11.4-5 and 2.17.26.1-2

453 Lewit (2013) "The Lessons of Gaulish Sigillata and Other Finewares" in Lavan, L (ed) *Local Economies? Production and Exchange in Inland Regions in Late-Antiquity*, p 236 citing Arnold, D.E. (2005) "Linking society with compositional ethnography" in *Pottery Manufacturing Processes: Reconstitution and Interpretation* , BAR-IS (1349) pp 15-21; Gosselain, O.P. and Livingstone Smith, A. (2005) "The source: clay selection and processing practices in sub-Saharan Africa", in *Pottery Manufacturing Processes: Reconstitution and Interpretation* , BAR-IS (1349), p35

454 Veal, R. (2013), pp 55ff

455 Nenninger, M. (2001), p 81

456 Veal, R. (forthcoming), pp 216-222

457 Bouchaud, C. (2014), p 600

458 Bouchaud, C. (2014), p 605

against CO-poisoning.[459] Pliny the Elder remarks that soot was often collected for making ink when the hypocaust was cleaned.[460] This could indicate that the fuel commonly burned was not charcoal but wood, as charcoal would not produce enough soot for making ink. We have already seen several ancient sources mentioning wood, and not charcoal, as fuel (cfr section 1).1.[461] One exception to this is a receipt for the payments of upkeep for a public baths from Oxyrynchus from the early 4th century CE.[462] This mentions a delivery of charcoal being made, which served to fuel the baths. Though Meyer disputes this reconstructed reading where εἰς τὸ δημόσιον πανίδιον (=βαλανίδιον), which would mean 'for delivery to the public baths'.[463] Instead she follows Remondon in his correction that this is actually a formula for reimbursement, thus disconnecting the charcoal from the baths.[464] Even though we have found no ancient sources securely connected to the use of charcoal to the baths, we shall explore its possibility.

Nielsen believes Egypt's lack of wood resources means that here instead charcoal was imported. This is evidenced by another papyri documenting fluvial transport of charcoal.[465] This evidence rules out concerns that could be had with fluvial transport of charcoal. These concerns being when charcoal turns wet its core structure might be affected, collapsing it and turning it into an 'unusable carbon mush'.[466]

From a rational perspective, there is an issue with the use of charcoal in Egypt (or any other wood-scarce environment) for large scale (public) purposes. Especially when considering alternatives such as chaff and reeds were widely available and its use has been widely attested (cfr infra). The 6th century attestation of the use of brushwood for public baths in Egypt is probably an exceptional case.[467]

The production of charcoal is expensive. Ethnographic data suggests one batch of charcoal required at least three to four times that amount of wood, up a factor of 10-15.[468] Some of these data come from tropical and/or very dry climates with different types of wood than what would be found in the Mediterranean. For the Roman period, a factor of 4-7 is usually reckoned.[469]As wood was already scarce in Egypt, using charcoal would then represent at least four times as much wood being used to heat this bath. It is likely that accordingly the price of charcoal was quite high, perhaps similar to Delos where fuel also had to be imported (cfr section 2.3.3).

There are different types of fire however, and from a cost-benefit analysis, each has its preferred fuel source. As Veal points out, activities like fulling and tanning simply required a regular fire temperature that could have been provided by any open fire.[470] This type of open fire would generally have used raw wood, as charcoal provides little benefits at a much higher cost. Next up, Veal notes that other processes like ceramics manufacture or glass making would require higher temperatures than an open fire could have provided.[471] The increased heat for these processes however is achieved by containing the heat using a kiln or oven type structure. This way, raw wood can still be used. Lastly,

[459] For example Lucretius De Rer. Nat. 6.800, see Nielsen (1993), p 19 for the argument that this either dealt with private bathrooms where braziers were used, or the smaller public baths we know of at that time (1st C BCE) where a similar system was used.
[460] Pliny the Elder, HN 35.41
[461] CIL X, 3678 (the inscription from Misenum), CIL II, 5181, lines 19ff (the inscription from Vipascum)
[462] P. Oxy 12. 1430
[463] Meyer, B. (1989), p 556
[464] Meyer, B. (1989), p 556, quoting *Revue de Philologie de litterature et d'histoire anciennes* (1958), p 250
[465] P. Amh. II, 138
[466] Veal, R. (2013), p 216
[467] SB 1, 1970
[468] Veal, R. (2013), pp 47-48; a full acount of the process and a review of this data can be found in Veal, R. (forthcoming), pp 142-147
[469] Veal (forthcoming), p 146, Olsen (1991), p 412
[470] Veal, R. (2013), p 45
[471] Veal, R. (2013), p 45

more 'industrial-like' processes, like iron-smelting, required high and sustained temperatures up to 1100°C. These kinds of processes would have needed to use high-quality charcoal, as it burns cleaner and with a more constant temperature.[472] Veal notes that Roman bathing falls somewhere between an open fire and a kiln; a hypocaust system was designed to trap and conduct heat.[473] Indeed, as Rook notes, early heated baths copied the construction design of a kiln.[474] We have also noted that the hypocaust likely functioned as an open fire or bonfire (cfr supra section 1.2.1). These are typically more associated with the use of raw wood.

According to Veal, this 'high quality charcoal' can be recognized from certain characteristics.[475] This charcoal would have come from the highest heat value woods (beech, maple, oak). They would have been procured especially for an industrial purpose and thus would have only used a few species (a single taxon usually). Lastly, they would have used old and dense wood, probably from pollarding a 40-50 year cycle or possibly clear felling. It is unlikely this type of charcoal was used for the baths, as we have noted that quite often trimmings, small branches and coppice was found in our survey (cfr section 3.1.2).

General quality charcoal, made from small branches or coppice would have existed as well, and is a more probable type of charcoal for heating the baths.[476] It is likely that personal heating and cooking in cities was performed with this type of charcoal. Indeed Veal points out that the hearths and stoves recovered from Pompeii did not have space for fueling with raw wood.[477] Charcoal in general burns longer, cleaner, and has a higher calorific value to weight ratio than raw wood.[478] Because of these characteristics, its use was appreciated in cities, especially where space was limited and smoke could be a nuisance. In general, the use of charcoal in cities in comparison to wood is often assumed to be of a ratio 80/20 (whereas the reverse is true for the countryside).[479] There is however very little quantitative evidence to support this for the Roman period. Most hypocausts however had enough space for fueling with raw wood, and we have noted that the amount of smoke from stoking with raw wood was limited (cfr section 2.2). From a rational perspective this only leaves the longevity of charcoal as a possible benefit, which of course compares unfavorably to its cost.

A method is currently under study called reflectance microscopy which claims to be able to determine whether charred wood was burned as charcoal, or as raw wood.[480] It is based on a supposed relationship between the increasing light reflectance of charcoal fragments. Wood burnt as charcoal will show reflectance values starting at 350°C, whereas wood fires exhibit a range of temperatures starting from circa 100°C.[481] If this method is refined and proven reliable, it could shed light on how much charcoal was used, in the baths and also in general. Preliminary results point toward the use of wood, and not charcoal.[482]

It is possible though that charcoal was mixed with raw wood. This way the fire would have reached a higher temperature sooner and could have burned more steadily during active stoking. Whether this steady heat was a requirement is uncertain, as the hypocaust system itself is already constructed to trap and conserve heat (cfr section 1.2.1, 1.3.).

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472 Veal, R. (2013), p 45
473 Veal, R. (2013), p 45
474 Rook, T. (1992), pp 10-11
475 Veal, R. (forthcoming), pp 157-158
476 Veal, R. (forthcoming), pp 157-158
477 Veal, R. (forthcoming), pp 34-35
478 Veal, R. (forthcoming), p 35
479 Veal, R. (forthcoming), pp 34-35
480 See for example McParland, L. et al (2009)
481 Veal, R. (2013), p 54
482 McParland, L. et al. (2009), p 182

Though a cost-benefit rationale might not have always applied, it is expected that charcoal's cost would have discouraged widespread use. It can be securely stated that its use was not strictly necessary for a hypocaust system (cfr section 1.3). In the case of wood scarce regions, it is far more likely –and rational- that other fuel sources would have been explored. As we shall see, these other non-wood fuels have been widely attested.

3.2 The use of non-wood fuels

3.2.1 The meaning of the term 'lignum'.

The term 'lignum' is generally understood as 'fuelwood'. This fuelwood would be all kinds of wood that could not be used for building (timber), or for instruments and poles (which would usually be begotten from coppice wood). Prepared chunks of wood usually spring to mind. Ulpianus, in the Digestae expounds on what could, by law, be understood as lignum:

> *"Cui ligna legata sunt, ad eum omnia ligna pertinere, quae alio nomine non appelantur, veluti virgae, carbones, nuclei olivarum, quibus ad nullam aliam rem nisi ad comburendum possit uti. sed et balani vel si qui alii nuclei"* [483]

> "When 'wood' is bequeathed, it is understood that all which has no other name is contained within the term 'wood', this includes small branches, charcoal, olive pits, anything of which no other use can be made than to burn them. Also included are acorns and other seeds"

Lignum is not only actually (coppice) wood but includes: small branches, charcoal, olive pits (anything of which no other use can be made than to burn them). Included in the term 'fuel' are acorns and other seeds,[484] and also pine cones.[485] The passage's context is the bequeathing of wood in a legacy, and from this fragment it could be deduced that the practice of donating wood for heating of the baths was commonplace.[486] Benefactions mentioning 'fuel' for the baths could possibly have included these non-wood fuels.

Compare the fragment of the Digesta to the inscription from Misenum, where the 400 cartloads were specified as containing hardwood.[487] We noted earlier that the qualification of cartloads containing 'hardwood', probably as opposed to vegetation from maquis or all the other kinds of 'lignum' quoted above, probably to stress the opulence of the gift (cfr. section 1.1).

Despite the duumvir from Misenum drawing a contrast between these two types of fuelwood, the Digesta confirms that, at least in legal language, the term 'lignum' was broader than is often thought. In contrast to other words, such as *cremia* (also found as '*gremia*'; brushwood), 'lignum' took on the meaning of the more general 'fuel'. This makes it likely that the use of these types of 'lignum' use was more or less equally appreciated. Ulpianus even asks rethorically: *"In some countries (as, for instance, in Egypt, where reeds are used for wood, and both reeds and papyrus for fuel), certain kinds of grass, thorns, and brambles are included in the term "lignum." Is there anything extraordinary about this ?"* [488] We shall see in the section on harvest by-products that several public baths were found to contain them, sometimes in large quantities.

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[483] Dig 32.55.1 'All which has no other name' refers to building timber (*materia*)
[484] Dig 32.55.1
[485] Dig 32.55.10
[486] Dig 32.55.3
[487] CIL X, 3678
[488] DIG 32.55.5 translation from Scott, S. (1932)

3.2.2 The use of chaff and the use of reed

The use of chaff has been widely attested in papyri and ostraca from Egypt (as 'αχυρον'), and is considered to have been its main fuel source.[489] In our survey, several baths outside of Egypt were found using chaff (cfr infra), although all of them pertain to the Eastern Empire. Though its absence in the Western Empire might be due to differential preservation, it is largely accepted that these fuel types were commonplace in the Eastern Medditeranean region.[490] It has for example been found both charred and dessicated at the Egyptian quarry settlement of Mons Claudianus, in what was probably part of a sites' kitchens.[491] Similarly, several charred samples have been found in several of the sites discussed in the Lyban Valleys survey.[492]

Chaff is defined by Van der Veen as 'all the components of the cereal ear other than the grain'.[493] According to Redon, there were two general uses for chaff; for burning and as fodder.[494] The chaff for burning, in some sources is qualified as 'αχυρον καυσιμον', and would have had to be dryer than chaff intended as fodder. According to Meyer, this chaff was not simply dried and burnt, as this would burn too quickly. It was probably made into 'bricks' (briquettes), sometimes mixed with dung and called 'guellé'.[495] The chaff would be wetted and mixed with clay, sawdust to form a paste that was cast as a brick and then used for burning.[496]

It is possible this chaff was collected on the village threshing floor, where it was 'produced'. We have for example an account from 255CE of a private estate mentions chaff was brought from the village threshing floor for the heating of its baths.[497] It is not difficult to imagine that this chaff could also be put to a communal use. Several papyri and ostraca attest to the collection of 'taxes' in chaff for the purpose of heating the baths. An ostracon from the early 4th century CE records a donation of chaff for baths in Alexandria.[498] A papyrus from 255 CE possibly records chaff being used to exact taxes, possibly for this communal purpose.[499] Another papyrus from the 3rd-4th century mentions the collecting of chaff from three villages, which Maréchal interprets as possibly originating from a liturgical official and concerns supply for the public baths.[500] Furthermore, a papyrus from the 2nd century CE records an instance where this chaff was donated by a public official to the gymnasiarchs who oversaw the baths.[501] Because the origin of the chaff was communal, and no amount of money was mentioned in the document, Meyer speculates this was simply collected and freely given, possibly having already come about through taxation anyway.[502] Another –though fragmentary- papyrus from the 5th century CE places an order of 54 baskets of chaff for heating the public baths, again though no

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489 Meyer, B. (1989); see for example BGU 14 col III, l 18; BGU 3. 760; P.Mich. V 312; P.Lond. III 1166; WO 901, 905, 927, 936, 1447; O.Bodl. II 1667

490 Van der Veen, M. (1998), pp 213-215, 218-220

491 Van der Veen, M. (1998), p 213; nine cylindrical ovens were found in the south-east corner of the Annexe

492 See Van der Veen, M. et al. (1996) in Barker, G. (1996)

493 Van der Veen, M. (1998), p 211

494 Redon, B. (2009), p 416

495 Meyer, B. (1989), p 568; see also Charles, M. (1998) and Van Der Veen, M. (1999)

496 See note 83 in Redon, B. (2009), p 416; and Meyer, B. (1989), p 568 citing Preaux, C. (1947) Les Grecs en Egypte d'après les archives de Zénon, p 44

497 BGU 14 III line 18

498 O. Mich 219

499 P. Lond. 1212, see also Johnson (1936), p 506; other sources indicate this as well, see for example O. Mich. 1, 221

500 P. Oxy. 56, 3856, and Maréchal, S. (2016), p 748

501 BGU 3.760

502 Meyer (1989) p 570

price is mentioned.[503] This public way of funding would be the Egyptian equivalent of public forests reserved for the heating of the baths (cfr section 2.1.4). Other expenses, such as the actual supplying of chaff (by 'αχυροπρακτορες'), usually by donkey trains, were also paid for by the city, as several sources indicate.[504]

The use of reeds to fuel the baths is attested for Egypt in ancient sources, one of them being the edict of Caracalla.[505] Our survey however did not find any archaeological reports of the use of reed, though it is mentioned by Meyer to have been found in the hypocaust of Kom-el Dikka.[506]

Chaff was attested in Bosra, Syria in the baths of the 'Palace of Trajan'. The 8th century CE layer just on the exterior of one of the praefurnia yielded 165 carpological remains (compared to 30 anthracological remains; these have been reported on in section 3.1.2). According to Bouchaud, the find context indicates a significant use of non-woody plant material in the hypocaust.[507] 81% of these carpological remains were of cereal origin. Of this percentage, more than half were harvest by-products such as chaff, stalks, and cobs (53.5%).[508] This would point toward the use of chaff as a significant fuel source, similar to what is reported in Egyptian papyri. There were no remains of coprolite found, which probably indicates, as stated above, the use of compressed briquettes of chaff and plant material, rather than those mixed with dung (guellé). The use of other plant material, such as the stalks (often also called straw) indicates, according to Bouchaud, that agricultural by-products were gathered and disposed of by burning it in the baths as a supplement to the primary fuel source (chaff).[509]

The use of these chaff and harvest by-products is not out of place here, as the plateau surrounding Bosra at this time was occupied with large grain fields.[510] As Bouchaud notes, the use of chaff in Bosra would indicate that availability and proximity of the fuel-source are important.[511] It is quite possible that the production, transport and use of these chaff blocks would have required little time and effort, therefore making it a suitable 'alternative' fuel source to wood. This also argues against the idea that fuelwood was imported (cfr supra, section 3.1.2 the use of pine and conifers found in the sample from the Bosra Amphitheater section), though we shall revisit this discussion at the end of the chapter (cfr section 3.3).

