TERRACOTTA SPACER PINS IN LYCIAN BATH BUILDINGS

By A. FARRINGTON AND J. J. COULTON

A puzzling feature of a number of Lycian bath buildings is the array of holes cut in their walls at intervals of about 0.5 × 0.5 m. In size they are often about 0.12 × 0.12 m. × 0.06 m. deep, and so too large for the normal iron spikes which hold marble veneers or other wall facings in place. A chance find made during the course of the survey of Balboura in 1986 provides an explanation for these holes; they were to take spool-headed terracotta spacer pins which in turn held a series of large flat tiles with a space behind for the circulation of hot air from the hypocaust (Fig. 4), so providing the same effect as the better known *tubuli* and *tegulae mammatae*.

The bath building at Balboura lies to the west of the agora, on the north side

Fig. 1. Balboura, plan of bath building and its neighbours (JJC)

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of the broad east-west street which runs through the centre of the lower city (Fig. 1). Its construction is probably to be related to the establishment of a new piped water supply, which is firmly dated to the reign of Vespasian by two inscriptions, one on the aqueduct which crossed the valley to the south of the city hill, the other at the termination of the pipeline just above the bath building, where there appear to have been a nymphaeum and cisterns. The plan of the building is unfortunately not clear, but it appears to have consisted of at least two rooms facing southwest onto the street. The western Room 1 has an arched doorway in its north wall, and a doorway in the middle of its east wall connecting it to Room 2 to the east. A north-south wall divides Room 1, but its different construction, including reused material, suggests that it does not belong to the original plan. To the east of Room 2 are the elements of a small colonnaded court (probably Severan) entered by an impressive doorway from the street; but it is not clear whether this or the structures to the north belong to the bath building.

There has been some illegal excavation in the southeast corner of Room 1, and a virtually complete spacer pin (Fig. 2A, Pl. V(a)), presumably dug up in the course of this, was found close to the bath building, where it must have been tossed by the treasure seekers; a number of other fragments of similar pins were found nearby. The complete pin was broken in four pieces, but when joined together, only a few chips from the head were missing. It is 0.25 m. long, with a spool-shaped head.

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3 Redrawn after the survey and plan of the city centre by Dr L. Bier, Brooklyn College, New York. For the location see L. Bier, AS 40 (1990) 71, fig. 1, squares Pn-Qn.
4 IGR III 466; for the location of the aqueduct see J. J. Coulton, IV Araştirma Sonuçları, 172–3.
5 The terminal inscription was re-used as the lintel of a doorway leading into the hillside at the head of the street (C. Naour, Ancient Society IX (1978) 165–70, no. 1; now reburied). Above is a terrace backed by a curved retaining wall, and in front are lying fragments of entablature forming ressauts.
6 The complete pin was deposited in the Fethiye museum.
consisting of two disc-like flanges about 0·10 m. in diameter, separated by a neck about 0·03 m. long and 0·06 m. thick. The shank, 0·19 m. long, is circular just below the head, but becomes rectangular at the other end, where it measures 0·065 x 0·052 m. The whole pin was thrown in one piece on a potter’s wheel, with the shank originally tapering towards the head; the wider part of the shank was then trimmed to a rectangle before the pin was fired. The other fragments are all of the same general type (one of the better preserved is illustrated in Fig. 2B), although differing somewhat in profile and diameter. Some variation is unsurprising, since the pins were invisible in use, and providing their length and the neck of the spool head were consistent, other differences would not affect their function. The fabric of the pins is orange to buff, sometimes with a black section at the centre of the shank.

The pit in the southeast corner of Room 1 has also revealed the inner faces of its east and south walls, built of rough polygonal masonry with rather open joints. In the east wall (Fig. 3, Pl. V (b)) a number of square holes can be seen; those which fall completely within one block are about 0·08 x 0·08 m. and 0·06 m. deep, but in many cases the hole runs across a joint in the stone work, which was enlarged as necessary; since the wall has not remained completely stable, the original dimensions of these holes have altered. Most of the holes are empty, but some still contain the broken-off stumps of terracotta spacer pins (marked by solid black squares in Fig. 3), held in place with mortar. The stumps of some other pins are simply fixed where the joints in the stone work are open, and so no cutting was needed. Some similar holes are also visible in the south wall of the room, but less of the wall is visible, and many of the pins seems to have been set in joints in the masonry, so that it is not possible to reconstruct the grid. Although only a narrow strip is visible of the other walls of Room 1 and Room 2, it appears that there were comparable holes in the west wall of Room 1 and the east and west walls of Room 2, but that the dividing wall in Room 1 had none.

