Fuel and Fire in the Ancient Roman World
Towards an integrated economic understanding
Edited by Robyn Veal & Victoria Leitch
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with contributions from
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This book, and the conference upon which it was based, were funded by: the Oxford Roman Economy Project (OxREP), University of Oxford; a private contribution from Jim Ball (former FAO forestry director, and Commonwealth forests director); the British School at Rome; and the Finnish Institute of Rome. The editors would also like to acknowledge the support of the McDonald Institute for Archaeological Research, and the Department of Archaeology (University of Sydney).
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Preface

This book arises from a conference held at the British School at Rome, and the Finnish Institute in Rome, in March 2013, entitled Fuel and Fire in the Ancient Roman World. The conference represented the first real attempt to try to bridge the gap between ‘top-down’ generalized models about Roman energy consumption (itself, still a relatively new area of research), and research carried out by artefact and environmental specialists. In many ways it exceeded our expectations, although it probably raised more questions than it answered. As fuel is used in many different domestic and industrial contexts, the papers were very heterogeneous; some presenters came from a strong archaeobotanical background, which is a central area for fuel research, while others came from social, technical and economic spheres, opening up the discussion beyond archaeobotany. Some papers presented more ‘qualitative’ rather than ‘quantitative’ results but, as a new research area, this was inevitable and qualitative evaluation can provide the framework for approaching quantitative studies. Nevertheless, useful quantitative beginnings are proposed in a number of papers. Although focused on the Roman period, the research often extended beyond this chronological span, to help contextualize the results.

We gratefully acknowledge the support and assistance of the British School at Rome and the Institutum Romanum Finlandiae (Finnish Institute of Rome). In particular we thank Professor Katarina Mustakallio, then director of the IRF, for generously hosting the conference lunch on the final day. The financial support of the Oxford Roman Economy Project, through Professor Andrew Wilson, and a significant private donation from Mr Jim Ball, former Commonwealth Forests Chairman (administered through the BSR Rickman Fund) allowed speakers’ travel, accommodation and subsistence costs to be covered, as well as a contribution towards publication costs. Professor Wilson and Mr Ball both provided much appreciated moral support and intellectual input, acting as our major discussants. The McDonald Institute for Archaeological Research, through its Conversations series, also helped fund publication. Professor Graeme Barker (McDonald Institute director to September 2014), Professor Cyprian Broodbank (current director), Dr James Barrett (current deputy director) and Dr Simon Stoddart (former acting deputy director) all provided advice and guidance over time. This was much appreciated. Dora Kemp provided initial advice on manuscript preparation, and after her untimely death, Ben Plumridge took over the practical side of production. Maria Rosaria Vairo, then a Masters student of the University of Lecce, and Dana Challinor, a doctoral student at the University of Oxford, provided significant voluntary support during the conference and we thank them both profusely. Robyn Veal would also like to acknowledge the long-term financial and intellectual support of the Department of Archaeology, University of Sydney, through much of her early work on fuel. This led to the opportunity of a fellowship at the BSR, and the idea for this conference. The feedback from reviewers has greatly improved the book.

Robyn Veal & Victoria Leitch
Chapter 4

Throwing money out the window: fuel in the Forum Baths at Ostia

Ismini Miliaresis

The public baths of the ancient Roman world provide a window into many aspects of Roman life. They served as venues for cleansing, as gathering places, and as inspiration for technological innovations. Baths were frequented daily, and the operation of these facilities impacted both the local surroundings and the greater environment. They varied in size and importance, and some were paid for, and operated, using Imperial funds. The Forum Baths at Ostia, near Rome, are an excellent example of an ancient Roman Imperial bathing complex. Regular and rectangular in their northern sector, the baths contain unique and polygonal rooms in their southern sector. Most of the heated rooms are equipped with grandiose windows facing southwest, several metres high. This study examines the nature of these openings and demonstrates the effect that they had on the consumption of energy in the baths by using a combination of archaeological evidence, ancient literary sources and modern heat-transfer equations.

The Windows of the Forum Baths at Ostia

The Forum Baths at Ostia (Fig. 4.1) are generally accepted as Antonine (AD 138–192), and they probably remained in use until the sixth century. DeLaine (2002, 49) calls them the ‘largest and most sophisticated Ostian building of the second century AD’. Their location next to the Forum enhanced their importance, and their elaborate and opulent decor speaks of their stature within the city. The facility was refurbished many times throughout the centuries, particularly in the Severan period (AD 193–235) and in the fourth century (Cicerchia & Marinucci 1992, 135–9; Poccardi 2001, 164). Excavations began at the baths in 1920 under the direction of Guido Calza, but the site had already been plundered for building material and precious objects.