It is possible even to see a pattern for Bosra in our survey, which features different time periods and contexts (cfr supra section 3.1.2, the samples from the amphitheater section from Imperial times). This pattern would be a move from using wood-fuel from pines and conifers, and the use of olive pits (cfr infra section 3.2.3), toward a predominant use of agricultural by-products and chaff. Wood would have served as a secondary fuel. This could be because of a change in land-use regimes in Byzantine times, as Bouchaud noted, though further research will be necessary.[512] The current absence of non-cultivated pines and conifers could equally be connected to this trend (cfr section 3.1.2), as the area is still being cultivated according to Bouchaud.[513]

Two other instances are known that could attest to the use of chaff as fuel for the baths. In the 6th century CE rural baths of Kirbat-al Dharih in Jordan, cereal remains formed around 8% of the

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503 Stud. Pal XX 132
504 WO 936; P. Brem. 47
505 P. Coll. III, 5 = P. Col. IV,63, col 2, l26-27; P.Giss.40, III
506 Meyer (1989) p567
507 These were sampled using flotation and wet sieving of 13l of soil
508 Bouchaud, C. (2014), p 600
509 Bouchaud, C. (2014), p 604
510 Bouchaud, C. (2014), p 603
511 Bouchaud, C. (2014), p 604
512 Bouchaud, C. (2014), p603
513 Bouchaud, C. (2014), p 603

carpological sample.[514] This indicates chaff or similar plant material could have been used here as well. Lastly, chaff was also reportedly found in the baths at Djemila (Cuicul, Algeria).[515]

3.2.3. The use of olive pits and pomace

The use of olive pits in ancient sources is hinted at in the *Digesta*, where they are included among what is considered 'firewood' (*lignum*, cfr. supra section 3.2.1).[516] The process of burning olive pits is the same as burning hardwood; they will burn if simply chucked into an oven when dry. Olive pits have an estimated energy rating of 20,6 MJ/kg, which is actually higher than that of firewood (note for example that Yegül used an energy rating of 18,1 MJ/kg for his firewood, cfr. section 1.3.4).[517] As evidenced from ethnographic research, olive pits can also be made into cakes, along with the olive pomace, which can serve as fuel or as fodder.[518] This type of fuel reportedly has an 'average' calorific value, produces little smoke, and burns relatively slowly, making it quite suitable for use in hypocausts.[519]

The process of acquiring these olive pits would have varied. Lazreg states that olives can be crushed by foot to produce the highest quality oil in the first cold pressing.[520] This would result in the finding of complete, unchipped stones in waste dumps (or hypocaust burn layers). White suggested that olive pits were removed by the ancients before milling.[521] Mattingly however contests this view on the grounds that it would have been impractical to not crush the olives and argues the sharp fragments would aid with the "free flow of oil from the paste during processing".[522] When olive pits show rounded fractures, swollenness, or signs of being chipped or shredded these are evidence of pressed olives or olive pits used for the purpose of extracting oil.[523] Arnould on the other hand believes however that the olive pits could remain intact after the pressing process, which might surprise when compared to the modern process.[524] Arnould also refers to Brun who argued that the ancient agronomers, such as Cato, were adamant about not damaging the olive stones so as to not corrupt the taste of the olive oil.[525] Whatever the case, in our survey evidences both types and probably attest to different preferences and processes.

The practice of using olive pits, and likely pomace, as fuel has been found in Greece since well before our time period.[526] Its use spans the entire classical period and beyond. In Jerash, Jordan, the 6th century urban 'baths of Placcus' were found to contain a significant amount of olive pits (91% of the carpological sample were olive pits from Olea Europaea), several among them in between the burnt anthracological remains of conifers we noted earlier (cfr section 3.1.2).[527] Similarly, the rural baths of Kirbat al-Dharih (also Jordan) contained a large number of olive pits (92% of the carpological sample),

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[514] Bouchaud, C. (2014), p 603
[515] Allais, Y. (1938) *Djemila*, p 77
[516] Dig 32.55.1
[517] Schubert, F. and Parkinson, I. (2009)
[518] For Tunisia, see Sethom, H. (1964); for Greece , see Matson, FR. (1972) in WA McDonald and GR Rapp Jr. (Eds)
[519] Nefzaoui, A. (1988), as quoted in Bouchaud, C. (2014), p 603
[520] Lazreg, B. (2001), addendum in Smith, W. (2001)
[521] White, K.D. (1975), p 225
[522] Mattingly, J. (1996), p 226
[523] Bouchaud, C. (2014), p 603, citing Neef, R. (1990); Margaritis,E. and Jones, M. (2008); Salavert, A. (2008)
[524] Arnould, P. in Broise, H. and Thébert, Y. (1993), pp 132-134
[525] Arnould, P. in Broise, H. and Thébert, Y. (1993), referring to Brun, J.P. (1986) L'oleiculture antique en Provence, Rev. Arch. Narb. supp 15, Paris, p 46; and Cato De Agri Cultura 66;
[526] See Margaritis, E. and Jones, M. (2008a) for a short overview, starting in the Bronze Age
[527] Bouchaud, C. (2014), p 601

aside from a minority of cereal remains we noted earlier (cfr supra, section 3.2.2).[528] Both feature signs of being pressed or used for the purpose of extracting oil (rounded fractures, swollenness), but show no signs of being shredded.[529] The significant use of olive pits corresponds to the significant archaeological attestation of olive production in both regions. [530]

Though securely Byzantine in time period, both the baths at Um-Qeis in Palestine and those at Qal'at Sam'an in Syria featured the use of olive pits.[531] The baths associated with the pilgrimate site of Saint-Symeon at Qal'at Sam'an found an almost exclusive use of olive pits for fuel.[532] Though Bouchaud cautions that the absence of charred wood could also be due to too small and targeted sampling.[533] This was done via flotation and wet sieve from 20l of soil from the interior of the hypocaust, which actually is a standard oft encountered our survey. In the baths and Umm al-Amr the 6th century layers were found to contain trace amounts of grape pits, possibly resulting from the use of pomace[534] , which would accompany the anthracological remains of vine trimmings noted earlier (cfr. Supra section 3.1.2).

The use of olive pits is also attested outside of the Roman East however, most notably in Roman North Africa. This attestation goes back to the find of carbonized olive pits in two baths at Cuicul (Djemila, Algeria) in the first half of the previous century.[535]

The public baths at Bulla Regia, Tunesia yielded plenty of carbonized olive pits in several of the 3rd to 4th century layers of the stoke room.[536] Arnould, who supervised the analysis of these fragments, thought it likely many came from olives destined for olive oil and they might have been remains of pomace.[537]

A similar situation can be found in Leptiminus. The Eastern baths site yielded plenty of carbonised olive pits (the minimum amount was estimated at 485 specimens).[538] These were found in large ash layers associated with amphora wasters[539] on top of a collapsed hypocaust. The stoke room started operation in the 3rd century CE, and after its collapse the site was in use as a kiln for pottery production until the 6th century CE. Especially the older layers include numerous carbonized olive stones and slag. Though not directly associated with the active baths, the context of this find leads us to presume it highly likely that olive pits were also used in stoking the baths. As Mattingly notes, the Tunisian Sahel produced olive oil in large quantity in the Roman period.[540] This is evidenced by the find of both complete and fragmented pits were found, from various species.[541]

According to Smith, the use of such (olive) pressings and olive pits fits into the picture of an organized agricultural practice, whereby residues of crop processing and food production were gathered, and

[528] Bouchaud, C. (2014), p 601
[529] Bouchaud, C. (2014), p 603
[530] Bouchaud, C. (2014), p603 also citing Al-Muheisen, Z., Villeneuve, F. (2000) and Al-Qaisiya, M.K. (2002)
[531] Umm Qeis: Holm-Nielsen, S., Nielsen, I., & Andersen, F. G. (1986). The Excavation of Byzantine Baths in Umm Qeis. Annual of the Department of Antiquities of Jordan, Amman, 30. p 226; Andersen, F.G. et al (1990) as reported in Nielsen (1993) pp 19-20; Qal'at Sam'an: Bouchaud, C. (2014), p 600
[532] Bouchaud, C. (2014), p 600
[533] Bouchaud, C. (2014), p 600
[534] The solid remains after pressing, which consist of skins, pulp, seeds, and stems
[535] Allais, Y. (1938), p 77
[536] Broise, H. and Thébert, Y. (1993), pp 132-134
[537] Broise, H. and Thébert, Y. (1993), pp 132-134
[538] Smith, W. (2001), pp 420-441. Especially pp 428-429, 434-38
[539] 'Wasters' denote the amphora spoiled in manufacture
[540] Mattingly 1988 pp 44-45
[541] Smith, W. (2001), pp 428-429, 434-43

used in the community.[542] Though at the same time she does not exclude the possibility of them being sold or transported to places requiring fuel. Lazreg typifies the ancient olive oil industry as a huge industry with several symbiotic processes at work.[543] A large scale industry of olive oil implies another one for its containers. As evidenced from the Leptiminus site it is likely that locals saw the benefits of the co-location of pottery production with the olive groves- and presses (perhaps resulting in 'vertical integration' of some sorts).[544] The very groves used for oil also used the residues of this production from processing as fuel for their containers (in the form of pits, pomace and trimmings). Furthermore, the carbonised ash and stones could then be recycled in construction industry, especially in mortars. Lazreg notes that this has been observed in the mortars of the cisterns at Leptiminus and at nearby Thapsus.[545] Further use of this olive paste as fodder is also possible.

Smith argues that the specifics of olive oil production seem to demand stable property relations and favor large landowners.[546] It stands to reason then that these land-owners would have had a stake in aiding to provide public amenities, especially those as popular as the baths. This establishes a view whereby the use of cheaply available leftovers from olive oil production for municipal purposes is mutually-beneficial. We have already noted the practice of municipal beneficence in the form of providing fuel (cfr section 1.1, 2.1.2). These benefits are especially clear when seen from the perspective of what Wrigley calls an 'organic economy' (cfr infra section 3.3).[547] This view would contradicts the treatment of olive pits or pomace as simply waste-products. These products could have served several functions in the countryside (cfr supra), yet still appear in the city's public baths.

Although the regions featured above (Roman North Africa, Jordan, and certain areas of Syria) are noted for their scarcity of wood resources, it is possible that the use of olive pits was not inherently linked to this aspect. The small baths at Musarna, Etruria for example attest to the use of olive pits in the 1st century CE.[548] They attest furthermore to the use of an alternate type of fuel, which will be addressed in the next section.

3.2.4 The use of bones and the use of dung; The Bosra and Musarna finds

The use of bones as fuel might be considered the most 'unorthodox' type featured here, though their use for cooking or heating is commonly accepted for the Stone Age.[549] For our period however, the use of bones as source of fuel is unexpected. Yet in Bosra, Syria and likely in Musarna, Etruria charred bones have been found that might be connected to the functioning of the baths.

A small survey was conducted of one of the major public baths in Bosra (the 'Center baths' site) by Henri Broise in 1987, as a quick addition to the ongoing restauration.[550] In the north-western stoke

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542 Smith, W. (2001), for a fuller discussion see Smith, W. (1998). Fuel for Thought: Archaeobotanical Evidence for the Use of Alternatives to Wood Fuel in Late Antique North Africa. *Journal of Mediterranean Archaeology*, *11*(2); and Stirling, L., Stone, D., & Ben Lazreg, N. (2000). Roman kilns and rural settlement: interim report of the 1999 season of the Leptiminus Archaeological Project. *Echos du Monde Classique/Classical Views*, *44*(19), 170-224.
543 Lazreg, B. in an addendum to Smith, W. (2001), pp 434-439
544 Smith, W. (2001), pp 420-441; See also Leitch, V. (2011)
545 Lazreg, B. in an addendum to Smith, W. (2001), pp 434-439
546 Smith, W. (2001), pp 420-441
547 Wrigley, E.A. (2016), p 16
548 Broise, H. and Jolivet, V. (2004), p 118
549 Théry-Parisot, I. Costamagno, S., et al. (2002), pp 50-51
550 Under the guidance of J.-M Dentzer (Institut de France) and Fr. Braemer (EFR and Cepam-UMR 6130). For the excavation of the other baths, the 'southern baths', see Dentzer-Feydy, J., et al. (eds.) (2007) *Bosra. Aux*

room he uncovered 440 bones (pertaining to roughly the 5th century), many of them charred. In total 220 bones were studied and determined (totaling a little less than 500g). In 2001 another, more extensive, survey took place under Fournet and Lepetz.[551] The study considered more than 5800 bones or bone fragments, weighing in total 3.8 kg. Most of them pertaining to a layer of similar date as Broise's (5th century CE). Quite a few bones show signs of butchering or of being leftovers from handicraft. However, almost all of the bones were burned to a black, greyish-blue and some to a white color, this indicating calcination.[552] Furthermore, many of the bones were transformed into a glassy type of mineral, a process called vitrification. Fournet and Lepetz claim this would require temperatures of at least 500°C going up to 1500°C.[553] So, they argue, this definitely excludes the possibility that this is the result of a cooking fire and a deposit of kitchen waste. Additionally, Rook's calculations of combustion temperatures in the furnaces of the public baths correspond to these figures.[554] Pointing to the context of the find (the stokeroom), the sheer number of burnt bones found, and the degree of calcination (indicating high temperatures), they instead put forward the hypothesis that these were burned as fuel for the baths.

