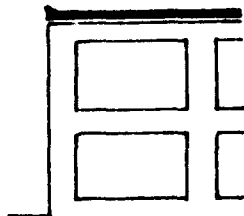


ROOFS

INTRODUCTION



The primary objective of the roofing membrane is to absolutely keep out weather - primarily moisture. To satisfy this objective the most critical attribute of this system is to prevent any moisture penetration which may occur through improper design, faulty construction practices or through weathering action on this tenuous membrane.

The roofing membrane is the most 'sensitive' of all the building subsystems examined in this study. This is due to its having a constantly high exposure to the elements; the nature of water's insidious ability to infiltrate into a building and the numerous possibilities for error in design and construction.

Since this is so tenuous a membrane a reasonable course of action would be towards overdesign for moisture protection, very careful supervision of construction, and, getting the water off of the roof as quickly as possible.

METHOD OF EXAMINATION

Very rigorous measures and a detailed visual examination were made of this membrane. Evidence of moisture penetration was of prime importance as was evidence of weathering and entrapped air and moisture.

A 4' level, inclinometer and small rule calibrated to 1/32" were used to measure pitch, depth of standing water and deterioration. For a more detailed description of testing procedures used refer to the Field Tests Manual, 'Buildings In Use' Study, December 1974. A comparison of these measures and observations with existing standards was used to determine the quality of performance.

SUMMARY OF PERFORMANCE

	P	R	S	M
DRAINAGE				
Ponding	○	●	○	○
Details	○	⊙	⊙	○
Roof Slopes	○	●	⊙	○
MOISTURE PENETRATION				
Details	○	○	○	●
Movement	○	●	○	○
DETERIORATION EROSION	○	●	○	⊙
IMPACT/INDENTATION/ BRITTLENESS	⊙	●	○	○

SUMMARY OF FINDINGS

The roofing membrane is one of the most tenous systems in any building. Roofing failure is a serious and frequent problem in any facility. Such failures are due to many causes: incorrect detailing, poor quality materials, Improper construction practices, effects from other building subsystems, etc. None of these are without remedy in existing buildings nor unpreventable in future new construction.

The performance of the built-up roofing membranes of the four buildings studied was mixed. The Parkside roof is "the best in the district" (85% level) and the Mt. Healthy roof is generally satisfactory (75-85% level). The Smith School is rated at the 75%-85% level because of a potential for future problems though it is now performing satisfactorily. The Richards School is rated at below 75% because of numerous problems resulting from detailing, construction and deterioration during the life of this building.

No convergence of problem types is present. What exists is a cornucopia of causes, many of which are 'textbook cases'.

DETAILS OF FINDINGS

DRAINAGE

DRAINAGE/PONDING (Figure B.1 through B.4)

Results: Performance was generally satisfactory at the Parkside and Mt. Healthy Schools. Ponding due to inadequate drainage is a problem at the Richards (below 75%) and the Smith (85%) Schools. Within 1 year of occupancy all of the built up roofing at Richards had already been replaced when core samples revealed total saturation of the roof membrane and insulation. Richards Elementary School has the most extensive ponding closely followed by Smith. Roof construction at Smith is of such high quality, which is rare, that existing ponding does not now, and may not, cause future moisture penetration. The Richards School has a less well constructed roof and alligating, brittleness and membrane movement due to ponding caused many problems in the past and may well cause future problems.

Probable cause: No slope or inadequate slope specified in the original design is the major cause of ponding.

Discussion: The main concern of the designer should be getting the water off of the roof. Ponding consists of substantial amounts of water which do not drain off of the roof surface. This can immediately cause leaks if the roof is not 'tight'. Even more insidious, however, is the deterioration of the membrane due to ponding. Freezing of this standing water, which is, of course, relatively shallow and easily frozen, can literally tear the roofing membranes. The more typical effect, however, is movement of the membrane caused by a temperature differential between the exposed roofing, which on a sunny day may be 180 degrees and the membrane under the pond which is substantially lower in temperature. Other effects of ponding are erosion of the protective gravel surface and alligating-minute cracking of the membrane. Moisture penetration is a cause of blistering, caused by expansion of the water vapor, and also a cause of roofing movement due to water vapor migration between the felts.