Panels of glass for windows first came into use during the reign of Augustus, and window glass became especially popular in the high empire. Sheets of glass that completely fill window spaces are a modern invention. Glass panes were composed of smaller panes that were mounted in windows using either mortar or frames made of wood, stone or metal. Large openings in the Forum Baths were added in the fourth century AD restorations to the heliocaminus (Room 15), the sauna (Room 16), the two tepidaria on the southern end of the baths (Rooms 17 and 18), and the caldarium (Room 19), but it is unclear if similar windows were present in the earlier facility.

The characteristics of these windows have been debated over time, beginning with Thatcher (1956, 170–3). He found no evidence of glazing in situ and, unable to accept that glazing could have been present without leaving some trace, he concluded that glass must have always been absent. However, lack of evidence is not proof, and we know that little attention was paid to stratigraphy or small finds in early excavations. Thatcher mentions that enough heat could have been generated to keep the rooms with large unglazed windows at the desired temperatures by having very high temperatures in the floors, and by heating the vaults. Heating the baths to such high temperatures would have consumed more fuel, and there is no evidence in situ that the vaults were heated; however, Thatcher’s work on the structure and layout of the baths remains valuable.

Meiggs (1973, 414 n. 2) politely refutes Thatcher’s approach. He points out that the frames for the glass panes could have been wooden, leaving no record. Other scholars have also questioned Thatcher’s theories on the windows of the Forum Baths (Broise 1991, 76–7; Nielsen 1990, 17–18 n. 41; Yegül 1992, 382–3). Leaving the windows unglazed would have wasted a tremendous amount of fuel.

The effects of glazing windows or leaving them open can be understood only through a scientific heat
Room 16 (Fig. 4.3) has been identified as a sauna, either a laconicum or a sudatorium, making it the hottest room of the baths. Minimizing heat loss from this room would have been important. In fact, although Room 16 has been identified as having a large window because of the presence of a column base on its outer wall, I am not convinced that the current configuration of this window is correct, or that a large window was present in this room at all. Early excavation photographs do not show the column base in situ, and later photos show an entire column reconstructed on the damaged wall (Cicerchia & Marinucci 1992, 36, fig. 41, 111). Currently there is only a column base in the same location, casting doubt on the entire reconstruction. Under this reconstruction, this window would have been the largest in the entire bathing facility.

The evidence for large openings in Rooms 17, 18, and 19 is more convincing, although these walls were damaged as well. Rooms 17 (Fig. 4.4) and 18 (Fig. 4.5) have been identified as warm rooms, or tepidaria; Room 19 has been identified as a hot room, or caldarium. The window in Room 17 is formed by two Corinthian columns on a curved wall, which is also a later addition.

Figure 4.1. Plan of the modern remains of the Forum Baths at Ostia (I. Miliaresis).
Figure 4.2. Plan of the modern remains of Room 15 (I. Miliareis).

Figure 4.3. Plan of the modern remains of Room 16 (I. Miliareis).

Figure 4.4. Plan of the modern remains of Room 17 (I. Miliareis).

Figure 4.5. Plan of the modern remains of Room 18 (I. Miliareis).

Figure 4.6. Plan of the modern remains of Room 19 (I. Miliareis).
There is no evidence of window frames abutting these columns, making it difficult to draw any conclusions, although Broise (1991, 76–7) finds the evidence for glazing of the windows in Rooms 18 and 19 (Fig. 4.6) irrefutable. The opening in Room 18 is 5.53 m wide in total, and approximately 5 m tall. The double row of holes found along the interior of the Preconnesian marble pilasters demonstrates to Broise that a double-glazed window was supported in this space.10 Thatcher (1956, 209) instead contends that an ornamental grille was secured by the outer holes, while a movable frame was secured by the inner holes.

A problem must be noted with all the arguments concerning the glazing of Room 18: only one pilaster with its capital, a second capital, part of the architrave, and the cornice were actually recovered at the site. The second pilaster was not found. Moreover, the rectangular capitals of the pilasters were decorated with a marine motif, convincing Cicerchia & Marinucci (1992, 37–8), that these pilasters may actually be part of a modern reconstruction.11 Calza (1930, 297–8, 301 fig. 13) mentions that only restoring one of the pillars and the associated fragments of architrave and cornice was the better and more scientific option rather than recreating the missing elements in concrete. On-site inspection today, however, illustrates that the second pilaster was reconstructed at a later date. The accuracy of this reconstruction and the holes in the two pillars that appear to align perfectly cannot be accepted, due to the tenuous nature of the evidence.

The tripartite window was added to Room 19 in the fourth century AD, according to Broise. The opening is divided by two Corinthian columns and spans a total width of 6.73 m and a height of approximately 5.8 m. Roughly square holes can be seen on the columns, along with traces of mortar on the eastern side of the eastern column. Broise (1991, 74, 76–7, 78) interprets these elements as evidence of a claustra, or window screen, similar to one reconstructed at Bosra in the fourth century AD.12 These columns are unlike any other found in the Forum Baths, both in marble type and size. This variation may be due to the late date of their installation, when large portions of the baths were refurbished using spoliated material. The holes and traces of mortar could be attributed to an earlier function of the columns, rather than attesting to the presence of window glazing. There is another opening on the west side window of the pool in Room 19, also without any clear evidence of glazing.