Anything that is organic can be used as a fuel, and an oven heated by bones is subject to the same principles as one heated by wood. Bones usually contain on average 24% organic matter, which is the part that can burn proper.[555] As bones don't burn of themselves, the fire would need a 'starter' to bring the fire to a critical point for the fire to transmit enough heat to make the bones start burning. This is due to the relatively poor conductivity of bone as compared to other fuel sources.[556] It should be noted however that *every* combustible needs a 'starter' to reach a point at which it will start burning of itself.[557] This point, called the point of critical incident flux, is at about 340°C for bones. [558] In experimental tests Thery-Parisot et al. have achieved a fire consisting of 85% bone and 15% hardwood, and from then could maintain it by adding only bones. [559] Their experiments had earlier shown that a batch with up to 80% bones and 20% hardwood could last longer than a mix containing only hardwood; up to double (!) the amount of time.[560]

It is not quite clear however which kind of fuel mix would be best for the task of heating a building such as a hypocaust. The results of the early Thery-Parisot tests might have been overstated by

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portes de l'Arabie , Collection : Guides archéologiques 5, and accessible online courtesy 'Presses de l'Ifpo' and 'Open Edition books' at : <<http://books.openedition.org/ifpo/666>> (last check 7 July 2015)

551 Fournet, Th. and Lepetz, S. (2014), p 615

552 Fournet, Th. and Lepetz, S. (2014), p 615.
Calcination means the substance was heated to a high temperature, but without melting it, causing it to lose moisture. When applied to bones, this could also be the step in producing bone ash, which makes for a great fertilizer.

553 Fournet, Th. and Lepetz, S. (2014). p 615

554 Rook, T. (1978), pp 278-281, see also McParland et al (2009) for recent additions and corrections to estimates.

555 Susini (1988), as quoted in Fournet, Th. and Lepetz, S. (2014), p 616

556 Thery-Parisot, I. (2001) p 109

557 For dry tinder then, this means the spark of a flint or the friction between two sticks of dried wood used in a hand drill or a fire plough would be enough for it to catch fire.

558 Thery-Parisot, I. (2001). p111. In technical terms, it is the phase at which the endothermic energy becomes sufficient for the fuel source to sustain itself. See also Thery-Parisot, I., Costamagno, S. et al (2005), p51 who state that this temperature is actually at 380°C, and is equivalent to that of undried wood. Conversely Thery-Parisot (2001), p109 states that the point of critical incident flux is actually not a very relevant indicator of itself. She states that the burning of a fuel is equally influenced by positioning, the degree of rise in temperature and burn length (cfr infra).

559 Thery-Parisot, I., Costamagno, S. et al (2005), p 53

560 Thery-Parisot, I. (2001), p 112. This experiment showed a strong correlation between increasing the proportion of bones and burn length (R= 0.6). It found no significant difference in these results with smaller or larger batches (2.2kg up to 9 kg)

Fournet.[561] In their experiments Vaneeckhout et al. that adding too much bone in the mix (75/25) makes the fire too unstable, meaning the temperatures of the fire fluctuate too heavily. This results in the bones not being burnt properly, and subsequently lowers burn duration.[562] Vaneeckhout (et al.) suggest a more even bone count in general and their experiments showed better results with a 50/50 mix. More data would certainly be welcomed, both on the particulars of heating a hypocaust with various fuels, as to their efficiency.

Nevertheless it is quite certain that compared to hardwood bones would definitely give off less heat.[563] The calorific value of a cadaver has been estimated to be between that of undried (or green) wood and chaff.[564] When stripped of flesh (and the fat it holds), the calorific value would then be lower. Also, once the flames die out, the bones stop smoldering quickly and combustion temperatures drop very rapidly.[565] In itself, this of course hurts their efficiency as a fuel source.

However, if Rook is correct in asserting that a continuous fire would have been preferred to letting the fire die down at night and re-heat the building every morning, this could still be a very interesting find.[566] As bones burn less hot and slower, their fire lasts longer. This way the use of bones could have provided a cheap way to sustain a fire in an already heated building. This might especially be useful if the baths encountered the problem of being stoked too hot (cfr supra, section 1.2.3). Selecting this type of fuel over those that burn more quickly (such as dried softwood or chaff) would then be another way a stoker could have affected the temperatures of the hypocaust (cfr section 2.2). They would require attention and skill however, in order to ensure a high enough temperature so that the bones continue to burn. Using bones could also be a cheap way to keep hypocaust going during the night, when less heat was necessary. Lastly, as the bones might have been waste products, they might have cut fuel costs considerably (cfr infra).

The bones found in Bosra show a significant selection for sheep and goats. Specifically, it showed a marked selection for parts of their heads with 897 identifiable samples, making up 90%.[567] These would imply the presence of at least 11 individuals. The base of the legs (metapodials), were a secondary selection, with 76 parts identified (7.5%).[568] It could be possible that other parts were burnt too severely for identification. A minority of the total assembly were the 51 samples of longer bones, probably belonging to a larger mammal, like cow or dromedary, also showing burn marks. The craniums that were found did show butcher's markings but were largely intact when burnt.[569] The selection of these large bones corresponds to Mentzer's results, showing they correlate positively to increased burning time.[570]

It is likely however that any technical limitations on using bones as a fuel source are secondary. The real limitation of using bones, as also stated by Fournet and Lepetz, would probably be their supply.[571]

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561 Fournet, Th., and Lepetz, S. (2014), p 616
562 Vaneeckhout, S. et al (2010), p 11, fig1. A batch of 25% bones and 75% wood was also tested, and had similar, though smaller, fluctuations as compared to the mix with 75% bones and 25% wood.
563 Thery-Parisot, I. (2001), p 110
564 Thery-Parisot, I. (2001) p 110, and Thery-Parisot, I., Costamagno, S. et al (2005), p 51. Costamagno states that Susini measured that the calorific value of a human body (including all the fats) would be 1900kcal/kg. However for bones without flesh (and therefore many of the fats), this figure would definitely be lower. She estimates this to be at 1500 kcal/kg, close to that of green, undried wood. For a definition of calorific value, see footnote 15
565 Thery-Parisot, I. (2001), p 113. In these tests smoldering would only last 15 to 30 minutes. See also Thery-Parisot, I., Costamagno, S et al (2005) p 54 fig 4
566 Rook, T. (1978), p 278
567 Fournet, Th. and Lepetz, S. (2014), p617
568 Fournet, Th. and Lepetz, S. (2014), p616
569 Fournet, Th. and Lepetz, S. (2014), p 616
570 Mentzer, S. (2009), pp 61-63
571 Fournet, Th. and Lepetz, S. (2014), p 617

As bones are a by-product of husbandry or hunting, their usage would be linked -and subservient- to the killing of animals for the consumption of meat, milk and other animal products. Secondary to this, bones have many other uses. They could be boiled for glue or be used to make household items such as combs and needles, serve a decorative purpose in tabletop games for example or as dice. Artisans would have sought out parts of interest when an animal was slain. This way the skin, the horns and certain bones (such as the base of the feet, used in making door hinges) would be collected shortly after the animal had been killed. Quite often the primary waste of a killed animal (such as the cranium, parts of the spine and other offal) would have been thrown in an *ad hoc* deposit near the butcher's. Other parts not used or consumed would end up in domestic deposits or would have been ground up and used as fertilizer.

The only other fuel type found in Bosra was camelid dung, probably used for starter.[572] Several Byzantine Egyptian sites attest to the use of dried dung, often accompanied with the use of chaff.[573] The practice of using dung and waste to fuel public baths is not unknown to history. Bouchaud noted the 16th century judico-medical treatise Kitab al-Nuzah by Al-Munawi, which recommends the hammams stop using waste as fuel for medical reasons.[574] The practice is also referred in 16th C Egyptian state property acts.[575]

Fournet and Lepetz propose that in Bosra's urban setting, the public baths could provide an alternate –and beneficial- location for bone and other waste. If studied further they could reveal a connection between the shepherds or cattle herders, the butcheries and/or the bone-artisans, and the public baths. Perhaps even connecting with the local authorities. The municipally organized collection of dead bodies by public slaves has been attested for 5th and 4th century BCE Athens.[576] Furthermore the collection of excrement was a private enterprise, for which the municipality might have given out contracts.[577] Similarly, these bones that were waste products for one industry could have been collected or perhaps sold to serve a public function.

In Bosra, as in many other cities, these bathhouses were located very centrally in the city, along one of the major roads. Butcheries and artisans' shops also provide a somewhat centralized point and a steady enough 'stock' to merit the effort of setting up a transport to the bathhouses. Fournet and Lepetz admit that though currently too little is known of the manner in which the animal processing sector was organized in the Hauran environment of Bosra, they believe Bosra would have had a distribution network to make the most out of these animals, by drawing comparison with known cases from other cities in the Roman-East.[578] They also found that the animals most consumed during the Nabatean, early-Roman, Ayubbite and Mamluk period were sheep and goats (between 75 and 90%, with 77% for the early-Roman period), displaying continuity and a similarity in selection to the ones found in the baths.[579] Lastly, they support their connection of butchers and artisans to the baths by arguing if there were only a domestic processing of animals, we would have found whole skeletons burnt, and not a marked selection of craniums and metapodials.[580]

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572 Fournet, Th. and Lepetz, S. (2014), pp 616, 627 fig 15
573 Maréchal, S. (2016), p 496 citing Szymanska, H. & K. Babraj (2008) *Marea Vol. 1. Byzantine Marea. Excavations in 2000-2003 and 2006,* p 45; and Maréchal, S. (2016), p 554 citing de Vries, B. & A. Lain (2006) The Legionary Baths (Area C10), *in:* Parker, S. T. (ed.), *The Roman frontier in central Jordan : final report on the Limes Arabicus Project, 1980-1989*, p 220
574 As quoted in Bouchaud, C. (2014), p 596 from her personal communication with Valentine Denizeau
575 Bouchaud, C. (2014), p 596, see also Denoix,S., Depaule, J-C, and Tuchscherer, M. (1999), vol II
576 Owens, E.J. (1983), passim
577 Owens, E.J. (1983), pp 47-50
578 Bouchaud, C. (2014), pp 617-618, for a schematic of such a distribution network, see p628 fig 19
579 Bouchaud, C. (2014), p 618
580 Bouchaud, C. (2014), p 618

It could be argued that the addition of bones for heating public baths was a response to the arid environment of Bosra. As Fournet and Lepetz call it, a 'culture of recuperating waste' might have developed to mitigate pressures on forests and wood resources. Cultural aspects would certainly have played a role in the Romans' attitude to fuel, as evidenced from Ulpianus' remarks in the *Digesta* (cfr. Supra section 3.2.1). To my knowledge, there is one reference in Antiquity toward the use of bone as fuel. Herodotus, describing the Scythians' holy rites, mentions their use of animal bones to cook sacrificial meat.[581] He specifically connects their use of bone to a shortage of wood in their lands. Herodotus' approving mention that bones actually burn nicely does also suggest that the practice might not have been common and that he had to reassure his readers of the feasibility of this practice. The absence of bones as fuel in official documents like the *Digesta* could further indicate bones might not have been regularly used.

On the other hand, it is possible however that the use of bones simply escaped the view of ancient writers, who altogether paid little attention to this topic. Furthermore, there is little reason to weigh the accounts of ancient writers greater than what can be derived from the evidence of their use in Bosra. As evidenced by the selection of type in the bones, these people in Bosra arguably did not consider these bone products simply as 'waste' (cfr. infra section 3.3 'organic economy'). They could still produce energy and were used for this purpose. This runs counter to our pre-conceived preference for wood-fuel, which –as we have seen- needed to be cut, processed and transported to the city. This obviously required many man-hours and the use of beasts of burden. As a great many of resources would flow toward the city, the question could be posed conversely: Why would these 'waste' products that end up in the city *not* be used for a beneficial communal purpose?

The case Fournet and Lepetz made on the basis of the Center baths find in Bosra should encourage different interpretations of newer finds and reinterpretations of existing work. This might be possible for example with a find dating from the early 1st century CE from Musarna, Etruria.[582] The 2004 report of Broise and Jolivet describe 1835 bones found near the service corridor of a small bath, in reservoir 14. Of these around 1560 were found to be indeterminable, and 1500 showed signs of calcination due to combustion. The severe fragmentation of the bones made identification especially tricky. Most bones however were burnt severely and only a very small part of the longer bones showed light burn markings. The examination under Grossi Mazzorini considered that at least 525 fragments probably pertained to a large animal like a cow (Bos taurus).[583] Of these, 93 could be identified with certainty. They imply a minimum of 8 individuals. Bones that were complete enough showed signs of butchery. There were also several burnt bones linked to sheep, goats and even cats.[584] The link between these bones and the actual workings of the baths is not entirely certain however, and was evaluated negatively in the original analysis. The depositional layer corresponds to around the last stages of occupation of the site, around early 1st century. This layer was topped with signs of destruction; fragments of building blocks, mortar, etc.

There are elements though that favor speculation toward their use as a fuel. The great amount of burnt bones implies these came from a stock, perhaps as butchers waste. The severity of their burn and their location near the service corridor is another. Lastly in the same layer were found a respectable number of burnt olive pits and charcoal remains. We have seen that olive pits were used as fuels for the baths (cfr supra section 3.2.3). The possible implications of this find does beg a revisit of the analysis.