Specifying minimum slopes (1/8 inch/ft.) can be nullified by settling, construction tolerances, workmanship during construction or roof sag during the life of the building. In fact some roofs specified to slope towards the roof drain were found to actually slope away from the drain because of the above mentioned factors.

DRAINAGE/DETAILS (Figure B.6)

Results: Performance was adequate at all facilities examined. Drains can sometimes be higher than the roof surface due to additional flashing and therefore cause or exacerbate ponding conditions. Gutters between adjacent skylights at Mt. Healthy were found to be a trap for leaves and a potential source of blockage.

Probable cause: Architectural detailing and construction tolerances due to flashing, protection around drains.

Discussion: Typically all openings through the roof are protected by additional layers of roofing felt and flashing materials. This causes the roof to pitch up slightly at the drain. If a drain is chosen or installed in a manner which also raises it above roof level--the combination of the higher drain and the additional protection can actually be 2-3" above the roof level which will cause ponding in this location.

DRAINAGE/ROOF SLOPES (Figure B.1 through B.4)

Results: Performance was satisfactory (85%) at Mt. Healthy, at the 85% level at Parkside, but unsatisfactory (75% or below) at the Smith and Richards Schools where a lack of slope results in ponding.

Probable cause: Design did not specify sloped roofs.

Discussion: This, of course, is the primary cause of ponding. 'Dead' flat roofs were specified at the Smith and Richards Schools. At Richards the roof actually slopes away from the drain. This, we believe, is caused by some small amount of settlement in the exterior wall or poor construction which at

first caused minor ponding. The weight of this additional water gradually caused the roof membrane to sag in this area and increased its capacity to hold water, producing a cycle of increasing ponding.

The Smith School has two roof levels over each typical wing, the higher draining via scuppers to the lower on which are located the roof drains. Ponding is extensive on the upper roof levels. Extensive water protection raises the roof edges enough to prevent water from reaching the scuppers. This results in an extensive pond at the center of each upper roof area. The roof construction, though, is excellent and does not allow any moisture penetration.

MOISTURE
PENETRATION

MOISTURE PENETRATION/DETAILS (Figure B.5)

Results: Performance was satisfactory (85%) at Parkside and Smith, unsatisfactory (below 75%) at Richards and Mt. Healthy. Detailing permitted water to penetrate the roof.

Probable cause: Inadequate detailing and/or unsatisfactory construction practices at locations of potential moisture penetration.

Discussion: In general all roof penetrations and changes in levels are well detailed in terms of tolerances and materials at all schools. A notable and inconsistent exception is the circular skylight details at the Richards School in which upstand flashing is omitted and the roofing felts are not carried up the edge of the raised skylight. These omissions provided a direct path for moisture and extensive leakage and water staining occurred inside the building. This may have been the major factor which caused total saturation and replacement of the roof a year after occupancy. This has been corrected. The valley flashing over the multipurpose room was incorrectly installed--the flashing was improperly soldered--and this too caused leakage and was corrected.

At Mt. Healthy flashing was improperly installed at the junction of a lower roof that meets an exterior wall and around skylight monitors. This is in the process of being corrected. In the first case, the lower Roof/Exterior wall detail, the exterior wall material was changed from that specified on the working drawings— from diagonal wood siding to brick. We have not seen any revised drawings and there is a possibility that this change was made without the care of the original set or that because the original building form was unaltered, that this form was not sympathetic to the new and unanticipated materials, thus causing problems.

MOISTURE PENETRATION/MOVEMENT (Figure B.8)

Results: Performance is satisfactory (95%) at all schools with the exception of Richards (below 75%) where structural movement has resulted in moisture penetration through the roof membrane.

Probable cause: Thermal expansion and contraction of the 54 foot trusses over the multipurpose room causes openings in the roofing membrane.

Discussion: Unusual circumstances must be present for this phenomenon to occur for the roofing membrane is flexible. At the Richards School we believe these exceptional circumstances did occur as a result of some rather complex relationships.

The 54 foot long roof trusses over the multipurpose room are not free to move at their ends. Since the school is not air-conditioned and the trusses are at the top of this high space they are subject to considerable thermal expansion (and contraction). As they expand and contract they push the exterior walls in and out. This exterior wall is, in turn, restrained at its midheight by the adjacent corridor structure and this joint between the lower (corridor) roof and this moving wall is constantly opening and closing. This is beyond the capacity of the membranes and flashing to absorb this movement leads to water leaking in. This condition exists in the corridors at every point where the lowest roof truss abuts the corridor wall.