The effects of window glazing

Using in situ structural remains alone to conclude that the windows of the Forum Baths were glazed is difficult, as has been reviewed. A useful research approach is therefore to determine scientifically the relative effects of having open vs glazed windows. Windows are very complex moderators of inside temperature, since they are subject to direct, diffuse and reflected heat radiation from the sun, and to heat loss through ventilation, infiltration and conduction. Certain aspects of function must be surmised.13 Sunlight is an economical way to light and heat rooms, particularly in the Mediterranean, and open windows allow the maximum amount of solar radiation to enter. With completely open windows, however, heat is lost through ventilation. Ventilation refers to air that enters or exits a space, and it is dependent on the temperature difference between the room and the outside.14

Glazed windows would have prevented a lot of heat loss, although some heat would still have been lost from improperly sealed junctures between the glass, the frames and the walls. Also, heat is transmitted through glass.15 The amount of heat exchange depends on the thickness and the translucency of the glass. Although window glass was not recovered from the Forum Baths, extant glass panes have been found in other bathing facilities, e.g. the Suburban Baths at Herculaneum and the baths at Lepcis Magna and Perge.16 From these data, the glass used in the Ostian baths is assumed to have been approximately 3 mm in thickness.

Glass clarity also affects heat exchange. However, determining the clarity of Roman glass is problematic, since glass fragments in the archaeological record are often iridescent, opaque or greenish in tint.17 Some of this clouding is due to post-depositional oxidation, although most scholars agree that Roman glass was not as clear as modern glass18 (and see Cool, this volume). Seneca (Ep. 86.11; 90.25) complains about more modern baths by describing windows that were transparent, causing people to ‘roast in the strong sunlight’. Pliny the Younger (Ep. 2.17.11) also describes a scene of swimmers bathing in a pool in the private bath of a country villa. The bathers are able to view the sea through the windows from the pool, which Pliny specifically mentions is heated. These descriptions do not clarify if there was glass in the windows or what ‘transparent’ meant to ancient people. For the sake of simplifying comparative calculations in this study, the glass in the Forum Baths is assumed to have been clear.

Other window configurations have also been reconstructed for the Forum Baths at Ostia. For example, Connolly & Dodge (1998, 244) contend that the windows of the Forum Baths were double-glazed, but evidence is lacking. The existence of double-glazed windows in the excavations of the Suburban Baths of Herculaneum is attested (Pappalardo 1999, 237–8). Pappalardo discovered that the windows of the caldarium...
were closed with two fixed wooden frames, set 10 cm apart. Double-glazed windows separated by a heated space of 10 cm have also been suggested in the Baths of Neptune at Ostia, by Broise (1991, 62–3, 64–5, 69). Since such evidence exists in nearby contexts, it is useful to test the effects of double glazing on the heated rooms of the Forum Baths to provide a complete spectrum of possibilities.

Another scenario worthy of consideration is the possibility of windows being kept partially open with a composite pane of glass. Broise postulates that at least the lower parts of the windows in the Forum Baths could be opened to allow for an outdoor view and for ventilation. Glass panes that could be opened and closed according to the weather and the desires of the bathers would have been ideal, but no evidence exists in situ to support such a reconstruction. Testing every possible dimension for a partial opening would be unnecessarily tedious, while testing a half-open window adds an extra scenario to the study.

A final way of reducing heat loss with or without using glass was to add wooden shutters to the windows. Shutters would have decreased the heat lost from open windows through ventilation, although they also would have eliminated much of the heat gain through solar radiation. Closing them on days of inclement weather may have made a significant difference, and at the very least would have helped keep precipitation out. When used in conjunction with glazed windows, they would have protected the glass during stormy weather or from intruders at night, and they would have provided shade in rooms if they got too hot in the summer months. There is no evidence of any shutters in the Forum Bath windows, but such an arrangement can be seen on the windows of the frigidarium in the nearby Terme del Invidioso: travertine consoles with round depressions in them for holding the metal hinges of shutters are located immediately outside the opening. The effects of having shutters on the windows of the Forum Baths are therefore included in this study.

**Heat study method and initial results**

As part of this study, I have modelled the manner in which heat moved throughout the fabric of the Roman baths using data that included the necessary components of the baths and the appropriate heat transfer equations. This approach has allowed variations to certain factors, like temperature or time of day, in order to understand how these permutations affected the heating system.