The holes in the visible part of the east wall belong to two distinct but overlapping arrays which belong to different phases. One set, joined by solid lines
in Fig. 3, are at vertical intervals of c. 0.66 m.; most of the horizontal intervals are c. 0.51 m., but there are two wider intervals of c. 0.70 m. The other set, joined by broken lines in Fig. 3, are centred c. 0.66 m. apart vertically and c. 0.79 m. apart horizontally. Pin stubs survive in each array, so it is not possible to identify the earlier set on these grounds.

Tiles with dimensions corresponding to the intervals of the pins could be set tight against each other only if their corners were broken or cut off, to allow room for the neck of the spool-headed pin, and this was apparently done in the similar systems used in North Africa (see below). Alternatively slightly smaller tiles could be set with a gap between them for the pins, and so would not need to have their corners removed (Fig. 4). The surviving fragments of thin flat tile (0.033 m. thick) are no larger than 0.14 × 0.16 m., too small to decide between these alternatives, but no corner pieces were found with the angle removed. In addition, there are a few holes for pins which are not set at the normal intervals, and so would have anchored the tiles not at the corners but along one side; this would be easier if the tiles were set with a gap between, for tiles with no gap would require a semicircular or V-shaped cutting for the neck of the pin, which would be hard to cut without fracturing the tile. (It could not be cut before firing, because these pins are not at regular positions.)

Several of the pins still have remains of plaster adhering, and there are lumps of a similar softish, coarse plaster in the spoil dug out of the room. The skin of tiles held by the spacer pins would therefore have been covered with a thick layer of

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7In addition to the thin tile, fragments of tile 0.05–0.07 m. thick could be seen on the spoil; also circular tiles (diam. c. 0.28 m., th. c. 0.08 m.) from the hypocaust pillars.
plaster to form the base for the visible surface finish. Fragments of thin marble in the spoil suggest that, as in other examples of the tile and spacer pin system, this finish was of marble veneer.  

Neither array of spacer pin holes extends to the southeast corner of the room. Instead, there are two small holes for iron spikes, set about 0·30 m. out from the corner. They are on the same horizontal lines as the more closely spaced array spacer pin holes (and so c. 0·65 m. apart vertically), but are only 0·46 m. south of the southernmost spacer pins. It is possible that these were to hold special flue pipes for the corners of the room. A third small hole can be seen at the north end of the exposed wall; it is not related in position to either of the systems of spacer pin holes, and without more information on its context, no explanation is possible.

Similar holes for terracotta spacer pins are known in 14 other baths at nine sites throughout Lycia (listed in Table 1), although their presence has generally gone unnoticed in publications. In the North Baths at Kyaneai they appear in the vault as well as in the walls, but more commonly (Baths of Antoninus at Kyaneai (Pl. VI (a)), baths at Limyra, Southwest Baths at Patara, and baths at Sidyma) there is a projecting ledge in the stonework at the springing of the vault, and this closed off the spacer pin cavity. In other cases the spacer pin holes do not occupy the whole of the wall surface; thus in the central chamber of the row along the northwest side of the bath block of Baths A at Tlos, the pin holes occur only in broad, shallow panels between projecting buttresses (Pl. VI (b)); in the rooms which form the main, northwest part of Baths M1 1 at Oinoanda, the horizontal spacer pins stop at a point about 2·5 m. beneath the level of the springing of the vault (Pl. VI (c)); and in the baths at Rhodiapolis the holes are restricted to the interior face of the east wall of the southeastern room of the main block.