581 Herodotus, *The Histories* 4.61
582 Fournet, Th. and Lepetz, S. (2014), p 619
583 Grossi Mazzorin, J. in Broise, H. and Jolivet, V. (2004), Musarna 2. Les bains hellénistiques, pp 299

Furthermore, there may be taphonomical[585] reasons to explain the lack of attestations of burnt bones for the period of Antiquity. Mentzer combined numerous studies to indicate that calcined bones are probably underrepresented in archaeological finds.[586] She states that these bones, being brittle, might easily be reduced to a powder, perhaps not immediately identifiable as bone. This could happen during occupation, by cleaning activities, or post-deposition by trampling or burial. The resulting bone ash might have also been mixed with wood ash, which increases the likelihood of going unnoticed, except with microscopic techniques. Some of these have only recently been added to an archaeologist's toolbox, while others are still being researched.[587] Additionally, where calcined bones are found, a number of them are often too small to be identifiable. For the Bosra find, this was about 1.8 kg of the total 3.8kg bones sieved. Mentzer notes these are, in practice, often overlooked as they are usually unidentifiable.[588] These fragments of themselves, could be a good indicator of bone having burnt and, when analyzed in detail, could also point to the intensity of the burning. [589] Though of course keeping in mind the possible aforementioned post-depositional activities. They might of course also be a result of the histological nature of the bone burnt (e.g. bone density).[590] Different bones conserve very differently and even big bones have ended up completely fragmented in experimental combustion.[591] The weight of bone residual after combustion has also been estimated to represent only about one sixth of the total initial fuel load.[592]

In Bosra the argument could be made that barren, unforgiving landscape made wood resources scarce, so this necessitated the (temporary) use of alternate fuels that weren't otherwise preferred. Perhaps, it could be argued, bones were used temporarily as a response to economic pressure on the price of wood. But Musarna is located in the countryside, where it would be surprising that wood resources in 1st century there were so scarce that they couldn't support to fuel this small bathhouse. Perhaps the mere availability of waste products from slaughtered animals merited their use, recuperating resources as much as possible. The Musarna find is then perhaps another argument that there was a greater variety in fuels used and an appreciation that extends beyond the use of wood.

3.2.5 The use of coal in Roman Britain

The widespread use of coal has been shown for Roman Britain since Webster's compilation of archaeological excavations in the 50's.[593] Since then, Dearne and Branigan have added another 150 Romano-British sites where the use of coal has been attested. [594] Most of these finds are related to metallurgy.[595] It is also in this context where we find ancient references to coal. Theophrastus for example notes the use of coal related to smith work in Liguria and Elis.[596] It should be noted though that the Vindolanda tablets might yield more information, but have not been considered here due to time constraints.

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585 The study of decaying organisms and their fossilisation over time.
586 Mentzer, S. (2009), p 54
587 Mentzer, S. (2009), p 54. One of these is a chemical test, the Fourier transform infrared spectroscopy (FTIR), which Mentzer claims, can distinguish between pure wood ash, powdered calcined bone or mixtures thereof. See also Costamango and Pariso (2009) in BAR 1914
588 Mentzer, S. (2009), p 55
589 Mentzer, S. (2009), p55
590 Costamagno, S, et al (2005)
591 Thery-Parisot, I. (2001), p 125
592 Thery-Parisot, I. (2001)
593 Webster, G. (1955)
594 See Dearne, M.J. and Branigan, K. (1995), for an appendix of these sites pp 87-105
595 Dearne, M.J. and Branigan, K. (1995), p 72
596 Theophrastus, de Lapidibus II, 12

Conform to the limitations of our survey, several sites in England and Wales have yielded coal in the context of a hypocaust. Many of these were villa baths and dated between the 2nd and 4th century CE, such as in Chedworth (Gloucestershire), Dry Hill villa (ditto), Chester's villa (ditto), Whittington Court villa (ditto), Daventry villa (Northamptonshire), Northfleet (Kent), and the Shakenoak villa baths (Oxfordshire).[597] Others were forts or related to the military, such as Corbridge (Northumberland, 1st - 2nd century CE), Caistor-on-Sea (Norfolk, 3rd century CE).[598] Reportedly, the public baths at Wroxeter coal was also found in the stoke room, though their excavation was in 1872 by Wright and again in 1953 by Webster provides little detail.[599]

The attestation of the use of coal in these baths might challenge the argument that has been put forth so far in this work, namely that the factors 'proximity' and 'availability' determine the type of fuel used in baths. As Smith states, 'The Romans were exploiting coals in all the major coalfields in England and Wales by the end of the second century'.[600] These were exposed seams and probably harvested with simple tools such as pick and shovel.[601] Branigan and Dearne point out that in general coal was most attested near Hadrian's Wall, and densely settled regions. This is also true for the baths sites which yielded coal in / or near the hypocaust.[602] Only the site of Corbridge is in the vicinity of an open coalfield.[603] There is thus ample evidence to suggest coal was transported overland, or by river to the sea for shipment to coastal sites between Yorkshire and London.[604] On this basis Smith argues the exploitation and transport of coal was not haphazard but to some extent organized. This means coal was purposefully gathered and transported within Roman Britain.[605]

There is no real technical advantage to using coal over wood or charcoal, especially when it is not coked. It is notable that the use of coal likely does not pre-date Roman occupation.[606] Branigan and Dearne therefore suggest the use of coal was to relieve pressure on timber resources in densely settled areas and military forts following occupation by the military.[607] For the findings of coal in the villa baths they suggest the availability of coal at a distance may have been dependent on the communications or trading links of a specific area rather than the status of a particular site.[608]

The use of coal throughout Britain in both military and civic contexts suggests a fuel economy that merits further research. Furthermore, the use of coal has also been attested outside of Britain in Bonn, in Saarland, and Decize-La-Machine.[609] It is possible that coal was useful enough (burning roughly as raw wood does), yet its value low enough for it to be viable and transported. As coal is a fossil fuel, it was not subject to concerns of sustainable exploitation and could simply be mined and its value might simply have been the labor cost of mining it (either in wages or in food for slaves) plus transport. It is quite possible, as Dearne and Branigan suggest, that economic feasibility of coal trade networks in Roman Britain show that local fuel resources were not able to withstand long term exploitation. This due to the pressures of a growing population, a military occupation, and amenities such as the baths. This offers a different view than what has thus far been argued for the areas of the Roman Empire surrounding the Mediterranean. On the other hand, it would be best to confirm this with palynological studies, as coal might have simply fit into the agenda of the military occupation of

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[597] Dearne, M.J. and Branigan, K. (1995), see Appendix
[598] Dearne, M.J. and Branigan, K. (1995), see Appendix
[599] Dearne, M.J. and Branigan, K. (1995), see Appendix
[600] Smith, AH.V. (1997), p 323
[601] Dearne, M.J. and Branigan, K. (1995), p 73
[602] Dearne, M.J. and Branigan, K. (1995), p 86
[603] Dearne, M.J. and Branigan, K. (1995), p 87, fig 5
[604] Smith, A.H.V. (1997), p 323
[605] Smith, A.H.V. (1997), pp 316-323
[606] Dearne, M.J. and Branigan, K. (1995), p 73
[607] Dearne, M.J. and Branigan, K. (1995), pp 80-81, 86-87
[608] Dearne, M.J. and Branigan, K. (1995), p 80
[609] Dearne, M.J. and Branigan, K. (1995), p 75

Britain, being redistributed along its lines, instead of widely circulating (cfr Erdkamp's consumer economy section 4.2). The establishment of these Roman distribution networks would then coincide with coal's adoption, instead of being the result of pressure on forests. Further research into the management of the landscape and the relationship between the influences of the Roman occupation on land- use patterns in Britain could provide us with the solution to this conundrum.

3.3 The types of fuel: concluding remarks

The woodlands used to fuel the public baths were likely part of a bigger land use scheme. As seen previously, some of them were reserved especially for public purposes. Accordingly, several management strategies existed to exploit them. It is likely that the fuel from these woodlands were selected specifically from the perspective of a management strategy intended to exploit them sustainably. It is currently unknown at a global level to what extent this sustainable exploitation was successful.

It is evident however that the baths did not solely rely on these woods for a source of fuel. Coppice woods and trimmings from orchards from nearby the city very likely had a large supporting role to play. These came from organized type of land use (fundus suburbani), which was actively pursued. The archaeological record proves that these contributed to supplying fuel for the baths in some way or another.

Preliminary in-depth studies point out that the landscape became increasingly cultivated and managed. This was for example evident in the villa of Farangola, where both orchard trimmings from nearby cultivated landscape and more 'wild' vegetation became an important source of fuel.

This use of 'wild', 'uncultivated' or 'peripheral' macchia or desert vegetation (what Forbes calls 'the waste') is not inconsistent with the increased use of cultivated landscape.[610] They both point to an intensification of land use to supply local needs.

Though it is possible that this is due to a failed management strategy, it is perhaps more likely the cause is external. A range of factors could have resulted in this trend: changing trade patterns, land-use and a growing population or living standard, or to secure wealth in the form of a steady investment, perhaps less prone to bad harvests. This is beyond the scope of our work. We have given as example Bosra, where pressure from grain cultivation likely ousted local woodland to higher elevations or could have outcompeted it entirely.

The use of these peripheral local sources argues for a predominant connection between a city and its hinterland in supplying fuel for the baths, perhaps precluding interregional trade in fuel. Especially considering wood fuel was bulky, the rationale for this has been called the 'Principle of Least Effort' (PLE). This principle cannot be definitely proved and there are indications to its opposite, for wood fuel there is speculation that short-distance overseas trade might have been viable, as evidenced in Veal's analysis of the fuel supply in Pompeii. Similarly, in Roman Britain and possibly in Gaul and Germania, coal was traded between regions.

However the likely absence of charcoal does tend to confirm the PLE. Charcoal of course would have been far easier and more valuable to trade than the more bulky raw wood. The validity of PLE indicates that local fuel resources would have been rationally exploited. The limited use of charcoal has not

[610] Forbes, H. (1994)

been conclusively proved however, and new methods are being studied. These do seem to point in the direction of limited charcoal use.

The main result from our survey research is that non wood fuels were widely used as well. These are most evident in what are considered arid regions low on wood. There are ever more examples of the use of non-wood fuels in areas which are usually not considered arid and are rich in woodland, such as Britain or Italy. We've compiled a table in Addendum 5 that compares the different fuel types listed in this section by calorific value. Though at this point beyond the scope of this work, they might serve to expand and enhance estimates of fuel consumption, like those in section 1.

The use of non-wood fuels reveals that local agriculture, husbandry and industry might have been linked in a number of ways to the city, and the baths. Specifically supposed 'waste' and by-products, have been found in the stoke-rooms of the local public baths, instead of being disposed. This usually entails a distribution network for getting these waste and by-products from the hinterland to the city (public baths usually being in the city center). In the case of bones however, these were likely already present in the city.

This use of alternate fuels also implies that it was somehow more beneficial for the 'waste'-producing party to get rid of it in the baths via this network, instead of using it on their own land, for example as fertilizer (this is especially the case in areas where dung was used). It is possible that the collection of these 'waste' and by-products was wholly similar to the fuel contracts given out by the local council. In the case of chaff, it is likely a special tax in chaff existed in Egypt for this purpose.

At the same time, the use of alternate fuels implies these were not simply considered 'waste'. This has varyingly been called a 'culture of recuperation' or has been typified as an 'organic economy'. The latter is determined by, as Wrigley puts it: "the degree of success with which the vast flow of solar energy can be captured for human use (...)".[611] This means that as long as these alternate fuel sources produce energy, they would still have a certain value.

The use of these alternate fuels further substantiates the connection between the city and its hinterland with regards to the fuel supply of the baths. Though the case of Roman Britain shows that there are exceptions and further research is needed to see to what degree this was an exception. The existence of a fuel trade would of course imply a thoroughly interconnected economy. Though it is possible trade in fuel occurred, the imported fuel, as far as we can tell, did not have as its destination the public baths. The arguments made above toward the structure of the types of fuel used in the baths, seem to confirm the idea of the 'consumer-city', which we shall discuss in the next chapter.

[611] Wrigely, E.A. (2016), p 16

4. Modelling the fuel economy of Roman public baths.

The aim of this work has been twofold. First of all we've tried to provide estimates for the fuel consumption of the baths. We've then tried to couple this with its economic context. In this section we'll try to quantify and qualify what we know about the fuel economy of the baths.

4.1 Quantifying

One aim of our work was trying to build upon the fuel consumption model of Pompeii by Veal (see Addendum 2). This model uses the following basic equation to guess the city's fuel consumption:

Population (000s) **X** *Consumption of fuel (tons) per head* **/** *Forest productivity (tons/hectare)* **=** *Forest Area to provide the fuel (hectares)*

The strength of this model is that on the basis of few variables, it can offer a range of areas needed to sustainably provide fuel (cfr addendum 2, table 'Model of Wood Fuel Supply: Forest Area Required'). These can then be compared to a geographic context. The consumption of fuel per head was based on ethnographic proxies, which offers a quick and easy way to approach Roman fuel consumption.

The model can be built upon and its variables expanded. The equation above can perhaps be sharpened by breaking up 'consumption of fuel per head' into domestic consumption (such as heating, cooking), public and commercial consumption (baths, bakeries, tanneries, potteries, brick, tiles, etc.) and industrial consumption (smith work, smelting). This distinction is based on different types of fire which might be necessary (and therefore types of fuel, cfr section 3.1.3). This is similar to the Xylarch project, which aims to approach the fuel consumption of Sagalassos.

The equation would then look like:

(*Population (000s)* **X Domestic** *consumption of fuel (tons) per head* ***+ public and commercial consumption + industrial consumption)* / *** *Forest productivity (tons/hectare)* **=** *Forest Area to provide the fuel (hectares)*

Our interest of course was to add to '*public consumption*' guesstimates for the fueling of the baths. This is what we have done in section 1. By cross-checking ancient sources with calculations based upon archaeological research, we've shown the range of possible fuel consumption. The Xanten 'Herbergsthermen' and the lower range of the NOVA baths estimate a yearly use between 30 to 50 metric ton of wood. The higher estimate of the NOVA baths and the Phaselis baths was around 130 metric ton. These figures correspond to small or modest establishments. Finally, on the basis of ancient sources we've seen the Achillean baths at Catania at one point could have used up to 1700 metric ton each year, but this was lowered to around 1000 metric ton. Provisionally, the fuel consumption calculated for the baths at Sagalassos show a similar magnitude.[612] These higher figures correspond to imperial establishments.

Veal's model estimates fuel consumption in order to map the physical determinants on fuel use. Assuming little interregional trade occurred, this allows us to imagine how the ancient economy might have been organized geographically, as can be seen in Addendum 2. Veal determined between a 60 000 – 232 000 hectares (between a quarter to about all of southern Campania's hills) would have been necessary. The ongoing Xylarch project would build upon this idea in order to provide a "simple calculation tool to estimate human wood resource extraction for a selected area during a defined period in the past."