To deduce the difference in energy consumption from having windows that are completely open vs windows that are closed in some way, the various scenarios described above were tested using this model. In this chapter I focus only on Room 18 for the sake of brevity. Room 18 is a tepidarium, and the temperature difference between the air in this room and the outside is less extreme than in the caldarium or sauna. Therefore, the effect of having unglazed windows was less severe than it would have been in the hotter rooms, where all the results would have been magnified. The ancient outside temperatures and the temperature sustained within the tepidarium are not easily determined, but logical values were selected for this study based on a combination of factors: ancient literary sources, modern experimental results and comparative evidence from similar types of facilities.

For the average outside temperature at Ostia, 16.67 °C was selected for May/October, 8.06 °C for January and 23.33 °C for August; 28.00 °C was selected as the temperature for the air of the tepidarium. Even if these values do not match exactly those of antiquity, (and some assumptions have to be made concerning the fabric of the windows), the comparative nature of this study still demonstrates the difference in energy necessary to operate the baths under the permutations described. In this way, the relative effects of each scenario can be demonstrated.

Room 18 was tested under six different conditions: (1) windows with no glass; (2) windows with clear 3 mm thick glass; (3) windows with two panes of clear 3 mm thick glass with a space of 10 cm in between (double-glazing); (4) windows partially (half) covered with 3 mm thick glass; (5) windows with no glass, but with slatted shutters covering them; (6) and windows with clear 3 mm thick glass, and with slatted shutters covering them.

The initial results of this heat study produce some expected and some surprising results. Computations show that having clear glass rather than completely open windows only reduces the amount of solar radiation that enters a room by 14 per cent. Having tinted glass reduces the value by 26 per cent. Roman glass was probably somewhere in between in opaqueness; therefore, it is concluded that having glass in the windows did not significantly reduce the amount of solar radiation entering the room. Furthermore, on a clear day, solar radiation contributed a great deal of energy to the rooms, with or without glass. Surprisingly, more solar radiation entered the windows of the Forum Baths at noon in January than at any other time. This effect is due to the angle of the sun with respect to the vertical windows. In fact, calculations demonstrate that there was enough energy from the sun entering Room 18 at noon (73,161 kJ per hour gained) to offset completely the effects of ventilation through the open windows (48,216 kJ per hour lost).
Was Thatcher right after all? Could heated rooms have large open windows without the temperature of the room dropping too much, even in winter? The answer is not that simple. The values expressed above are designed for a completely cloudless day, but there were probably not many pristine days in January, and some days were probably stormy and blustery. With the amount of solar radiation dramatically reduced, the heat lost through the open windows may not have been offset enough. More specific tests are necessary to evaluate Thatcher’s theory further.

Table 4.1. Room 18 with unglazed windows. (Shading illustrates hours of the day when sunlight would have been enough to compensate for heat lost.)

<table>
<thead>
<tr>
<th>Time</th>
<th>May/October</th>
<th>January</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:00 a.m.</td>
<td>-5997.24</td>
<td>-5997</td>
<td>-21590</td>
</tr>
<tr>
<td>7:00 a.m.</td>
<td>-5997.24</td>
<td>-4999</td>
<td>-16195</td>
</tr>
<tr>
<td>8:00 a.m.</td>
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</tr>
<tr>
<td>9:00 a.m.</td>
<td>8423.83</td>
<td>2427</td>
<td>8736</td>
</tr>
<tr>
<td>10:00 a.m.</td>
<td>11204.47</td>
<td>5207</td>
<td>18746</td>
</tr>
<tr>
<td>11:00 a.m.</td>
<td>13075.18</td>
<td>7078</td>
<td>25481</td>
</tr>
<tr>
<td>12:00 p.m.</td>
<td>13705.19</td>
<td>7708</td>
<td>27749</td>
</tr>
<tr>
<td>1:00 p.m.</td>
<td>13075.18</td>
<td>7078</td>
<td>25481</td>
</tr>
<tr>
<td>2:00 p.m.</td>
<td>11204.47</td>
<td>5207</td>
<td>18746</td>
</tr>
<tr>
<td>3:00 p.m.</td>
<td>8423.83</td>
<td>2427</td>
<td>8736</td>
</tr>
<tr>
<td>4:00 p.m.</td>
<td>4995.08</td>
<td>-1002</td>
<td>-3608</td>
</tr>
<tr>
<td>5:00 p.m.</td>
<td>1498.55</td>
<td>-4999</td>
<td>-16195</td>
</tr>
<tr>
<td>6:00 p.m.</td>
<td>0.00</td>
<td>-5997.24</td>
<td>-5997</td>
</tr>
</tbody>
</table>

Time of day and ‘no glazing’ vs ‘glazing’