It should also be noted (see exterior walls) that extensive cracking occurs on the multipurpose room side emanating from this lowest truss. This may be due to the weight of water in the valley above or to this restrained movement as the lower portion of the wall cannot move outward while the upper portions can.

We believe thermal expansion and contraction of the brick exterior wall of some classrooms has 'popped' the rivets holding sections of aluminum flashing together. Wind-driven water has penetrated the flashing at these points and run into the classroom staining the ceiling. This, however, may also have been caused by expansion of the flashing itself.

DETERIORATION

DETERIORATION/EROSION

Results: In general the roofs are weathering well with the exception of Mt. Healthy (85%) where erosion of aggregate is significant considering that the roof is only two years old. The Richards roof shows excessive deterioration (75-85%).

Probable cause: Unsatisfactory adhesion of the aggregate to bitumen roof membrane at Mt. Healthy. Poor construction seems to be a problem at Richards. A fire in one section of the school has also blistered the roof above it.

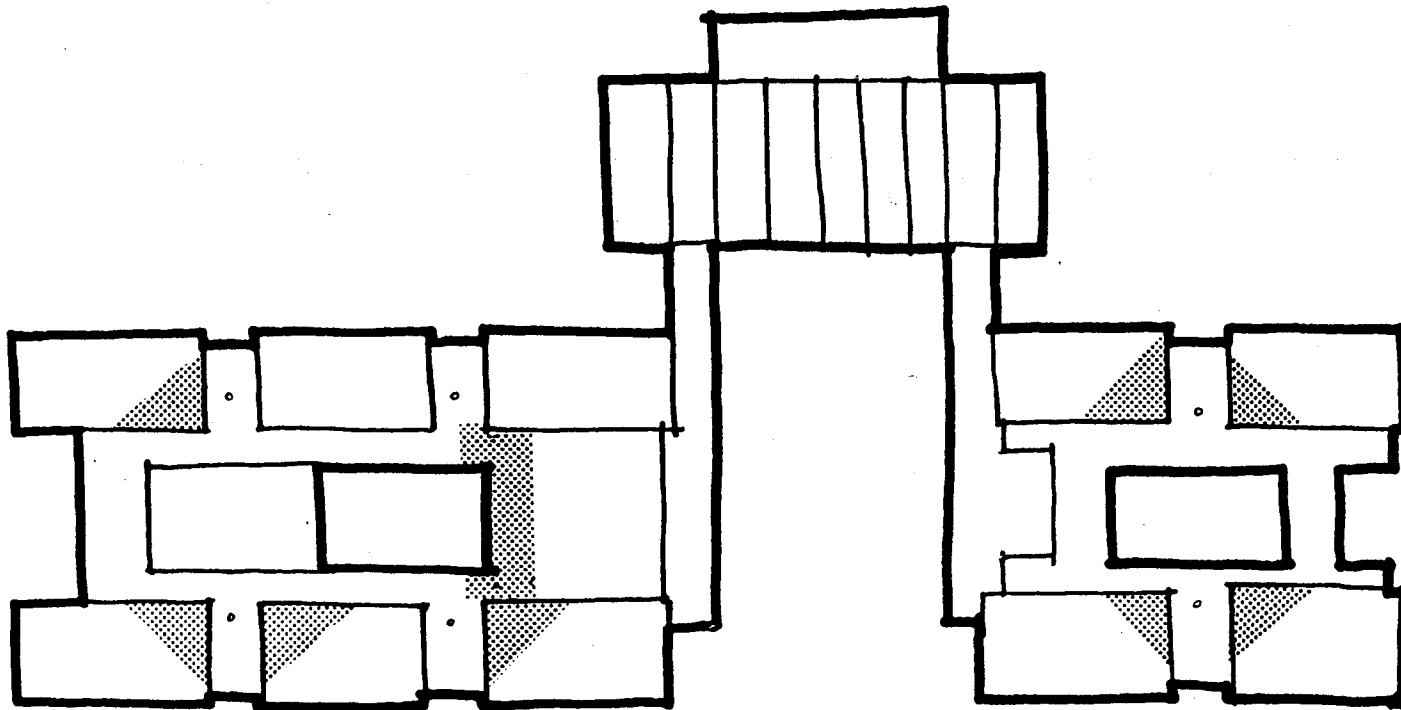
Discussion: The mineral aggregate on the roof surface is critical to the durability of the roofing system. It provides protection of the membrane from impact, infrared and ultraviolet light, to some extent minimized excess expansion and helps reduce blistering and alligatoring. The aggregate must be applied when the final layer of roofing bitumen is still hot so the aggregate is sufficiently bonded to this material.