Of course, while representing an implied geographical area needed for providing durable wood consumption is informative, it can only take us so far. Implicit in these models is the assumption

[612] Xylarch Project (Muys,B; Jansen, E; Poblomé,J and Degryse, P.), Leuven, and from personal correspondence

that the people in this area would simply organize to provide what is necessary. It is stripped of much economic context.

As far as we know, only Blyth and Miliaresis have previously focused specifically on the fuel economy of the baths.[613] Both have tried to determine the cost of this part of the fuel consumption. We too have tried our hand at this, sketching an idealized fuel supply chain in section 2 of this work. We've seen that the baths could have been funded through a variety of sources; entrance fees and rents, elite benefactions, municipal funds and public domains. These sometimes feature quantifiable data, mainly entrance fees and monetary benefactions. We've tried to determine the structure of bath management; who did what job, and how this might have affected fuel consumption. Finally, we've tried to estimate the cost of transporting fuel to the baths and tried to determine its price. These estimates are of course speculative, though both ours and Blyth's previous estimates compare to historical examples (cfr section 2.3.3). Miliaresis' results are awaited with interest, notably because they include the impact using various types of fuel would have had on fuel consumption. We've not attempted these calculations, though we have gathered their different calorific values in Addendum 5, which –for lack of experimental studies- could be a basis for comparison.

As we have seen in section 3, different types of fuel were used across the empire. We've seen that the wood used to fuel the baths usually came from a type of land use or silvicultural management. Though our survey too pointed out that wood often was bought from a city's neighboring farms, specifically organized for the urban fuel consumption market (the *fundus suburbanus*). Similarly, we pointed out that frequently, non-wood fuels would have been explored. Most of these were obtained as a by-product of agricultural production (chaff, olive pits, and pomace). Others might have been gathered while circulating inside the city (bones).

Our considerations in section 3 were qualitative, though here we can perhaps attempt to engage again with the denominator of Veal's equation:

Population (000s) X *Consumption of fuel (tons) per head* **/ Forest productivity (tons/hectare) = Forest Area to provide the fuel (hectares)**

The evidence of the use of alternate fuels shows Veal's equation is a wood-centered model. We too featured a similar calculation in section 1.3.6. While the assumption may hold true that wood would've predominantly been used to fuel the baths, probably from designated forests, we've seen several examples of the use of alternate fuels in areas where we do not expect a wood scarcity. This of course means calculations that do not take these into account probably overestimate wood fuel consumption, and thereby overestimate forest area needed. Perhaps then the baths did not necessarily imply, as Basaran and Ilken jokingly predicted, 'a big tree massacre'.[614] Similarly, we've seen examples where these 'alternate fuels' predominate in the archaeological sample. This phenomenon might more securely be linked with the expansion of agriculture, instead of profligate fuel use. This consideration shows that localized studies of a bath's fuel economy would benefit from integrating a city's hinterland into their perspective.

One of the weaknesses of the model above is that it neglects interregional trade as a factor. At this point however little can be proved in the way of an interregional trade in fuel, though some hints exist for Roman Britain. The discipline is highly reliant on archaeological data, and charcoal analysis is still in its infancy – the substance is not yet routinely collected by excavators.[615] For this reason

[613] Blyth, P.H. (1999) and Miliaresis (forthcoming); though it has been featured as a sidenote in a.o. Nielsen, I. (1993), Veal (forthcoming), Merten, E.W. (1983), Meusel, H. (1960), Schiebold, H. (2006)
[614] Basaran, T. and Ilken, Z (1998), p 11
[615] Veal, R. (2013), pp 37-38

we've mainly considered regional patterns of supply and consumption. This discussion however will be touched upon again in the next section.

4.2 Qualifying

The public bathhouses, often located in the city centers, fit Finley's view on the 'consumer city'.[616] The consumer city would claim agricultural surplus from its hinterland based on political and social entitlements, and use it to fund urban production of goods and services. This type of extraction is usually based on taxes and rents.[617] Erdkamp characterizes this as 'non-reciprocal exchange', meaning the agricultural surplus produced in the hinterland would not be exchanged for 'relevant products or services'.[618] A part of this surplus would have gone to fund and fuel the public baths. We've detailed this process in section 2, where both the municipality (through public lands) and elites (through benefactions, management) contributed toward fueling the baths.

This view also fits with Zuiderhoek's idea of elites providing these goods and services as a counterweight to economic inequality and social tensions.[619] The inexpensive, and often free public baths formed a basic foundation of civic life might have provided an ideological counter to the imbalanced economic exchange between elites and other sections of society. We've seen how more modest members of society, usually involved in urban professions (Rome's *mancipes* and *navicularii*), also contributed toward fueling the baths. This phenomenon could similarly be reflected somewhat by the use of bones in Bosra, essentially butcher's waste. The breakdown of this model near late-Antiquity meant that the Emperor and the Imperial administration might've stepped in by providing public forests and by settling debates on undertaking civic duty (again the *mancipes* and the *navicularii*). Though a full discussion on the decline of the bathing phenomenon and its causes is beyond the scope of this study.

In section 3 we've noted several management strategies to see how the hinterland coped with this pressure. Considering the relatively small capacity of ancient agriculture to produce a surplus,[620] we would argue that the use of what we -until recently- might have considered waste, is actually an ingenious and durable answer. Especially the use of olive pits and chaff would fit into the picture of elites using what would've been a typical rural waste product, for an urban public purpose.

In fueling the baths we have stressed the importance of the relationship between the city and its immediate hinterland. Erdkamp notes however that "the discussion (...) is often too much focused on the economic relationship between city and hinterland to make much sense of economic interdependence between cities" and that "attempts to estimate food production to which a city had recourse on the basis of agricultural productivity of its *territorium* are therefore bound to fail.[621] One could argue the same for fuel. Similar to food production, fuel was a basic, bulky good without which settlements could not function.

We must admit it is quite likely fuel could have been traded between regions. Very likely however, this fuel would not have its destination in the public baths. Several arguments support our view. First of all we have seen wood-scarce regions use alternative types of fuel, by-products from local agricultural production, rather than imported wood or charcoal. Though considerations of price and

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[616] This concept however goes back to Max Weber's *Die Stadt* and was further developed by Finley in *The Ancient Economy*

[617] Erdkamp, P. (2001). Erdkamp's model reminds somewhat of Quesnay's *tableau economique*, which emphasizes a productive agrarian class producing a surplus, a rentier class which extracts rents, and a 'neutral' artisanal class, which does not add to creating more surplus

[618] Erdkamp, P. (2001), p 340

[619] Zuiderhoek, A. (2009)

[620] Erdkamp, P. (2001), p 352

[621] Erdkamp, P. (2001), p 343

cost might not have fully applied to the ancient economy, we would argue that there was an aversion toward unnecessary effort (Principle of Least Effort), or perhaps classical Greek economic considerations of autarchy lived on in making the most out of local sources. To this end we have seen that alternative fuel sources show up in our archaeological record instead of charcoal or ‘foreign’ woods. Erdkamp states there is no reason to assume cities did not deal with farmers and landowners beyond one’s own *territorium (*the geographic hinterland over which the city could levy taxes).[622] While this is likely true, at the same time there would be no reason to assume interregional traded wood fuel or charcoal would have been preferred over olive pits, harvest by-products and bone-waste. It is very likely the baths were fueled as cheaply as possible, because the bathing experience itself is what mattered toward the prestige and status of its patrons. It seems difficult to argue fuel for the baths was imported into the city in the face of high transport costs because this fuel could belong to the *political territorium*, when alternative fuels are available in the geographical *territorium*. As Veal noted however, it is possible short-term overseas transport might have been viable. This is especially the case if this replaced a long distance overland trip.

The charcoal trade in Roman Britain might expose one of the weaknesses in our view, which emphasizes the relationship between a city and its immediate hinterland. Clearly, more research in this area would be welcomed. It should be noted however that Erdkamp’s view of the consumer economy still nicely accounts for this trade. Just as Rome could depend on more than its immediate geographical hinterland, there is a possibility the political hinterland allowed such products to travel beyond the boundaries of a city’s *territorium*. This is hinted at in Smith, who speculates that the coal trade networks in Roman Britain originally developed as a subset of military requirements.[623] These would then point to interregional networks, yet still fall within the consumer city model and non-reciprocal exchange, because they are extracted and no relevant goods or services are exchanged under Erdkamp’s criteria.[624] This is because goods or services did not flow back into agriculture to enhance production.

The same can be argued for the *fundus suburbanus,* which developed specifically related to the city and to fuel urban consumption. From the perspective of a ‘consumer economy’, we can explain the *fundus suburbanus*. These farms developed to provide a secure investment and a steady income. In late-Antiquity, Nenninger pointed out that forests too could have served this purpose (cfr section 2.1.4). Especially if they can be related to fueling the baths, these are far less an example of reciprocal-exchange.

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[622] Erdkamp, P. (1999), pp 342-3
[623] Smith, A.H.V. (1997)
[624] Erdkamp make an argument against the qualification of military presence as a meaningful service that is to be exchanged, p 340-41

Conclusion

In this work we've tried to sketch the fuel economy of public bathhouses in the Roman Empire. We have tried to pursue estimates of fuel consumption in section 1 on the basis of ancient sources and archaeological reconstructions. Then we showed how the baths were funded, how they were managed and who provided the fuel in section 2. In section 3 we demonstrated the results of our survey and tried to show the diversity of fuel types used in the baths. Finally, in section 4 we've tried to show how these elements could add to or confirm current models of the Roman fuel economy, both in the quantitative and qualitative sense.

In the first section, we've tried cross-checking ancient sources and archaeological calculations to see whether the public baths posed the heavy strain on resources Wilson suggested they would have had. It was found that fuel consumption for public baths was probably not disastrous, and could have been sustainably provided from the hinterland. We noted though that fuel consumption could be great in more opulent baths (such as the imperial ones). It is quite likely these would have required specifically designated forests of a respectable size in order to function adequately.

In section 2 we've tried to explore the economic context of the public baths and construct an ideal-typical fuel supply. We've noted Blyth's theory that public baths could be run on their own income due to economies of scale. Much more likely however, additional sources of income would have been required. Though benefactions were frequently made, this system was more occupied with providing access to the baths to interest groups, instead of actually funding the operation of the baths. For this the municipality likely intervened, funding the baths from a variety of sources (among which elite benefactions might have of course been appreciated). Public baths very likely had access to public land to fuel the baths. Coupled with municipal funds, the viability of public baths was probably sure from the start in most cases. Those involved in the baths were under supervision of local elites, who'd try to attain status and prestige by providing these public amenities. There might have been some consideration for using fuel efficiently. The hypocaust system was built for trapping and preserving heat. Slaves lived-in and were responsible for maintaining the fire, which would have actually reduced overall fuel consumption (as seen in section 1), though this might equally have been due to the difficulty of reheating a bath gone cold. A system of public employment or civic duty arose that went down to fuel supply and transport. The contracts that guide this transport usually stipulate fueling along the lines of daily (or very regular) and continuous supply. If fuel was imported, this would mean a fuel market that is very well interconnected. On the other hand, it could be explained by fuel transport from the immediate hinterland or perhaps close-by overseas trade. As all methods of transport are influenced by the variability in climate, the proximity of a fuel source would have been a great asset. We've tried our hand at calculating the cost of (wood) fuel and transporting it, and compared it with estimates from Veal, Blyth, and historical examples. Though difficult and based on problematic sources, we've tried to see some rationality in the corresponding prices. There are some suggestions these correspond to a rationally managed the environment.

In section 3 we've tried to synthesize from a small survey of archaeological sites what kind of fuels were used in the baths. It is quite likely that the ancients developed silvicultural practices to manage their woodland and fuel production sustainably. One of the results of our survey is that the wood fuel used in the ancient baths were usually local and close-by, probably coming from the immediate hinterland. This would have included, if necessary, wood from 'wild' vegetation from what we would now consider 'marginal lands', such as maquis vegetation (what Forbes referred to as 'the waste'). It is unlikely that the baths would have been fueled by imported wood or charcoal. The latter especially representing only marginal benefit at a much greater cost. One of the other results from our survey is that, for the fueling of the public baths at least, several alternate fuel-types likely presented a better alternative. Where Wilson argued these were used only when firewood became scarce, we've noted several examples of their use in an environment where wood fuel would likely not have been scarce. This is based on the rationale that the pre-modern economy was an organic economy, trying to capture as much energy as possible instead of solely relying on raw wood because 'reasons' (sic). Our focus on raw wood might be the result of a nearsightedness, seeing wood as an ancient *ersatz* for oil, which is what our economy still largely is based on.[625] This means that in the frame of mind of the ancients it would have been rational (not to mention quite as easy!) to use harvest by-products, and 'waste' from agricultural production. It seems, to fuel the baths at least, it was customary to look for fuel sources for the baths that would have been 'local' and 'available'. Coupled with the use of public lands to fund these municipal public amenities, the practice was likely relatively efficient and sustainable, in spite of a tendency to use heated baths to profile and gain prestige. There are several problems with our view though, that will require further research. Among them is the use of coal in Roman Britain, where a trade in coal developed. It is possible coal was adopted due to the pressure of these urban amenities. On the other hand, it is possible the use of coal, which did not need to be sustainably managed, provided certain benefits with little drawbacks to the type of occupation by the Romans. Coal was found being used alongside these trade networks, instead of generally popping up everywhere.[626] More research, specifically palynological research and research on land-use patterns could provide the solution to this conundrum.

The use of non-wood fuels, usually based on by-products from agricultural production, allow us to provide one suggestion, and perhaps pose one question in ongoing debates that try to model the fuel economy of the Roman Empire, which were explored in section 4. First of all, we've tried to provide additions to Veal's quantitative model of the fuel economy of a Roman city. We've noted that specialist studies that try to map and differentiate fuel use for domestic consumption, and that for commercial and industrial consumption might prove rewarding. We've tried to do this with our topic, the public baths. The results of our survey show that estimates toward the areas required in order to fuel the baths sustainably would overestimate forest area needed. Both the *fundus suburbanus* and the use of agricultural by-products might have lowered overall forest area needed. Further study of the urban fuel market, and further collection of charcoal and anthracological samples are needed to provide a better picture of their impact. We see no reason not to attempt this, as it not only would further help us to quantify, but perhaps better qualify the fuel economy.

Our results with respect to the fuel supply of the public baths tend to confirm the 'consumer city' model Finley had in mind. This argues that the agrarian surplus production was appropriated to fund urban goods and services. For the baths at least, this fits the idea that the elite claimed the surplus through a variety of sources (taxes, rents, entitlement), and used it to fund these public amenities in order to actually legitimize this unequal exchange. The use of agricultural by-products as fuel can only confirm such a view. At the same time however, this would have actually been a relatively durable answer toward the challenges the public baths posed as a playing field for elites to gather prestige.