Time of day is an important factor that must be considered for each season. Martial (Epig. 10.48) proclaims that the best time for bathing is the eighth hour of the day, which corresponds to approximately two or three o’clock in the afternoon. The Roman day was composed of two twelve-hour segments: the first began at sunrise and ended at sunset, and the second began at sunset and ended at sunrise. The length of each 12-hour period varied depending on the season and the hours of sunrise and sunset.25 For the purposes of...
it is assumed that the baths were open to the public between 7 a.m. and 5 p.m., and there was no change in hours by glazing the windows. The hours in January would vary open at different hours in each season, as Pliny the Younger suggests (Ep. 3.1.8), it is unlikely that they were only open between 9 a.m. and 3 p.m. in January. In fact, a contract concerning the management of a small bath from the mining town of Vipascum, in modern Portugal, mentions that the baths would have to operate every day between sunrise and the seventh hour (12–1 p.m.) for women, and between the eighth hour (1–2.30 p.m.) and sunset for men.²⁶ If it is assumed that the baths were open to the public in January from a little after sunrise to a little before sunset, it can be surmised that they opened at 8 a.m. and closed by 5 p.m. These additional hours would have been especially useful in winter, when many bathers may have flocked to the baths simply to warm up. Some heat would have been stored in the building fabric of the baths, but the Romans did not have solar panels to save the energy generated through solar radiation to be used as desired. Therefore, rather than comparing a daily value of heat lost and gained through unglazed and glazed windows in January, it is more useful to directly compare each hour between 8 a.m. and 5 p.m. on a completely cloudless day: at 8 a.m., 4 p.m. and 5 p.m., heat is lost from the unglazed windows of Room 18 that is not compensated for by solar radiation (21,530 kJ per hour, 21,530 kJ per hour and 48,216 kJ per hour, respectively) (Table 4.3). These quantities are equivalent to a total of approximately 3.5 kg of ash wood for these three hours.²⁷ Heat is only lost from the glazed windows (for which there is no compensation) at 5 p.m. (12,504 kJ per hour), which is equivalent to approximately 0.6 kg of ash wood. This difference in necessary fuel is significant considering that it would have been incurred every day during the winter months. Also, most of the solar radiation comes from direct sunlight, which would be drastically reduced on a very overcast day. Assuming conservatively that half of the heat energy from the sun would be lost on a cloudy day, then this would result in heat being lost without solar compensation (at all hours of the day) through unglazed windows; there would still be an overall positive heat contribution to Room 18 between 9 a.m. and 3 p.m. with glazed windows.

<table>
<thead>
<tr>
<th>Time</th>
<th>January unglazed</th>
<th>January glazed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contr. J/S</td>
<td>Cond. J/S</td>
</tr>
<tr>
<td>6:00 a.m.</td>
<td>0.00</td>
<td>-13393.20</td>
</tr>
<tr>
<td>7:00 a.m.</td>
<td>0.00</td>
<td>-13393.20</td>
</tr>
<tr>
<td>8:00 a.m.</td>
<td>3706.37</td>
<td>-13393.20</td>
</tr>
<tr>
<td>9:00 a.m.</td>
<td>7050.93</td>
<td>-13393.20</td>
</tr>
<tr>
<td>10:00 a.m.</td>
<td>9087.80</td>
<td>-13393.20</td>
</tr>
<tr>
<td>11:00 a.m.</td>
<td>10161.20</td>
<td>-13393.20</td>
</tr>
<tr>
<td>12:00 p.m.</td>
<td>10541.84</td>
<td>-13393.20</td>
</tr>
<tr>
<td>01:00 p.m.</td>
<td>10161.20</td>
<td>-13393.20</td>
</tr>
<tr>
<td>02:00 p.m.</td>
<td>9087.80</td>
<td>-13393.20</td>
</tr>
<tr>
<td>03:00 p.m.</td>
<td>7050.93</td>
<td>-13393.20</td>
</tr>
<tr>
<td>04:00 p.m.</td>
<td>3706.37</td>
<td>-13393.20</td>
</tr>
<tr>
<td>05:00 p.m.</td>
<td>0.00</td>
<td>-13393.20</td>
</tr>
<tr>
<td>06:00 p.m.</td>
<td>0.00</td>
<td>-13393.20</td>
</tr>
</tbody>
</table>
The total amount of fuel needed to compensate for the net heat loss for each hour between 8 a.m. and 5 p.m. is approximately 11.4 kg of ash wood for unglazed windows and approximately 0.7 kg of ash wood for glazed windows. These results demonstrate that glazing windows, rather than leaving them completely open to the air, would have always conserved fuel.

**Partially open**
The ideal scenario for having windows in a heated bathing room is to have units that can be opened or closed as necessary. If there is inclement weather outside, the windows can be closed; if there is too much sunlight streaming in on a summer day, the windows can be opened to allow some of the heat to escape and cool breezes to come in. There is no evidence to support the presence of windows with apertures that could be altered at the Forum Baths, but Pliny the Younger (*Ep. 2.17.16*) describes the windows of a cryptoporticus that could be manipulated to block the wind from particular directions on stormy days. He states that on nice days the windows were left completely open. Whether these openings were blocked with glass, or just shutters, is not clear. Assuming that adjustable glazed windows did exist in Roman facilities, it is useful to add this scenario to the study.