IMPACT/INDENTATION
BRITTLINESS IMPACT/INDENTATION/BRITTLINESS

Results: Performance levels are satisfactory at all schools examined.

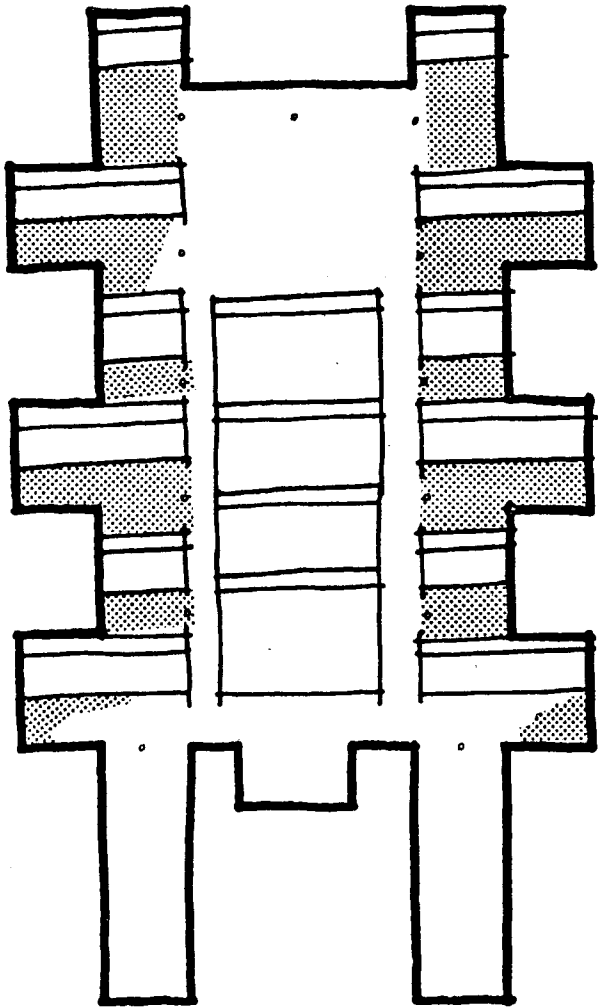
Probable cause: Not applicable

Discussion: The lack of impact and indentation problems to a large degree can be attributed to the fact that these roofs are only accessible to maintenance personnel. Most problems occur when roofs are used for activities or by hail impact. Brittleness is often caused by an inadequate final bitumen layer which by hastens the aging process of the bitumen. Neither impact or brittleness is a problem in these buildings.