**TABLE 1**

<table>
<thead>
<tr>
<th>Bath and location</th>
<th>Hole size</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W × H × D</td>
<td>Hor. × Vert.</td>
</tr>
<tr>
<td>Arif, both baths 13</td>
<td>Dimensions not known</td>
<td></td>
</tr>
<tr>
<td>Balboura, Baths</td>
<td>8 × 8 × 6</td>
<td>51 × 66</td>
</tr>
<tr>
<td>Room 1, E wall</td>
<td>8 × 8 × 6</td>
<td>79 × 66</td>
</tr>
<tr>
<td>Kadyanda, Baths of Vespasian 14</td>
<td>12 × 12 × 6–7</td>
<td>70 × 35</td>
</tr>
<tr>
<td>Cent. rm., E &amp; W walls</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8So at Pergamon, Kourion, and Mactaris (n. 38 below).
9Based on research on Lycian bath buildings by A. Farrington, carried out with the kind permission of the General Directorate of Antiquities and Museums of the Turkish Ministry of Tourism and Culture, and with the assistance of Bay Ramazan Peker of Aydin Museum.
10The holes at Kadyanda are described by O. Benndorf, G. Niemann, *Reisen in Lykien und Karien* (1884) 142, and a fragmentary terracotta pin was noted by the baths by Farrington. The imprint of another pin is visible over the west door in Room 2 of the Southwest Baths at Patara.
11Such ledges are a feature of other wall heating systems also; see A. M. Mansel, *Die Ruinen von Side* (1963) 145–6, fig. 119–20.
12These panels are closed at the top; the projecting ledge at the springing of the vault is bevelled, unlike those mentioned above, so a decorative feature.
The horizontal breadth of the terracotta spacer pin holes in these baths ranges from 0.07 m. to 0.23 m., their height from 0.06 m. to 0.23 m., and their depth from 0.06 to 0.13 m. The usual dimensions of the holes are, however, c. 0.12 m. broad by
c. 0.13 m. high by c. 0.06 m. deep. Both the horizontal and the vertical interval between the holes is most commonly from 0.35 to 0.55 m.; but the vertical distance varies from 0.33 to 0.96 m., the horizontal from 0.26 to 0.86 m. (Table 1). This variation in the distances between the holes, and in particular the large distances between the holes in the apse of the Baths of Vespasian and in the Southwest Baths at Patara, suggest that the spacer pin system, at least in Lycia, employed specially manufactured tiles. Those used in the east room of the Baths of Antoninus and the main room of the North Baths at Kyaneai are approximately *sesquipedales* (1 ½ feet square); but there are no clear instances of the other standard Roman tile sizes, *bipedales* (2 feet square) and *bessales* (8 inches square). The Lycian tiles were sometimes square, sometimes rectangular, with several examples approximating 2:3 or (less commonly) 1:2 or 4:5. When rectangular they might be set either vertically or horizontally.

Where there are overlapping sets of spacer pin holes, the wall heating system presumably needed to be replaced, as at Balboura, during the life of a bath. But where one or more sets of spacer pin holes overlap with small holes suitable for iron spikes, one might suppose that the latter belonged to a phase when marble veneer was directly attached to an unheated wall. In several of these cases, however, a projecting stone ledge shows that a heating cavity was intended from the start, and since it is unlikely that wall heating, once installed, would have been given up, the iron spikes in these cases were probably for alternative wall heating systems.

It is usually hard to see whether spacer pin systems or spike-held systems were the earlier. In the baths at Limyra and the North Baths at Patara, the small holes appear only over part of the wall surface occupied by spacer pin holes, which suggests that the small holes were for a repair to an earlier spacer pin system. On the other hand the reverse may be true in the Baths of Vespasian at Patara, where there are at least two sets of spacer pin holes and several sets of small holes. spacer pin holes occur on their own on the interior of the apse at the northern end, added in a second phase, and they so can not belong to the original state; it is reasonable to suppose that one set of the similar holes elsewhere in the baths belongs to the same phase. If the original phase had wall heating, therefore, it may have been held in place by some of the small holes.

Of the baths using spacer pins three are dated by inscriptions; those at Kadyanda were built in the reign of Vespasian, A.D. 69–79, while the baths of Antoninus at Kyaneai carry a dedicatory inscription mentioning Cn. Cornelius Arrius Proculus, governor some time between A.D. 138 and 142; the baths may belong to the great wave of building activity after the earthquake of A.D. 141–2. An inscription on the Baths of Vespasian at Patara refers to their construction under the legate Sex. Marcius Priscus, and Vespasian’s name is written on an erasure. Presumably, then, the baths were constructed while Priscus was legate at the very end of Nero’s reign and the beginning of Vespasian’s. However, some at least of