A further option of a window that cannot be manipulated but is always partly open is also tested here. In this case, the window functions as two separate segments: an unglazed opening and a glazed one. The amount of ventilation and conduction experienced through this window would have varied with the width of the aperture; for the sake of simplicity, the window is tested as being half way open.

The results shown in Table 4.5 logically indicate that having a window in Room 18 that is halfway open to the air would produce gains and losses of energy in between those of completely glazed and unglazed windows. Some days this would be a benefit, and some days it would be a drawback, since the lower the outside temperatures, the more losses that would be incurred by a partially open window. If the window could be closed at will, these losses could be avoided.

### Table 4.4. Room 18 with both glazed and double-glazed windows.

<table>
<thead>
<tr>
<th></th>
<th>May/October</th>
<th>January</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contr. J/s</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Loss J/s</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tot. J/s</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tot. kJ/h</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glazed</td>
<td>11244.65</td>
<td>-1613.36</td>
<td>9631</td>
</tr>
<tr>
<td></td>
<td>34673</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dble-glazed</td>
<td>9283.34</td>
<td>-833.31</td>
<td>8450</td>
</tr>
<tr>
<td></td>
<td>30420</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.5. Room 18 with unglazed, glazed and partially open windows.

<table>
<thead>
<tr>
<th></th>
<th>May/October</th>
<th>January</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contr. J/s</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Loss J/s</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tot. J/s</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tot. kJ/h</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unglazed</td>
<td>13075.18</td>
<td>-5997.24</td>
<td>7078</td>
</tr>
<tr>
<td></td>
<td>25481</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glazed</td>
<td>11244.65</td>
<td>-1613.36</td>
<td>9631</td>
</tr>
<tr>
<td></td>
<td>34673</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part. open</td>
<td>12159.92</td>
<td>-3417.13</td>
<td>8743</td>
</tr>
<tr>
<td></td>
<td>31474</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Throwing money out the window: fuel in the Forum Baths at Ostia

Conclusion

In every case mentioned above, some heat is lost through ventilation that is not replaced by solar radiation from open windows in the span of an entire day. Although sunlight would have made up the difference during certain hours or in certain seasons, the overall computation is still a loss. Covering unglazed windows with wooden shutters reduces heat transfer through ventilation significantly, but a deficit of energy is nevertheless incurred, wasting valuable fuel resources. Thatcher contends that this energy loss can be accounted for within the heating system, but additional fuel is necessary regardless. In contrast, adding glass to the windows, even if it was relatively opaque, would have eliminated these losses (and the need for additional fuel), without significantly affecting the amount of solar radiation entering. There is no way to be sure which choice the Romans would have made, but saving fuel appears probable. The windows of Room 15 could have been left unglazed if sunbathing with full sun was considered essential, but this room could have also been sealed off on days with inclement weather. There is no obvious benefit from having an unglazed window in any of the other rooms, and the numbers computed in this study clearly demonstrate that there were benefits for glazing the windows. The most logical conclusion, therefore, is that most of the windows of the heated rooms of the Forum Baths at Ostia were glazed. Whether or not they employed other useful features, such as window panes or wooden shutters that could be opened or closed at will, is impossible to determine in this case.

Acknowledgements

This chapter began as part of my doctoral dissertation research, and my initial conclusions were presented

Table 4.6. Room 18 with unglazed and glazed windows with no shutters, and unglazed and glazed windows with closed shutters.

<table>
<thead>
<tr>
<th></th>
<th>May/October</th>
<th>January</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unglazed</td>
<td>13075.18</td>
<td>-5997.24</td>
<td>7078</td>
</tr>
<tr>
<td>Glazed</td>
<td>11244.65</td>
<td>-1613.66</td>
<td>9631</td>
</tr>
<tr>
<td>Unglazed/shutter</td>
<td>4358.54</td>
<td>-1137.67</td>
<td>3221</td>
</tr>
<tr>
<td>Glazed/shutter</td>
<td>3748.34</td>
<td>-1468.22</td>
<td>2280</td>
</tr>
</tbody>
</table>

Shutters

Putting shutters outside of both glazed and unglazed windows, which could be closed when the weather was not favourable, would have reduced the heat loss by providing more insulation. This scenario would have been especially useful in winter, when outdoor temperatures were the lowest. Shutters would also have been helpful at night, allowing the heated rooms to retain as much heat as possible for the next day’s bathers, thus conserving overall quantities of fuel. For simplicity, only the results for the month of January are discussed here, since they illustrate the most extreme conditions. Shutters formed of slats would have still let some light in, while reducing the surface area of the opening.