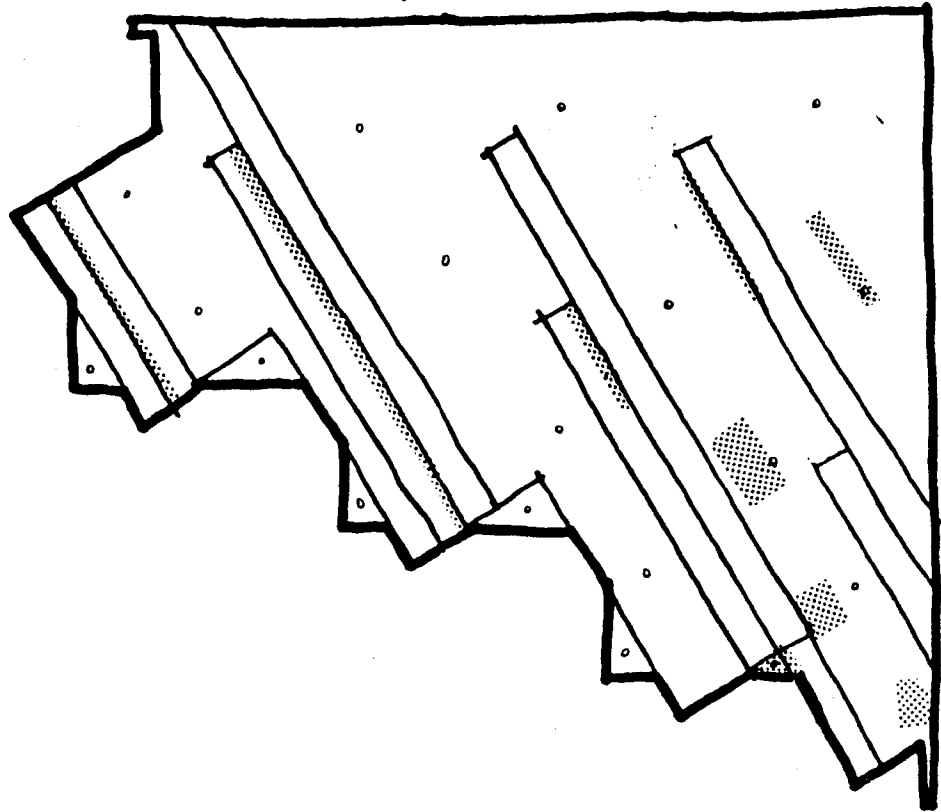


PARKSIDE SCHOOL: PONDING

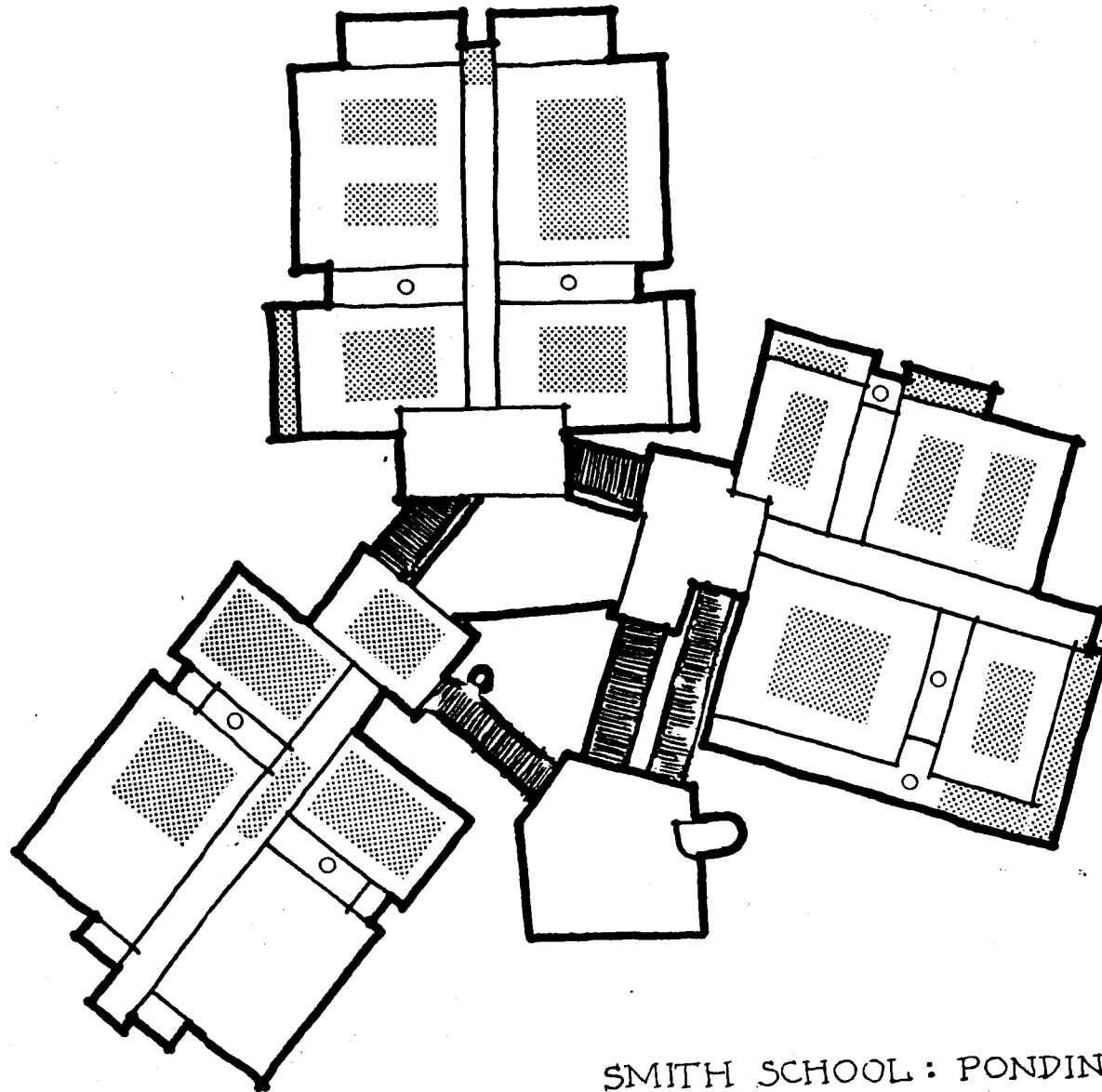
FIGURE B-1