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27 This occurs in the Baths of Antoninus at Kyaneai and the Baths of Vespasian at Patara.
28 This occurs in both bath buildings at Kyaneai, the baths at Limyra, and at Patara in the North and Southwest Baths and the Baths of Vespasian.
29 In other cases, as in the western room of the Baths of Vespasian at Patara, unheated walls clearly had veneer attached by iron spikes.
30 *TAM* II, 651; *IGR* III, 700; for the date of Proculus’ office see M. Wörnle, *Stadt und Fest im Kaiserzeitlichen Kleinasien* (Vestigia, XXXIX, 1988) 38.
the spacer pin holes belong to a later building phase to which no firm date can be assigned.32

Baths ZB/ZC at Phaselis are dated by coins to the fourth century AD, while the baths at Arif perhaps belong to the sixth century AD or soon after, for Harrison has suggested that the site was only occupied in the sixth century and soon deserted.33

Dates for other Lycian baths using terracotta spacer pins depend on more general considerations of the history of building techniques and of bath building in Roman Lycia, and cannot be discussed in detail here. The arguments are fully set out in Farrington’s forthcoming monograph on Lycian baths,34 and only the conclusions, with some indication of the evidence, are given here.

### Lycian Bath Summary

<table>
<thead>
<tr>
<th>City</th>
<th>Phase</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balbours</td>
<td>Vespasian?</td>
<td>(relation to dated aqueduct)</td>
</tr>
<tr>
<td>Oinoanda Ml 1</td>
<td>Flavian?</td>
<td>(related to aqueduct similar to that at Balbours, but undated; more elaborate plan than first phase of Baths of Vesp., Patara)</td>
</tr>
<tr>
<td>Rhodiapolis</td>
<td>Late Imperial?</td>
<td>(pitched brick vaulting with brick: mortar ratio = 1:1)</td>
</tr>
<tr>
<td>Patara,</td>
<td>Flavian?</td>
<td>(more elaborate plan than Baths of Vesp.: close-jointed polygonal masonry)</td>
</tr>
<tr>
<td>Central Baths</td>
<td>Flavian-Severan?</td>
<td>(heavily mortared but close-jointed, coursed masonry: signs of elaborate statuary decoration)</td>
</tr>
<tr>
<td>North Baths</td>
<td>Flavian?</td>
<td>(as Central Baths)</td>
</tr>
<tr>
<td>Southwest Baths</td>
<td>Flavian-Antonine</td>
<td>(elaborate plan, but close-jointed polygonal masonry)</td>
</tr>
<tr>
<td>Tlos, Baths A</td>
<td>Undated, but no re-used masonry</td>
<td></td>
</tr>
<tr>
<td>Kyaneai, N. Baths</td>
<td>Undated, but no re-used masonry</td>
<td></td>
</tr>
<tr>
<td>Limyra</td>
<td>Undated, but no re-used masonry</td>
<td></td>
</tr>
</tbody>
</table>

However, the date of construction of these baths can only provide a terminus post quem for the use of terracotta spacer pins, for some of them may originally have used some other system of heating or have had unheated walls. The termini ante quem would be provided by the dates when the baths went out of use, but those are unfortunately not known.

There is some evidence for other methods of wall heating in Lycian baths. In the southwest room of Baths Ml 1 at Oinoanda slightly recessed vertical strips are visible in some lights, running up the walls at intervals of 1·5 to 2·0 m. (barely visible in Pl. VI (c)). These have no discernible connection with the spacer pin system, and it seems likely that they mark the positions of widely spaced pipes through which the fumes from the hypocaust would pass to the exterior of the building. Such hypocaust flue pipes, which would contribute little heat to the room, are a feature of the earliest type of Roman hypocaust,35 and the spacer pin system, which heats the walls more fully, is likely to have been the later one in Baths Ml 1, and this sequence is also indicated by the absence of a ledge projecting from the masonry to close off the cavity created by the pins. Thus although the building

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32It is possible that this phase of reconstruction and enlargement also belongs after the earthquake of AD 141–2.
itself is (probably) Flavian, the spacer pin system, here as in the Baths of Vespasian at Patara, seems to have been introduced in a later phase.

The use of *tubuli* is not widely attested in Lycia, but there may be evidence of them in Baths B at Tlos. Here there is a projecting ledge along the interior face of the northeastern walls of the two northernmost rooms, beneath the tympanum, at the level of the springing of the vault, its centre pierced by a channel, square in section, which runs upwards to the top of the tympanum. The ledge is clearly to cap the cavity of a wall heating system, with the vertical channel conveying the fumes from the hollow wall up the tympanum to the exterior. However, the projection of the ledge is rather small for a spacer pin system, and there are no large spacer pin holes. Instead there are pairs of small spike holes rather irregularly spaced over the surface of the wall; these would probably have been sufficient to hold a jacket of *tubuli*, which are largely self-supporting. The mortared rubble masonry of Baths B suggests a later date than Baths A at Tlos, but no specific date can be suggested.