As can be noted in Table 4.6, adding shutters to either unglazed or glazed windows would have drastically reduced the amount of heat contribution from the sun at 1 p.m. on a cloudless day (13,075.18 J per second vs 4358.54 J per second for unglazed windows, and 11,244.65 J per second vs 3748.34 J per second for glazed windows). Logically, though, the shutters would only be closed on days when there probably was not much sunshine to exploit. Keeping shutters closed on a sunny day would have only been beneficial if the intent was to reduce the temperature of a room, especially for glazed windows. If the solar contribution is completely removed due to inclement weather or because it is night time, shutters only reduce the heat loss for glazed windows in January by 889.50 J per second (3202 kJ per hour), which is only equivalent to 0.16 kg of ash wood that must be burned to replace the lost heat. In contrast, shutters reduce the heat loss for unglazed windows in January by 10,809.25 J per second (38,913 kJ per hour), which is equivalent to 1.94 kg of ash wood (per hour). These values indicate that shutters were not very helpful in reducing heat loss for glazed windows, although they may have been needed for shade in the summer months. Shutters made a significant difference in reducing heat loss for unglazed windows on days or at times when solar contributions were negligible, saving almost 2 kg of wood per hour.
at the 114th Annual Meeting of the Archaeological Institute of America in Seattle, Washington, in January 2013. Thanks are due to the McIntire Department of Art at the University of Virginia and to the Council of American Overseas Research Centers (CAORC) for their financial support, allowing me to carry out extensive research at Ostia, as well as to Angelo Pellegrino and the Ostia section of the Superintendency of Rome. I would also like to thank Carlo Pavolini and Maura Medri for consulting with me about the site, and Tony Rook, Fikret Yegül, Janet DeLaine, Lynne Lancaster, Tahsin Basaran, Massimo Ragazzo, Vasilis Tsiolis and Robyn Veal for sharing their research. Thanks to John J. Dobbins, Tyler Jo Smith, Bernie Frischer, Renee Gondek and Carrie Sulosky Weaver for their editorial suggestions, and to Robert Ribando for his help with the heat transfer aspects.

Notes

1 Bloch (1953, 413–6) and Meiggs (1973, 415) both present detailed discussions of an inscription found in the baths and how it illustrates the likelihood that M. Gavius Maximus was their benefactor. According to Bloch (1953, 416), M. Gavius Maximus died in AD 158 or 159; however, it is possible the work was begun by him and finished after his death. The inscription has not been published in the Corpus Inscriptionum Latinarum (CIL). Poccardi (2001, 164) dates the baths specifically to AD 160, as does Pavolini (2006, 106). See also: Becatti (1948, 216); Bloch (1953, 414); Meiggs (1973, 415); Poccardi (2001, 164); Pavolini (2006, 106–9).

2 The advent of flat window glass coincides with the opening of the first glass factories in Italy. For more on flat window glass, see Jennings (2015). For more information on the manufacturing of glass in general, see Harden (1961, 48). See also: Gross (1977, 15); Ortiz Palomar & Paz Peralta (1997, 437-8); von Saldern (2004, 2).

3 Although few walls survive to heights sufficient to preserve windows, and there is no extant evidence of glass in the Terme del Foro at Ostia, there is material evidence that glass was placed in the windows of some Roman baths: Briggs (1956, 416); Broise (1991, 61–2); Bachman (2008, 118).

4 Large windows are also found in the Terme del Filosofo at Ostia. Boersma (1985, 127–8) states that it can be assumed that the large south-facing windows in the two tepidaria and in the caldarium of the Terme del Filosofo were closed, but he provides no evidence. He also mentions that these rooms were all heated by hypocausts under their floors, but that only the caldarium contained any wall heating devices. Boersma also assumes that the windows in the frigidarium were glazed. For more on window types in Ostia, see: Packer (1971, 24–7); Calza (1925, 97); Meiggs (1973, 414); Heinz (1983, 102).

5 Yegül (2010, 248) defines a heliocaminus as ‘A special room for sunbathing believed to have been a part of some Roman baths. These rooms enjoyed a southern or southwestern exposure and received the sun through large, possibly unglazed, windows.’

6 Broise (1991, 76); Meiggs (1973, 414); Yegül (1992, 382–3).

7 Thatcher (1956, 218) and Pellegrino (2000, 33) identify Room 16 as a laconicum, while Meiggs (1973, 414) and Pavolini (2006, 110) identify it as a sudatorium. Cicerrchia (1992, 35–6, 111, 112–3) also identifies Room 16 as a dry heat laconicum, basing his identification on the lack of evidence for any basins, labra or water systems. He also mentions that there is no trace in the room of water conduits or fistulae. In a contradictory statement, he describes Room 16 in its earliest phase as being almost completely filled by a pool. Yegül (2010, 6) mentions that laconica are usually round, but this room is elliptical, making it very unusual.