We note again however that our view does not entail no fuel was traded at all. Our view is based solely on the fuel consumption of the urban public baths, which as Wilson notes, would have been fueled as

[625] In 2012 about 40.7% of the total fuel consumption (which includes industry, transport, agriculture, public services, residential use etc) in the world came from oil, 15.2% from natural gas, 10.1% from coal, 12.4 percent coming from biofuels and waste, 3.5% was from renewables and 18.1% of total fuel consumption was electric. That 18.1% electricity consumed is itself made up of 40.4% coal and peat, 22.5% natural gas, 16.2% hydro-electric, 10.9% was nuclear power, 5% oil, and 5% of the total energy consumed came from renewables. Source: International Energy Agency (2014) "2014 Key World Energy Statistics" pp 24-29 made available on <<*http://www.iea.org/publications/freepublications/*>> last check 07/07/15

[626] We should note that due to the industrial revolution and the widespread use of coal in early-modern times, coal does *in fact* pop up everywhere, what is meant here is that the use of coal as a fuel source for our period does not seemingly transcend these networks and, though it widely circulated, it did not circulate everywhere

cheaply as possible. Considering the costly affair of transporting such a bulky good, and the ease by which local alternate fuels might be collected, there is little reason to assume imported fuel would have been preferred. Probably *because* elites were involved in the management of the baths' fuel supply it is likely they directed attention toward cheap harvest by-products (such as their olive or wine production), brushwood (olive and vine), rather than imported raw wood. Even supposing the bath's stoke room was a bottomless pit that required substantial quantities of fuel daily (which we have relativized somewhat), why would imported wood be preferred over local waste products that do the job (nearly) just as well?

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Addenda

Addendum 1: Map of Locations featured

Addendum 2:

Quantitative model: Pompeiian fuel consumption AD 79 (handout by Robyn Veal)

The basic calculation required is as follows:

Population (000s) X Consumption of fuel (tons) per head / Forest productivity (tons/hectare) = Forest Area to provide the fuel (hectares)

POPULATION

Jongman (1988: 108-112) provides a good review of the various estimates of Pompeii's population provided by different scholars. In the model proposed, one of the lower figures is Eschebach's of 8,000, while Nissen's figure of 20,000 provides an upper limit. These are figures for inside the city walls, and exclude those people living outside the city walls, but likely equally involved in consumption of all sorts of commodities brought to the city as the place of central commerce for the area. Beloch's revised figure of 15,000 inside the walls, and a population density of 180 people/sq km, is used as a base by Jongman to argue for a total economic territory supporting 36,000 people, (inside and outside the walls). For convenience of calculation we shall adopt figures of 15,000 inside the walls and 15,000 outside, following Jongman (nearly). For the purposes of simplifying the analysis, then, the model examines the smallest (8,000) and largest (20,000) figures, and the composite allowing for inhabitants in the city and its immediate surrounding territory (15,000/15,000).

CONSUMPTION

For consumption levels, ethnographic proxies for wood dependent societies, describe a range of 'low' fuel consumption of 0.5 tons/person/year, to a 'high' of about 2 tons/person/year. Both of these extremes are considered together with a more 'average' consumption of 1 ton/person/year.

PROPORTIONS OF RAW WOOD AND CHARCOAL FUEL

Complicating the matter somewhat is the definition of 'fuel.' The Pompeiians used both raw wood, and raw wood converted into charcoal as fuel. With regard to proportions of fuel types used there is sometimes a reflection of the pareto principle in wood/charcoal usage in wood-fuel dependent societies: in the city, 80% of fuel is charcoal, and 20% is wood; while in the country, the reverse is true: 20% of fuel used is charcoal and 80% is wood. These proportions are considered in the model, as well as a 50/50 split.

EFFICIENCY OF CHARCOAL MAKING

With regard to charcoal making, moderately efficient conversion (probably the most common) involving wood mounds in the open typically requires 6 or 7 tons of wood to make 1 ton of charcoal (at best). Therefore the model must include factors to account for differential use of raw wood and charcoal; and possible different levels of productivity of charcoal making. The model thus becomes:

POPULATION (a range of possible figures) X FUEL CONSUMPTION / FOREST PRODUCTIVITY, where

FUEL CONSUMPTION = (% RAW WOOD + % CHARCOAL) and

CHARCOAL = RAW WOOD X (EFFICIENCY FACTOR from 4 – 7)

to make a total of Raw Wood required for Charcoal production

That is, the figure for Fuel Consumption reflects consumption of raw wood, together with consumption of charcoal, the making of which has entailed the use of more raw wood. The resultant figure shall be called the Total Biomass Required.

FOREST PRODUCTIVITY

There are no specific figures in the ancient literature for forest productivity. General agricultural yields vary from poor to good, according to Spurr (1986: 82-88). If 5 tons/ha/year is used by Grove and Rackham to describe modern forest productivity in fertile areas with good rainfall (2001: 174), and 2-3 tons/ha/year define 'sustainable' use of beech wood in New Zealand, then a productivity of 1 ton/hectare can be described as 'poor.' It is possible ancient practices may have been more, and less efficient, depending on the wood type, soil fertility, altitude, and other factors. This model does not at this stage concern itself about these details, but a range of possible productivity levels from 1 ton/hectare to a maximum of 4 tons/hectare is considered.

RESULTS

Highlighted within the results are a number of the more likely figures of interest:

a) Highlighted in blue are possible figures for a population of 20,000 people, consuming 1 (or 2) tons of wood each per year in a ratio of 80% charcoal and 20% wood, assuming the least efficient charcoal production method in the table (7 tons of wood to produce 1 ton of charcoal), and alternate forest productivity scenarios of 1 or 2 tons per hectare. In these cases we see that at consumption levels of 1 or 2 tons per head per year, the resultant forest area required ranges from 58,000 to a maximum of 232,000 hectares.

b) If one wishes to take the theoretical position on population that also takes the inhabitants just outside the city walls into consideration, then we may use the figures for consumption at the rate of 1 ton/person/hectare for the population of 15,000 (yellow and green highlights) and add together amounts for the city dwellers and the country dwellers; i.e. 43,500 + 16,500 = 60,000 hectares at a productivity of 2 tons per hectare; or 87,000 + 33,000 = 113,000 hectares at a productivity of 1 ton/hectare. Clearly, forest areas required will be more conservative for any population below 15,000/30,000; with better productivity in charcoal production; or indeed with forest productivity in excess of 2 tons/hectare. All of these figures must be considered in light of the forest areas which were potentially available in ancient Campania and Samnium.

Model of wood fuel supply: forest areas required

Population	8,000									15,000									20,000								
Total fuel consumption wood and charcoal (tons)	0.5			1.0			2.0			0.5			1.0			2.0			0.5			1.0			2.0		
Made up as consumption ratio (raw wood : charcoal)	20/80	50/50	80/20	20/80	50/50	80/20	20/80	50/50	80/20	20/80	50/50	80/20	20/80	50/50	80/20	20/80	50/50	80/20	20/80	50/50	80/20	20/80	50/50	80/20	20/80	50/50	80/20
Charcoal making productivity measure (tons of wood required to produce 1 ton of charcoal)	**Total Biomass required ('000 tonnes)** = raw wood portion + raw wood quantity to produce charcoal portion																										
4	13.6	10.0	6.4	27.2	20.0	12.8	54.4	40.0	25.6	25.5	18.8	12.0	51.0	37.5	24.0	102.0	75.0	48.0	34.0	25.0	16.0	68.0	50.0	32.0	136.0	100.0	64.0
5	16.8	12.0	7.2	33.6	24.0	14.4	67.2	48.0	28.8	31.5	22.5	13.5	63.0	45.0	27.0	126.0	90.0	54.0	42.0	30.0	18.0	84.0	60.0	36.0	168.0	120.0	72.0
6	20.0	14.0	8.0	40.0	28.0	16.0	80.0	56.0	32.0	37.5	26.3	15.0	75.0	52.5	30.0	150.0	105.0	60.0	50.0	35.0	20.0	100.0	70.0	40.0	200.0	140.0	80.0
7	23.2	16.0	8.8	46.4	32.0	17.6	92.8	64.0	35.2	43.5	30.0	16.5	87.0	60.0	33.0	174.0	120.0	66.0	58.0	40.0	22.0	116.0	80.0	44.0	232.0	160.0	88.0
Forest productivity (tons per hectare)	**Hectares required ('000s)**																										
1	13.6	10.0	6.4	27.2	20.0	12.8	54.4	40.0	25.6	25.5	18.8	12.0	51.0	37.5	24.0	102.0	75.0	48.0	34.0	25.0	16.0	68.0	50.0	32.0	136.0	100.0	64.0
	16.8	12.0	7.2	33.6	24.0	14.4	67.2	48.0	28.8	31.5	22.5	13.5	63.0	45.0	27.0	126.0	90.0	54.0	42.0	30.0	18.0	84.0	60.0	36.0	168.0	120.0	72.0
	20.0	14.0	8.0	40.0	28.0	16.0	80.0	56.0	32.0	37.5	26.3	15.0	75.0	52.5	30.0	150.0	105.0	60.0	50.0	35.0	20.0	100.0	70.0	40.0	200.0	140.0	80.0
	23.2	16.0	8.8	46.4	32.0	17.6	92.8	64.0	35.2	43.5	30.0	16.5	**87.0**	60.0	**33.0**	174.0	120.0	66.0	58.0	40.0	22.0	**116.0**	80.0	44.0	**232.0**	160.0	88.0
2	6.8	5.0	3.2	13.6	10.0	6.4	27.2	20.0	12.8	12.8	9.4	6.0	25.5	18.8	12.0	51.0	37.5	24.0	17.0	12.5	8.0	34.0	25.0	16.0	68.0	50.0	32.0
	8.4	6.0	3.6	16.8	12.0	7.2	33.6	24.0	14.4	15.8	11.3	6.8	31.5	22.5	13.5	63.0	45.0	27.0	21.0	15.0	9.0	42.0	30.0	18.0	84.0	60.0	36.0
	10.0	7.0	4.0	20.0	14.0	8.0	40.0	28.0	16.0	18.8	13.1	7.5	37.5	26.3	15.0	75.0	52.5	30.0	25.0	17.5	10.0	50.0	35.0	20.0	100.0	70.0	40.0
	11.6	8.0	4.4	23.2	16.0	8.8	46.4	32.0	17.6	21.8	15.0	8.3	**43.5**	30.0	**16.5**	87.0	60.0	33.0	29.0	20.0	11.0	**58.0**	40.0	22.0	**116.0**	80.0	44.0
3	4.5	3.3	2.1	9.1	6.7	4.3	18.1	13.3	8.5	8.5	6.3	4.0	17.0	12.5	8.0	34.0	25.0	16.0	11.3	8.3	5.3	22.7	16.7	10.7	45.3	33.3	21.3
	5.6	4.0	2.4	11.2	8.0	4.8	22.4	16.0	9.6	10.5	7.5	4.5	21.0	15.0	9.0	42.0	30.0	18.0	14.0	10.0	6.0	28.0	20.0	12.0	56.0	40.0	24.0
	6.7	4.7	2.7	13.3	9.3	5.3	26.7	18.7	10.7	12.5	8.8	5.0	25.0	17.5	10.0	50.0	35.0	20.0	16.7	11.7	6.7	33.3	23.3	13.3	66.7	46.7	26.7
	7.7	5.3	2.9	15.5	10.7	5.9	30.9	21.3	11.7	14.5	10.0	5.5	29.0	20.0	11.0	58.0	40.0	22.0	19.3	13.3	7.3	38.7	26.7	14.7	77.3	53.3	29.3
4	3.4	2.5	1.6	6.8	5.0	3.2	13.6	10.0	6.4	6.4	4.7	3.0	12.8	9.4	6.0	25.5	18.8	12.0	8.5	6.3	4.0	17.0	12.5	8.0	34.0	25.0	16.0
	4.2	3.0	1.8	8.4	6.0	3.6	16.8	12.0	7.2	7.9	5.6	3.4	15.8	11.3	6.8	31.5	22.5	13.5	10.5	7.5	4.5	21.0	15.0	9.0	42.0	30.0	18.0
	5.0	3.5	2.0	10.0	7.0	4.0	20.0	14.0	8.0	9.4	6.6	3.8	18.8	13.1	7.5	37.5	26.3	15.0	12.5	8.8	5.0	25.0	17.5	10.0	50.0	35.0	20.0
	5.8	4.0	2.2	11.6	8.0	4.4	23.2	16.0	8.8	10.9	7.5	4.1	21.8	15.0	8.3	43.5	30.0	16.5	14.5	10.0	5.5	29.0	20.0	11.0	58.0	40.0	22.0

Wood fuel supply: quantitative model to predict forest area for annual consumption in AD 79.

Blue highlights show figures for a population of 20,000 people (intramural only), consuming 1 (or 2) tons of fuel/person/year at a ratio of 80% charcoal and 20% wood, assuming the least efficient charcoal production method (7 tons of wood to produce 1 ton of charcoal), and alternate forest productivity scenarios of 1 or 2 tons per hectare. Yellow and green highlights show figures for a population of 30,000 (15,000 inside and 15,000 outside the walls) consuming 1 ton/person/year, at a charcoal productivity level of 7, and a forest productivity of 1 (green) or 2 (yellow) tons per hectare; in this case the figures must be combined to provide total consumption for intra and extra-mural consumers. Beech constituted ca. 50% of the wood fuel supply in the 1st c. AD, and growing at least above 300m at the very minimum (for a population of 20,000), had to be supplied from the mid to upper montane areas in forests of 29,000 hectares (from a total of 58,000 hectares); or 116,000 hectares (from a total of 232,000 hectares), using the figures analysed above. Of the remaining 50% of the wood-fuel required, approximately half (namely the hornbeams and oaks) will have also likely come from the mountains, with only about 20-25% (being the orchard fruits and nuts) likely to have come from inside and just outside the city walls, or alternatively the lower montane slopes.