Baths Mk 1 at Oinoanda are also constructed of loosely fitting mortared rubble, combined (unusually) with horizontal brick bands. The inner wall faces of the two rooms to the southeast are pierced by small holes for iron spikes. These may have been to hold flanged tiles, *tubuli*, or simply marble veneer. These baths are more elaborate than Baths Ml 1, and were probably built in the second century A.D.; It is noteworthy therefore that the spacer pin system was apparently *not* used here.

These few instances are not sufficient to define the period of use of the spacer pin system in Lycia by exclusion, but since it did not apparently occur in the first phase of the Baths of Vespasian at Patara and Baths Ml 1 at Oinoanda, it may not have been used until after the Flavian period. Baths ZB/ZC at Phaselis and the baths at Arif show that the system was certainly in use in the fourth and sixth centuries A.D., and theoretically all the examples may be dated to the late Roman period; but it seems unlikely that baths like those at Kadyanda, Kyaneai and Patara, which were built in the first or second century AD but show no evidence of other heating systems, all had unheated walls until the late Roman period.

The spacer pin system was not used only in Lycia. Details of the system (with only minor variations) have been published from Pergamon, Kourion (Cyprus), and Maetarais (Tunisia). Other instances have been more briefly recorded as follows: in Asia, two more examples from Pergamon; on Crete from the Villa Dionysos at Knossos and from Gortyn; and in North Africa from a number of other sites including Cherchel, Tehouda and Timгад, perhaps also Cuicul and Hippo Regius. Thus although the use of spacer pins to produce a wall cavity has

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37R. J. Ling, *AS* XXXI (1981) 43–4; the baths are pre-Severan, and probably occupy a platform built in connection with Baths Ml 1; they may be those to which Opramoas contributed (*TAM* II, 905.XIXB.27–8).


not yet been reported from Italy, Northwest Europe or the Levant, it was apparently a system widely known within the Roman empire. Most of the dated buildings belong to the second century A.D.; as in Lycia, the dates of abandonment are usually unknown, but the baths at Pergamon were abandoned around A.D. 400, while the spacer pins at Knossos were found in a third century destruction deposit. The relatively early date of the deposit at Knossos supports the impression given by the dates of construction in Lycia and elsewhere, that spacer pins were introduced in the second century A.D.

In almost all cases terracotta spacer pins have been found in association with baths, and their function in providing heated wall cavities is clear at Pergamon, Kourion and Maactaris. But at Knossos no hypocaust has been found in the Villa Dionysos, and it has been suggested that the pins were used in vaults as an anti-earthquake device. The North Baths at Kyaneai show that the pins were indeed used sometimes in vaults (though the evidence has survived more rarely than in walls); but it is not clear how they would help the structure in an earthquake. Another possibility is that tiles and spacer pins were used as a protection against damp, like the system of *tegulae mammatae* described by Vitruvius. However, the pins at Knossos were not found in a certain architectural context, and may have been brought in with fill from a nearby building where they formed part of a wall heating system, as at other sites.

Although terracotta spacer pins were thus a fairly widely used method of creating a heated wall in a bath building, they are much less well known than the alternatives of *tubuli* (box flues) and *tegulae mammatae* (lugged tiles), so that some general discussion may be appropriate here. In form and in the way they are fixed to the structural wall, spacer pins vary considerably. Thus at Maactaris the pins do not penetrate the wall structure at all, but are simply attached to it by mounds of mortar; the pin shank is therefore given a spiral twist for better adhesion. At Tehouda, too, the pins are shown as penetrating only the wall plaster, although Cagnat and Chapot describe them as sunk into the wall. In the eastern Mediterranean, however, the pins are inserted into the wall. At Pergamon, where the associated wall is of small rubble and mortar, the end of the pin shank is not rectangular, but splayed into a chisel tip, which could be inserted into any convenient joint in the masonry; at least one of the Knoossos pins has a similar tip. But in Lycia most of the associated walls are built of large, more or less closely fitted blocks, and so there was little chance of a joint occurring at each position where a pin was required. Since a special hole would have to be cut to take the pin, it was more satisfactory simply to square the shank off. It is this difference in wall construction, and so in method of fixing, which allows the identification of the spacer pin system in so many Lycian baths. However, the same uniform shank thickness, and so the same need for specially cut holes, occurs also at Kourion, where the wall is of fairly small rubble, not large stone blocks. Since they extend further into the walls, the pins at Balboura and Kourion are longer than the others (Balboura 0·25 m., Kourion 0·26 m.; contrast Pergamon 0·19 m., Knoossos 0·182 m., Maactaris 0·21 m., Timgad 0·21 m.). Another difference, which may also be local, is in the manufacture of the pins. Those from the East Mediterranean, including the unique rectangular pins from Kourion, are solid, whereas most of the