8 Thatcher (1956, 218); Meiggs (1973, 414); Cicerrchia & Marinucci (1992, 36–7, 115, 221); Pavolini (2006, 110).

9 The southern wall of Room 17 was reconstructed in the modern period primarily using ancient bricks, creating a great deal of confusion. In addition, both pillars that would have formed these windows are missing from the excavation photos and may have been reconstructed incorrectly. There is even the possibility that there were no windows in this wall at all. Cicerrchia & Marinucci (1992, 115, 118, 137, fig. 46).

10 A similar arrangement of holes can be seen in the large windows of the South Baths at Perge, in Turkey.

11 They base their doubts on the fact that two identical marine-motif capitals were found in the area of the palæstra, and a more likely reconstruction would be that all four of these elements were derived from one structure. See also Pensabene & Lazzarini (2007, 275).

12 The windows of the South Baths at Bosra, in Syria, have been reconstructed as being divided with brick pillars, measuring 0.4 × 0.4 m. These pillars created three openings that were 0.55 m wide, where claustra window screens were inserted. Metal hooks and a coating of plaster were used to secure the bricks in place within the screen.


15 For the sake of simplicity, conduction is only evaluated through the glass, rather than including the conduction through the individual pieces of wood, metal or stone that would have held each pane in place.

16 During the AD 79 eruption of Vesuvius, the windows in the caldarium of the Suburban Baths at Herculanenum were blown out from the impact of the volcanic flow. A labrum that once stood next to a window was also pushed across the room by this violent force, leaving an imprint in the ash. Fragments of double window frames and of glass that had been blown into the labrum were found in this ash imprint. These fragments were measured to be 4.5 mm thick. Those from Room Y in the baths at Lepcis Magna, measured between 3 and 4 mm in thickness. See Bartoccini (1929, 60–1); Broise (1991, 62–3, 69); Pappalardo (1999, 237–8).
17 Decolourizers could be added during the glass manufacturing process, to produce a clearer glass. For more information on the process, see Freestone (2015, 30–31).

18 Some scholars, such as Esperanza, Palomar & Paz Peralta (1997, 438), assert that Roman glass was not as clear as modern glass. Broise (1991, 61) specifies that ancient glass was ‘translucide, mais non transparant’. See also Harden (1961, 52); Bachman (2008, 119).

19 Broise (1991, 61–72) also claims to have identified movable glass panes in the baths at Bosra, in the apodyterium and the tepidarium of the Forum Baths at Pompeii, and in the Suburban Baths at Herculanum.


21 I was assisted by Kostas Floratos with the development of this model using Microsoft Access software.

22 The Romans did not know the numerical value for the temperatures they maintained in the baths. Galileo Galilei invented a rudimentary thermometer in 1593 that was able to measure temperature variations, but it was not until 1714, when Gabriel Fahrenheit created the first mercury device, that quantities of heat could be measured numerically. Tonks (1908, 421) has suggested that ancient Greek potters may have used gold or silver wire to monitor temperatures inside their red and black figure pottery kilns, which had to be precisely regulated in order to produce the desired colour effect. The melting points of both metals (1062 °C for gold, and 961 °C for silver) are just slightly above the temperatures that potters needed to fire these vessels. Rehder (2000, 11–12) conjectures that someone with a ‘practised eye’ would have been able to tell the general temperature within 20 °C by colour. A 20-degree range of error in the baths, however, would have made the difference between having bathers enjoy a hot pool or being cooked alive. See Hasaki (2002, 125–6) on the relationship of bath furnaces to kilns; also Bellis (2012) and Noble (1965, 75).

23 The temperature was selected for the tepidarium based primarily on a combination of information calculated in previous studies: the measurements collected by Couch (2003, 169, 173–4) in the reconstructed NOVA bath near Sardis (Turkey), and the engineering study conducted by Basaran & Ilken (1998, 4) on the Small Baths at Phaseis (Turkey). The outside temperatures for ancient Ostia were selected based on monthly averages collected between 1961 and 1990 at the meteorological station on the Isola Sacra, adjacent to Ostia, and published in Sadori et al. (2010, 3294). Wind was not included in the calculations for simplicity.

24 Joules are a unit for measuring heat, energy or work in the SI system. One joule per second is equivalent to one watt. One joule is equivalent to 0.00094781712 British Thermal Units.

25 Calza & Nash (1959, 57); Nielsen (1990, 1); Yegül (1992, 429 n. 28; 2010, 11).

26 *CIL* It. 5181 = *ILS* 6891.20–21.

27 For the purpose of this study, ash wood was selected as the primary fuel because of its excellent burning properties and its propensity to grow around the area of (modern) Ostia. We lack published archaeological data at this time.

References