Data for the breakdown of (modern) Campania's altitudinal makeup are provided (Regione-Campania, 2007): *Modern* Campania[627] is made up of 1,359,025 hectares, consisting of:

15% 'plain' (199,216 hectares)

11% 'coastal hills' (154,568 hectares)

39% 'internal hills' (535,477 hectares)

35% 'mountains (469,763 hectares)

These figures relate to all of Campania, north and south, yet it is likely that the wood-fuel catchment area for Pompeii is limited to the southern half of the region, so we might consider that the southern slopes of Vesuvius, the parts of the Apennines directly east of the Sarno Valley and the northern slopes of the Lattari mountains would be of direct concern: i.e about half of the total 'mountain' area, or ca. 235,000 hectares. Now the figure estimates for forests have real relevance: total forest required for a population of 20,000, consuming 1 ton/head/year, and the lowest charcoal making and forest productivity rates was estimated to be 232,000 hectares, of which approximately 116,000 needed to be beech (however, a direct relationship between the proportions of the wood types in the charcoal assemblage and the environment cannot be assumed). In this scenario, it would appear nearly all of the available forested area would have been under management, and possibly even under pressure. The bringing of wood (from outside the delimited area) by ship from the Sorrentine peninsula may have occurred. Examining perhaps the more realistic population figures of 15,000 inside and 15,000 outside the city walls (where the differing proportions of charcoal for city and country dwellers are added together), and considering a higher rate of 2 tons/hectare productivity, still 60,000 total hectares are required, a far more manageable one-quarter of the montane forested area. More efficient rates of conversion to charcoal, or use of less charcoal, would mean much lower utilisation of potential forest. This is all predicated on this simple model having some moderate reliability, but there are a number of factors which have not been included here which will require consideration in the future (such as quality of charcoal, and volumes of same used in industrial vs domestic contexts).

[627] Modern Campania stretches north to south more or less in keeping with the ancient points on the Tyrrhenian coast; to the east however, it stretches all the way up to the apex of the central Apennines. For the purposes of this analysis, this is useful, since we want to consider the mountain slopes facing the Sarno Plain in their entirety as a possible supply source without regard in the first instance to limitations of political or other restrictions.

Addendum 3: Figures and Pictures

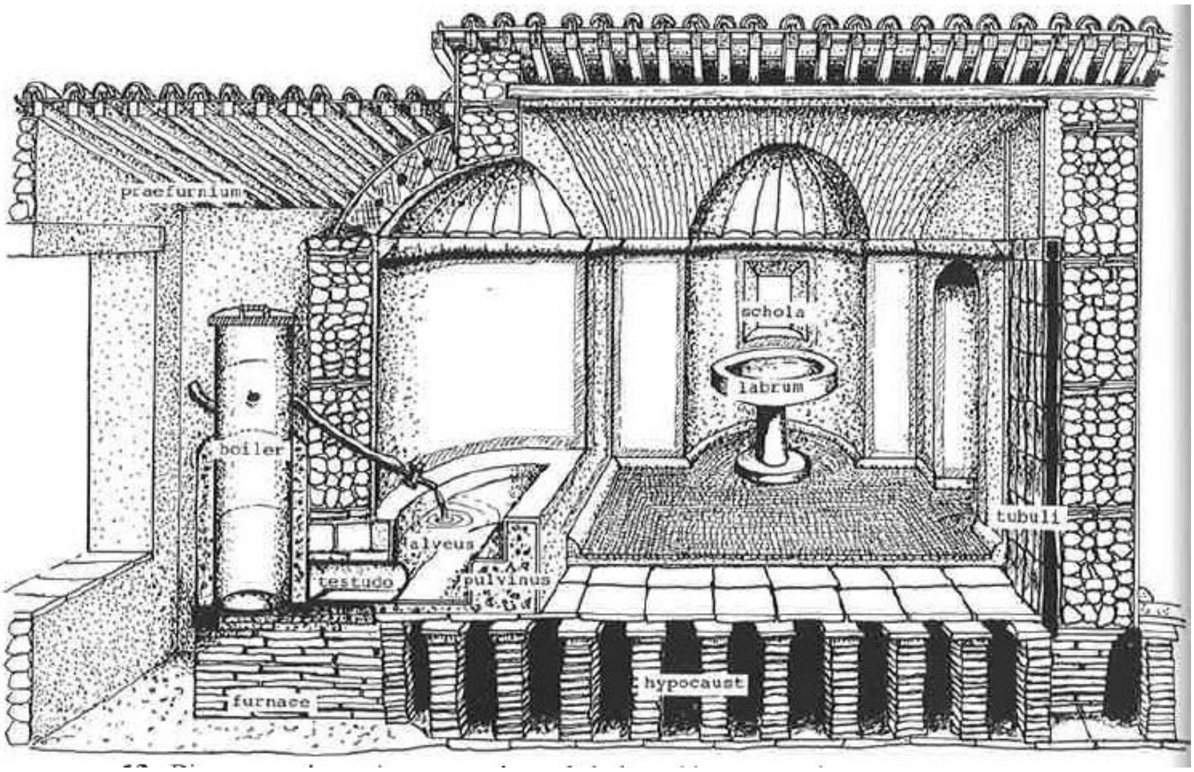


Figure A. Hypocaust system found in Rook (1992) p 24

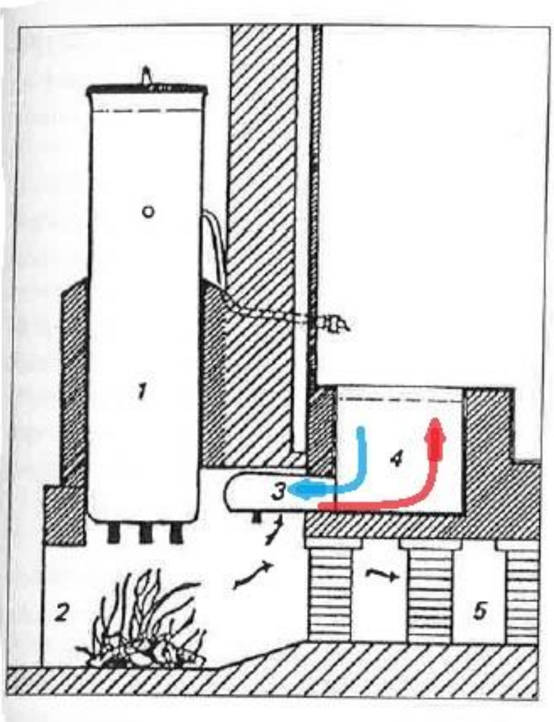
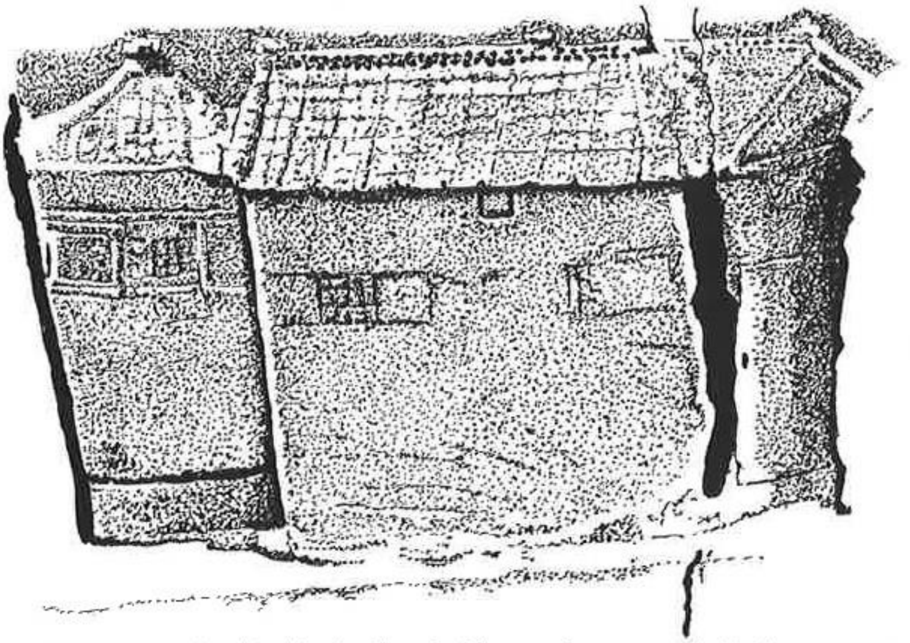


Abb. 44: Funktionsdarstellung des Feuerungs- und Rauchgasweges nach Krell (in Abänderung von Mau)
1 - Wassererwärmer
2 - Präfurnium (Heizraum)
3 - Testudo
4 - Warmwasserbecken
5 - Feuerungsraum (nach Krell nicht wirksames Hypokaustum).

Figure B. Functioning of a hypocaust according to Krell (found in Schiebold p 69) with my addition of water flow inside a testudo/alveus



22. The baths depicted inside the Simpelveldt sarcophagus, now in Leiden museum, Holland. The *caldarium* would be on the left. There are windows with shutters and a small vent high up under the eaves.

Figure C. Found in Rook (1992) p 32

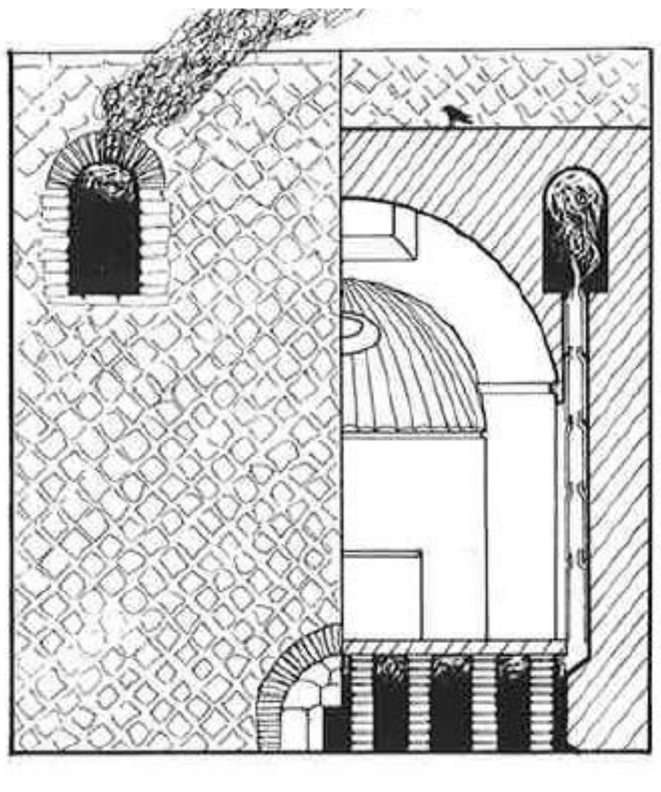


Figure D. The chimney-flues at Herculaneum, found in Rook (1992) p 30

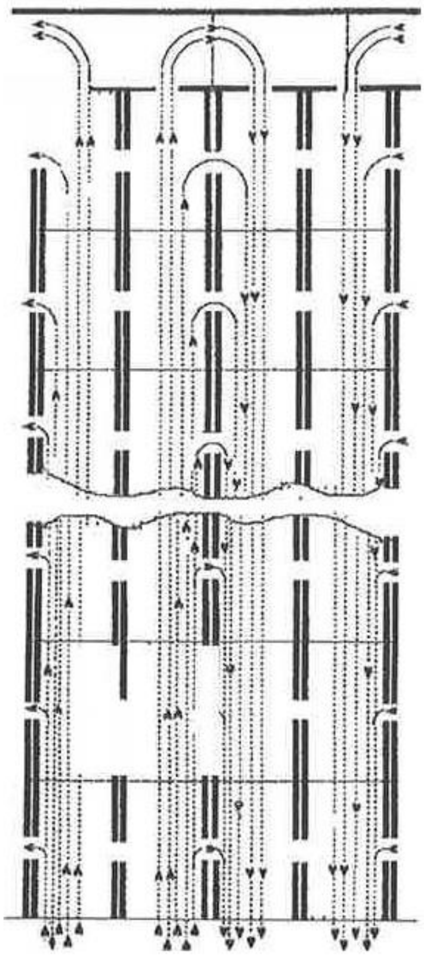


Figure E. Grassmann's flow of gas in the tubuli (BAR 2011; fig26)

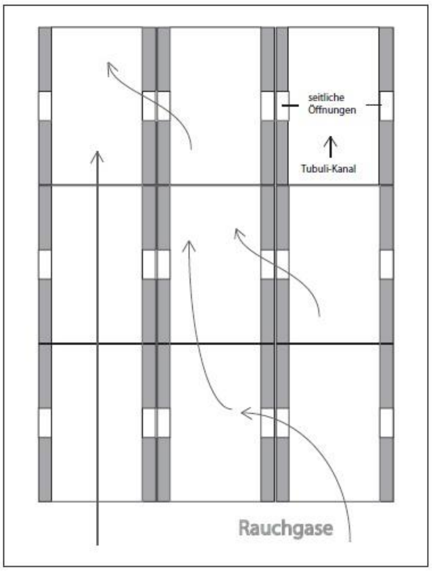


Figure F. Reichel's flow of gas in the tubuli (Reichel 2007, fig 2)