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40Kourion: Trajanic; Pergamon: late second cent. A.D; Knoossos: Late Antonine?
41J. W. Hayes, op. cit. (n. 39) 103.
42Vitr. 7.4.2.
43These are the only systems described by J. Durm, *Die Baukunst der Etrusker; die Baukunst der Römer* (1905) 187–8; G. Lugli, *La Tecnica edilizia romana* (1957) 550–1; L. Crema, *L'Architettura romana* (1959) 73; J. P. Adam, loc. cit. (n. 2).
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North African ones are apparently hollow (Mactaris, Timгад, and Tehouda; but a solid pin is reported from Cherchel).

With the exception of those from Kourion, all the spacer pins have heads of comparable shape, with a circular neck between two projecting discs. At Mactaris and Tehouda the associated flat tiles had quarter circles cut from their corners to allow space for this neck between four adjacent tiles, but, as we have seen, this may not have been done at Balboura. The situation at Pergamon is not yet clear. The rectangular pins at Kourion would need rectangular pieces removed from the corners of the flat tiles to allow four tiles to meet accurately, but it is not stated whether this was done. These pins are also unique in having a second groove, on the sides only, at about the point where the pin emerged from the wall. Scranton suggests that these were to hold another skin of tiles, presumably to protect the wall structure from the furnace gases. However, such a skin was not found necessary elsewhere, and it is not clear why the groove for the second skin was not continued round all four sides of the pin, like that for the outer skin.

In many ways the tile and spacer pin system can be regarded as a variant of that using *tegulae mammatae*, with the pin serving both as a detached lug and a fastening spike. Another variant, also found in both the eastern and western halves of the empire, replaced the lugs of the *tegulae mammatae* with separate terracotta spacer tubes or distance pieces, but continued to use iron spikes passed through these spacers to fasten the tiles to the wall. In comparing these systems with each other, and with the rather different system of *tubuli*, various aspects must be taken into account: the ease and cheapness of construction; the stability and durability of the finished system; and the effectiveness with which the hot gases from the furnace were drawn through the cavity and transferred their heat to the wall.

The terracotta elements required for both the spacer pin and the spacer tube systems could probably be produced with equal ease. The tubes and pins were both easily formed on a potter’s wheel, and both systems used plain flat tiles of either standard or specially chosen sizes. In both cases simple modifications were needed, for the spacer tube system normally required the tiles to have holes for the iron fastening spikes, while the spacer pin system often required the four corners of each tile to be cut or broken off; both modifications would be most easily made before the tiles were fired. The formation of lugged tiles is easy in principle, but might need a special mould; the practical limit of lug length was perhaps a more important disadvantage. *Tubuli* were perhaps the most difficult to form, requiring a large slab of clay to be bent and joined back on itself, after which holes were normally cut in two of the side walls.

Terracotta pins, even when chisel tipped, would normally require larger holes in the structural wall than iron spikes, so that the job of fitting the terracotta inner skin would probably require more work than with the other three systems. Durability and stability are harder to compare without practical experience. *Tubuli*, being self-supporting, would seem to form the most stable cavity construc-

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44Scranton, op. cit. (n. 38) 60.
tion, but the spacer pin system had one special advantage in that it used no iron spikes. Besides some possible saving in costs, this would eliminate the problem of corrosion by the hot flue gases. It is worth noting in this context that with spacer pins, spacer tubes, and lugged tiles, the completed inner skin carried its own weight down to the floor, and needed only to be prevented from moving sideways.