RICHARDS SCHOOL: PONDING
FIGURE B.2

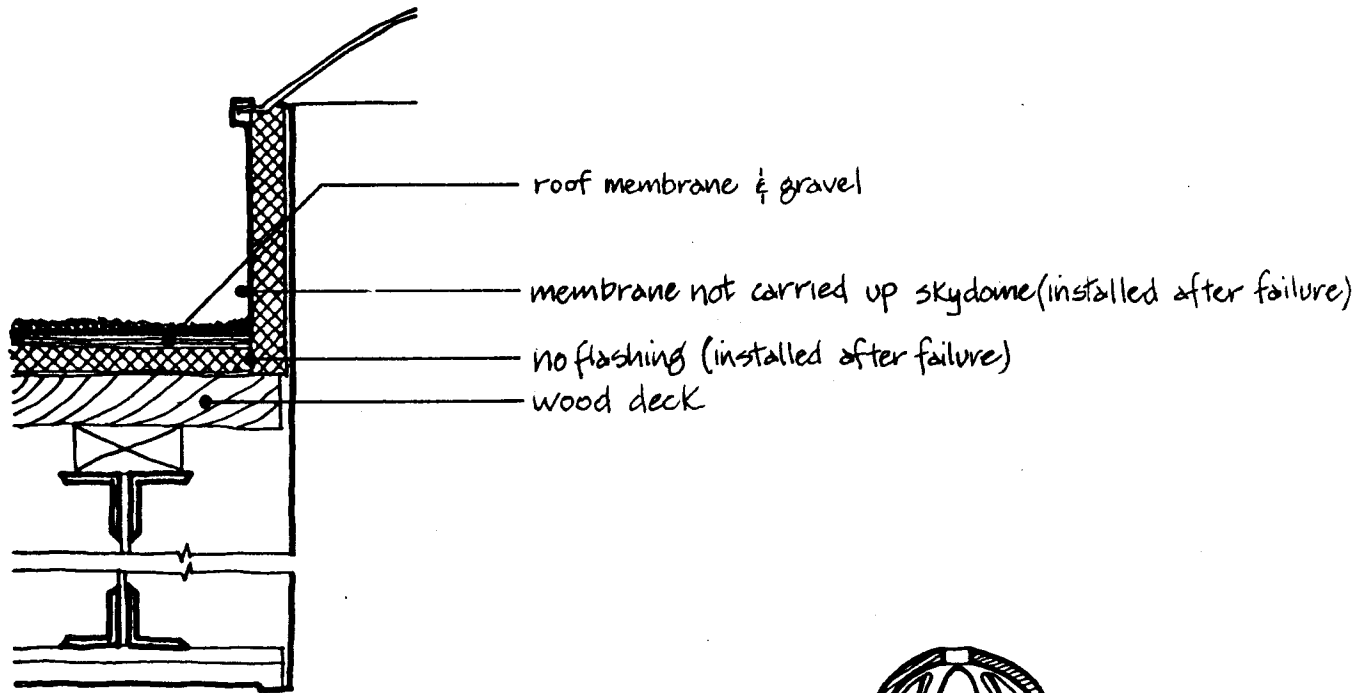


MT. HEALTHY SCHOOL: PONDING
FIGURE B.3

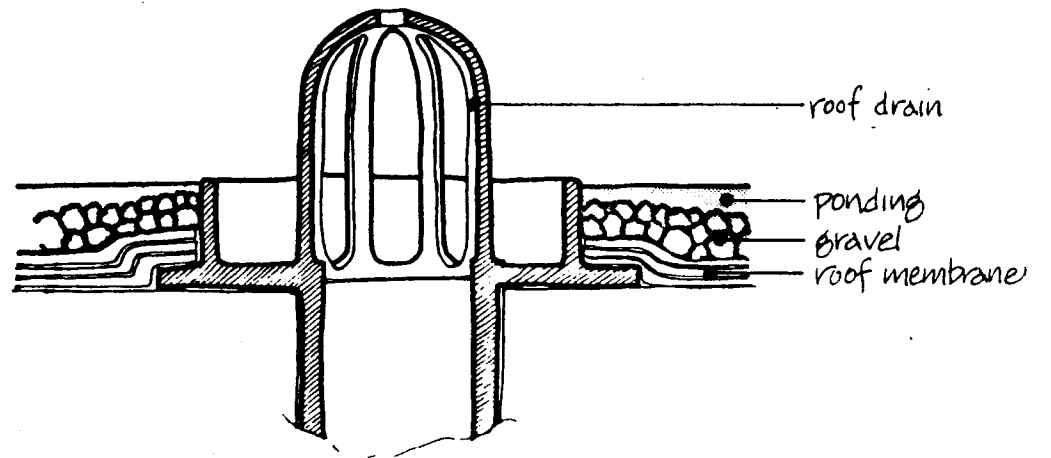