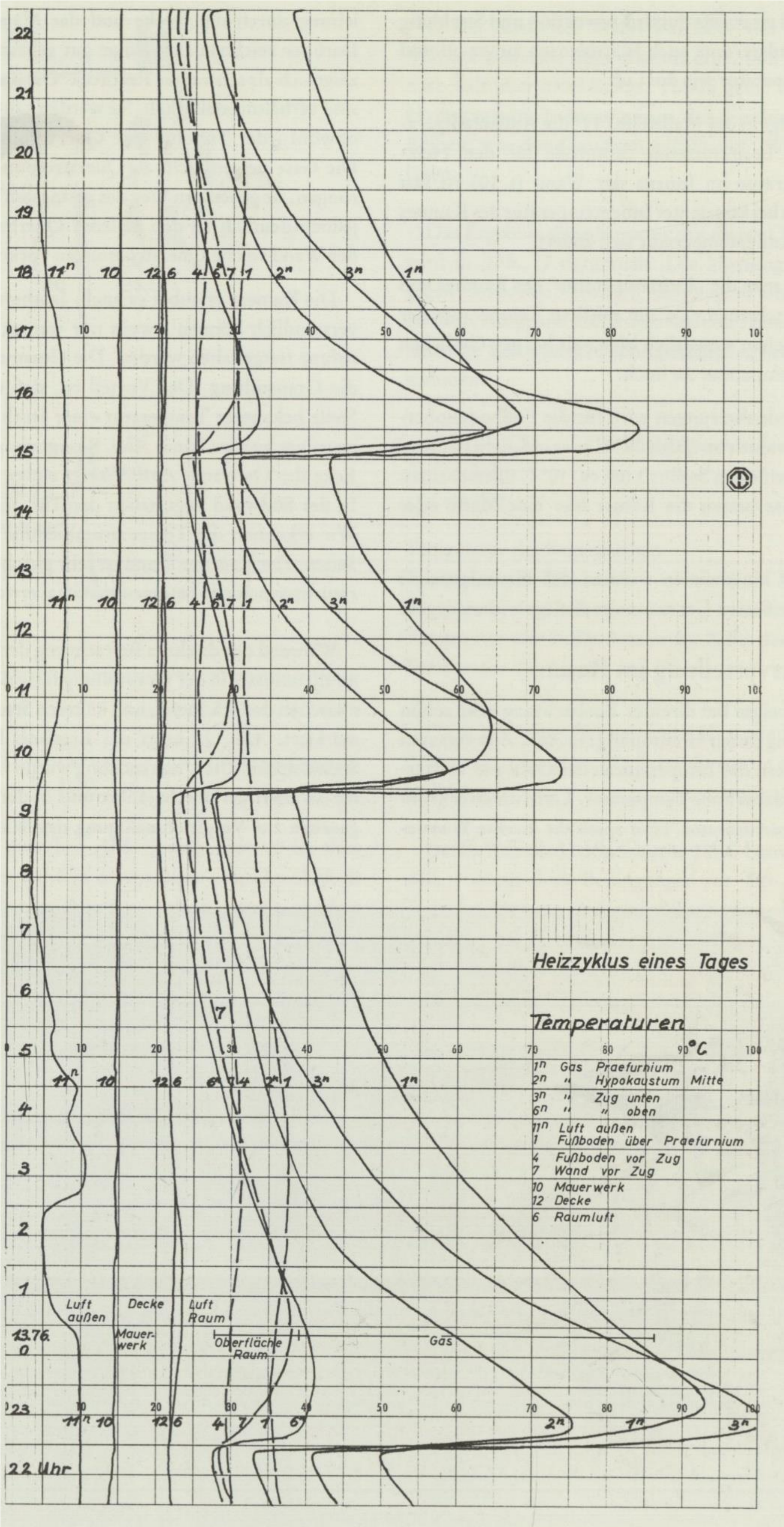


Figure G. Proceedings of a day of firing in the Saalburg hypocaust. From Hüser1979 p 17

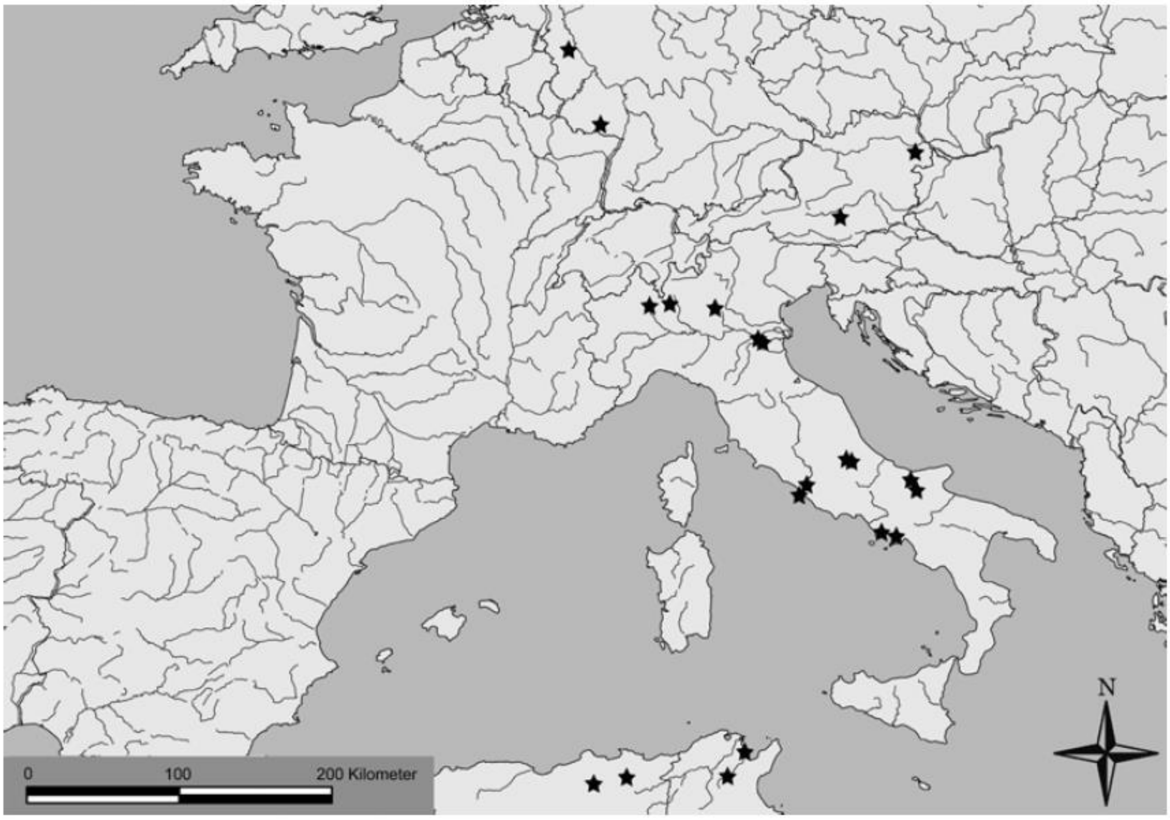


Figure H Distribution of the twenty four inscriptions of the saltuarii by Visser (2010) p 16

Addendum 4: Heat balance summaries

Heat balance for the Xanten ‘Herbergsthermen’, from Grassmann 2011

	Sommerversuch	Winterversuch
T_i	36.7°C	31.2°C
T_a	20.8°C	01.9 °C
$(T_i - T_a)$	15.9°C	29.3°C
V^*_{heiz}	2.774 Nm³/kg	2.774 Nm³/kg
G_{Holz}	63 kg	102 kg
Lambda	12	12
Q_{Abluft}	500 W	1492 W

Verbraucher	Wärmebedarf in W und in % Sommerversuch		Wärmebedarf in W und in % Winterversuch	
Heizraum	954	12.3	1802	15.0
Caldarium	419	31.3	4016	33.4
Tepidarium	2597	07.7	956	08.0
Lüftungswärme	1305	16.9	631	05.3
Kesselwassererwärmung	1148	14.8	1860	15.5
Alveuswassererwärmung	457	05.9	683	05.7
Feuerstellenverluste	352	04.6	570	04.7
Wärmebedarf Q_{ges}	7232	93.5	10518	87.6
Abluftverluste Q_{Abluft}	500	06.5	1492	12.4
Gesamter Wärmebedarf Q	**7732**	**100.0**	**12010**	**100.0**

Tabelle 2: Gesamtwärmebedarf, Herbergsthermen Xanten

Heat balance for the 'NOVA baths' at Sardes, from Yegül 2003

MEAN TEMPERATURE	
Outdoor	15.6°C
Caldarium	35.0°C
Tepidarium	26.5°C
Frigidarium	21.0°C
DIMENSIONS	
Thicknesses	
Floor	0.22 m
Mid *tubuli* to outdoor	0.44 m
Mid *tubuli* to indoor	0.06 m
Roof	0.40 m
Ext. wall unheated	0.44 m
Caldarium	
Floor length	3.00 m
Floor width	3.00 m
Wall height	3.00 m
Volume	37.6 m^3
Heated wall area	25.0 m^2
Heated area	34.0 m^2
Unheated wall area	22.0 m^2
Glazed area	1.5 m^2
Roof area	14.1 m^2
Door to *tepidarium*	2.0 m^2
Tepidarium	
Floor length	3.00 m
Floor width	2.00 m
Wall height	3.00 m
Volume	25.1 m^3
Heated wall area	7.0 m^2
Heated area	13.0 m^2
Unheated wall area	15.0 m^2
Unheated wall to *frigidarium*	4.0 m^2
Glazed area	1.5 m^2
Roof area	9.4 m^2
Door to *frigidarium*	2.0 m^2
Frigidarium	
Floor length	5.60 m
Floor width	3.20 m
Wall height	3.00 m
Volume	76.3 m^3
Unheated wall area	34.0 m^2
Heated wall from *caldarium*	9.0 m^2
Glazed area	1.5 m^2
Roof area	28.1 m^2
Door	2.0 m^2
VENTILATION	
Air changes/h *caldarium*	0.30
Air changes/h *tepidarium*	0.40
Air changes/h *frigidarium*	2.00
THERMAL DATA	
Thermal conductivity of stone	0.84 $W/m^2 \cdot K$
Radiant heat transfer coefficient	6.00 W/m^2K
U-values	
Sub-floor to floor surface	2.76 W/m^2K
Sub-floor to internal air	2.08 W/m^2K
Sub-floor to outdoor	0.78 W/m^2K
Mid-wall to outdoor	1.46 W/m^2K
Mid-wall to indoor wall surface	5.22 W/m^2K
Mid-wall to indoor air	3.21 W/m^2K
Roof	1.62 W/m^2K
Wall unheated	1.46 W/m^2K
Glass	6.00 W/m^2K
Door	4.00 W/m^2K

HEAT BALANCE		
Frigidarium		
Glazing	49 W	
Roof fabric loss	247 W	
Unheated wall	268 W	
Floor	75 W	
Door	43 W	
Ventilation loss	275 W	
Subtotal		**957 W**
Tepidarium		
Glazing	98 W	
Roof fabric loss	167 W	
Unheated wall	239 W	
Hypocaust floor to external	124 W	
Ventilation loss	36 W	
Subtotal		**664 W**
Caldarium		
Glazing	175 W	
Roof fabric loss	445 W	
Unheated wall	624 W	
Heated wall to external	501 W	
Hypocaust floor to external	292 W	
Ventilation loss	73 W	
Subtotal		**2109 W**
Caldarium		
Percentage heat from floor	0.26%	
Wall surface temperature	41.50°C	
Floor surface temperature	40.70°C	
Mid-wall temperature	53.64°C	
Sub-floor temperature	57.18°C	
Heat flow into bath from *caldarium* W wall	351 W	
Heat flow sub floor to *caldarium*	308 W	
Heat flow sub floor to *tepidarium*	150 W	
Heat gain from *caldarium* door	102 W	
Heat gain from *caldarium* ventilation	238 W	
Heat from floor/wall	324 W	
Percentage heat from floor	0.46%	
Wall surface temperature	30.65°C	
Floor surface temperature	30.65°C	
Sub-floor temp	42.66°C	
Hot water cylinder		
Heat loss		**734 W**
Heat loss from furnace		
Heat loss		**250 W**
TOTAL HEAT LOSS		**4714 kW**

Heat balance figure from the Phaselis baths, Basaran and Ilken 1998

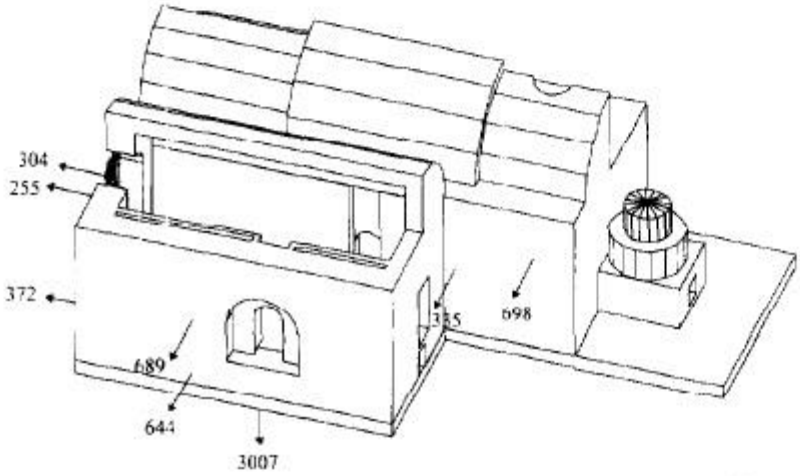


Fig. 2. Heat loss from different parts of the bath (in watts) on the tepidarium side).

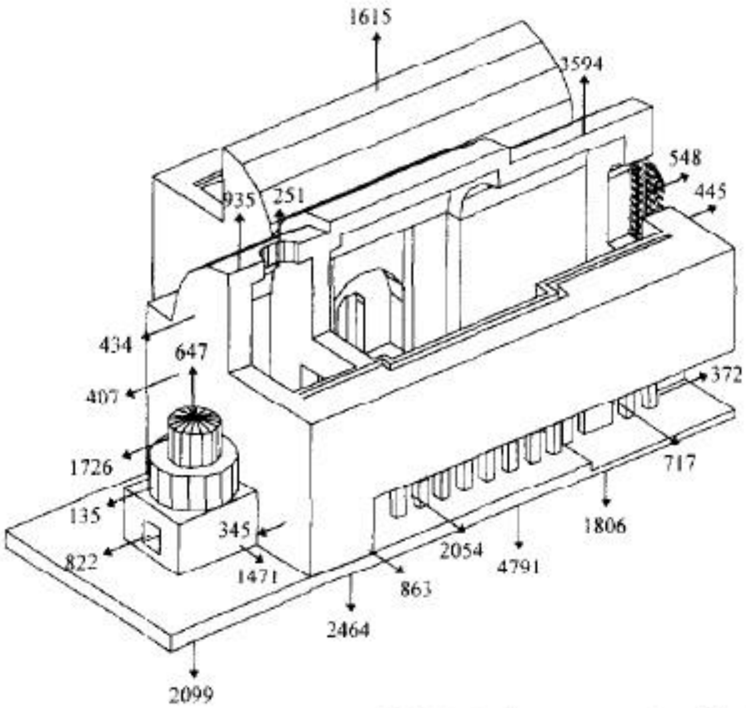


Fig. 3. Heat loss from different parts of the bath (in watts) on the caldarium side).

Addendum 5: Table of different calorific values of the fuels listed in section 3

Fuel source	Calorific Value
Dry fuelwood (15% water)	4000 – 4400 kcal / kg (14-18MJ/kg)
Charcoal	6500-7500 kcal / kg
Green wood (60% water)	2600 - 2900 kcal / kg
Straw (or chaff) briquettes	2866 – 3416 kcal/ kg (12-14.3 MJ/kg)
Olive pits	4927 kcal/kg (20,629 MJ/kg)
Bones	1500 kcal/kg
Coal	7800 – 8700 kcal / kg

Sources: Dry fuelwood: Wilson (2012), p 149; Yegül (2003); Charcoal: Olson (1991), p 412; Green wood: Costamagno, S. et al (2005), p 51; Straw: Jasinkas et al. (2011)