The actual performance of the systems required the balancing of conflicting factors. On the one hand a fast air flow in the wall cavity would make the furnace draw well (so increasing its heat output), would constantly replenish the supply of hot air at the foot of the wall, and would heat the wall more evenly. But at the same time it would lead to more, and hotter, air passing out at the top of the system to lose its heat in the open air, so wasting fuel. On the other hand a slow-moving air flow in the cavity would transfer more of its heat to the wall before leaving the system, and so provide a more economical use of fuel; but it would also heat the wall mainly at the bottom, and by slowing down combustion and reducing the volume of hot air reaching the wall, it would mean that less heat would be available for the wall to take up and transmit to the room.

An analysis of the optimum balance between these factors is hindered by our ignorance, in detail, about the conditions under which wall heating systems operated, but it is clear that a narrower wall cavity would tend to reduce the air flow. The earliest system of wall heating was certainly that using tegulae mammatae, with a cavity normally 0.05–0.07 m. wide, and tubuli, with a cavity characteristically 0.10–0.15 m. wide, were a later development. The popularity of tubuli in later bath buildings, in spite of their apparently greater cost of production, suggests that their wider cavity provided a more effective heating system. It is less easy, however, to compare the effectiveness of the spacer pin and spacer tube systems with tubuli. Both pins and tubes can also provide a cavity 0.10–0.15 m. wide, but, as with tegulae mammatae it is a continuous cavity, whereas with tubuli it is divided into a series of vertical flues. The effect of this difference is hard to predict. Separate flues, being more directional, might provide a better draft (i.e. a faster air flow to the chimney), and perhaps a more controllable distribution of hot air. But the holes normally cut in the side walls of tubuli would reduce these possible advantages, and suggest that they were not seen as crucial. The side walls of the tubuli would, like the fins on an air-cooled internal combustion engine, provide a greater surface area for the transfer of heat; but the low conductivity of terracotta (in comparison to metal) means that more heat would probably not be transmitted to the wall surface by this means.

Whatever the precise answer to this question, it is clear that the choice of wall heating system did not depend on effectiveness alone, for no single system wholly replaced another. Even tegulae mammatae were still used sometimes at least as late as the fourth century A.D. The choice may to some extent have been affected by

46 Cf. J. C. Biers, op. cit. (n. 45) 46, n. 28.
47 I have been helped here by an investigation by Miss S. Semple of Keble College, Oxford, and by discussion with Dr. D. B. R. Kenning of Lincoln College, Oxford.
48 Practical experiments have been carried out on hypocaust systems at Saalburg (F. Kretschmer, Saalburg Jahrbuch XII (1953) 7–41, W. Huber, ibid., XV (1956) 38–40, H. Häuser, ibid., XXXVI (1979) 12–30, and D. Baatz, ibid., 31–44), and at Welwyn (T. Rook, J. Arch. Science V (1978) 269–82); but there has been no practical comparison of different types of wall heating.
49 It should be emphasised that some tubuli provided a rather narrow cavity; a tubulus illustrated by Durm, op. cit (n. 43) fig. 197 has a cavity of only c. 0.06 m.
50 D. B. R. Kenning suggests that easier cleaning was an additional advantage of tubuli; systematic cleaning of an undivided wall cavity would be hard to achieve.
51 O. Broneer, Corinth I.4; The South Stoa (1954) 145–51; R. S. Young, Hesperia XX (1951) 279–82.
local habit, but cost was probably a more potent factor. Major bath complexes across the empire seem almost always to have used *tubuli*, whereas the baths with spacer pins whose plans are published, are small (Pergamon: 165 m².; Kourion: 240 m².). In Lycia, too, the bath buildings are generally small (mostly 200–700 m²., with a few c. 1000 m².). A significant link between Lycia and central North Africa, the two areas where the spacer pin system was most popular, is that both were occupied in the Imperial period by a large number of relatively small cities. In such a context of limited public resources a simply made heating system which local craftsmen could produce, would naturally tend to be preferred to the more elaborate, even if more efficient, system of *tubuli*.

**ABBREVIATIONS**

In addition to the abbreviations specified for *Anatolian Studies*, the following are used:

- *Araşturma Sonuçları* Republic of Turkey, Ministry of Culture, Department for the Protection of the Cultural and Natural Heritage (formerly Ministry of Culture and Tourism, General Directorate of Antiquities and Museums) *Araşturma Sonuçları Toplantısı (I, 1983- (Ankara, 1984- ))*
- **TAM II** E. Kalinka, *Tituli Asiae Minoris Antiquae II* (1920)