SMITH SCHOOL : PONDING

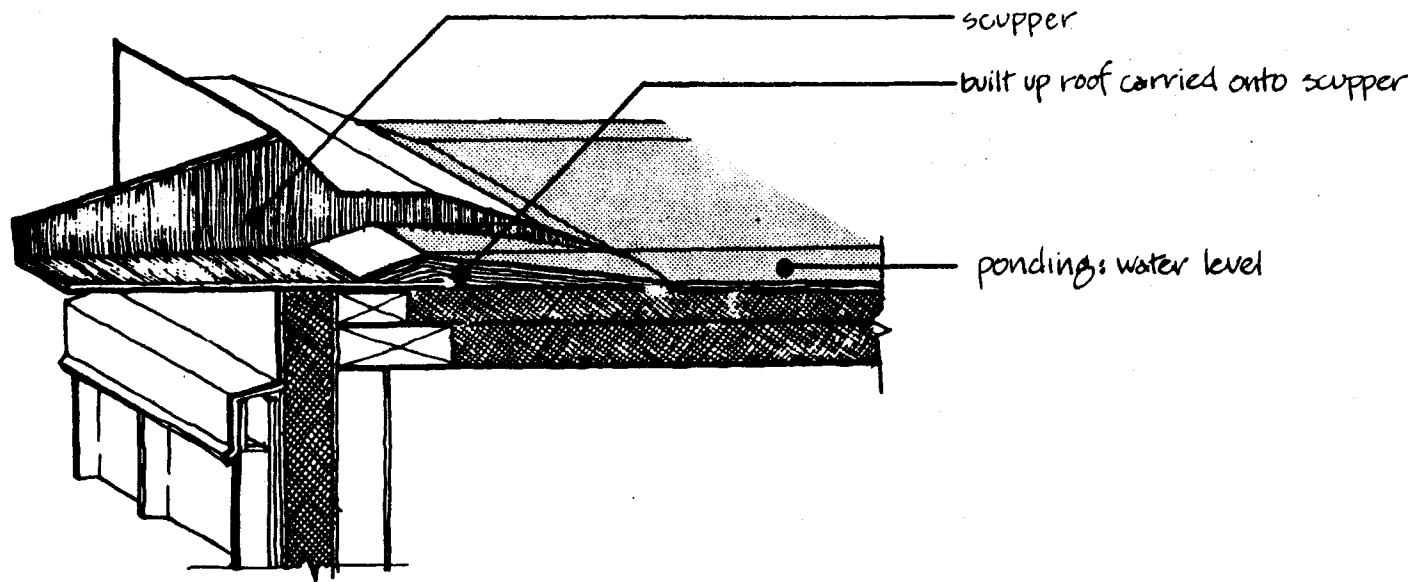
FIGURE B.4



RICHARDS: SKYDOME
FIGURE B.5

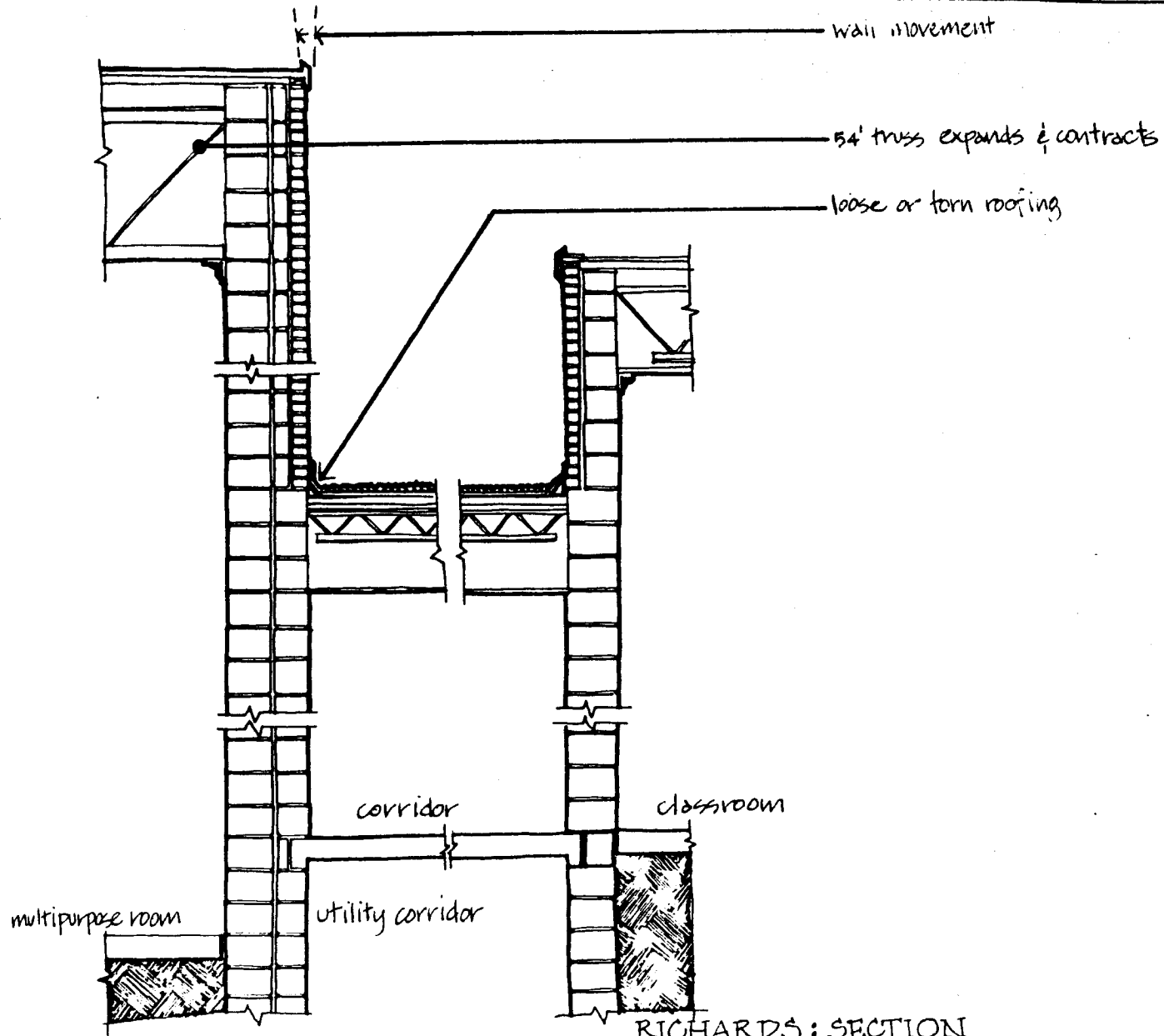


RICHARDS: ROOF DRAIN
FIGURE B.6



SMITH: SCUPPER

FIGURE B.7



RICHARDS: SECTION
FIGURE B.8