EVALUATING TEST EQUIPMENT FOR AIR TIGHTNESS OF CONSTRUCTION DETAILS

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This project was carried out with the assistance of a grant from Canada Mortgage and Housing Corporation under the terms of the Housing Technology Incentives Program (CMHC CR File 6521-12/95). The views expressed are those of the authors and do not represent the official views of the Corporation.

Evaluating Test Equipment
for
Air Tightness of Construction Details

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1. ABSTRACT

Confirmation Testing

The National Building Code 1985 identified the need to control movement of air through the exterior walls of buildings. The upcoming 1995 National Building Code has now placed recommendations on the amount of allowable leakage.

When the air barrier is being installed during the construction period it is practically impossible to monitor air tightness of the installation, in a quantified form. Retro-Specs Ltd. has developed equipment and a method for identifying leaks in construction details of air barrier systems, **during** construction, with "pass/fail" results. This report examines the performance and durability of the test equipment.

Phase 1 covers the development of the testing equipment to a working model stage, suitable for field testing.

Phase 2 incorporates field tests, both locally in Manitoba and one building in Montreal. Comparative testing was conducted versus existing smoke trace leakage tests, fan curve tests, pressure differential activated chamber testing system, pressure differential versus elapsed running time and pressure differential versus leakage area tests. The results were analyzed and conclusions drawn on the performance of the new testing method and equipment.

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3. EXECUTIVE SUMMARY

At the commencement of the project Retro-Specs Ltd. had developed a hand-held testing device, initially conceived for the testing of masonry ties. These ties were either surface-mounted or screwed into concrete masonry block or steel stud drywall assembly with appropriate fasteners, or cast-in-place during the laying of concrete block and then covered with membrane and sealed. Prototypes developed rapidly from the point of proving the concept to a hand-held device that was portable and suitable for use on a construction site.

During **Phase 1** of the project, undertaken on the H.T.I.P. program, component evaluation and selection developed the prototype to the final working model form that is now ready to commence with industrial design.

During **Phase 2** field tests on construction sites within Winnipeg took place, both new construction and retrofit projects. A trip to Montreal was taken to test the effectiveness of the equipment on a building system that consisted of exterior drywall on steel studs with membrane to all perimeters of windows and joints in the drywall, as an air barrier system. Field testing proved to be extremely positive, both in the ability to detect leaks and also in the psychological impact upon the installers of air barrier systems. The term that has been adopted is one of "find it - fix it" in regard to leaks. Not only are successful results obtained in the confirmation of masonry ties, but also in the laps, joints and seams of the membranes and at window to wall junctions. Additionally, a different method of fastening Z-girts for metal siding was developed on two projects, the design of which was changed by the architect to accommodate the tests.

Roofing membranes were also tested and it was discovered that likewise, laps, joints and seams could be tested and leaks detected, during construction.

Four shop/laboratory tests were performed - three for durability and performance rating, and one comparative test against existing technology. The test device outperformed the existing method of smoke trace to identify leaks and the durability testing confirmed that the components and operating parameters of the equipment were suitable for an on-site testing device.

The question that was expected to be raised was one of "allowable leakage," but at no time during field testing was opposition encountered regarding a given area being allowed a given leakage rate. The method of testing and correcting deficiencies is performed very quickly without interruption to the critical path of construction. Therefore, it is not logical to gamble on the collective total of leaks being over the recommendations. At the onset of projects, if a repeated pattern of leaking at similar details occurred, alternate methods of application were developed.

The results obtained from this program have proven that the P.A.C.T.S. machine's components are durable, results in superior installation of air barrier systems, with the testing procedures having little impact upon the critical path of the construction schedule.

RÉSUMÉ

Au début de l'étude, Retro-Specs Ltd. avait mis au point un appareil d'essai à main qui devait servir à mettre à l'épreuve des attaches à maçonnerie. Ces attaches étaient soit montées en applique, soit vissées au moyen de fixations appropriées dans des blocs de béton ou une ossature d'acier recouverte de plaques de plâtre, ou encore coulées en place durant la mise en oeuvre des blocs de béton pour ensuite être recouvertes d'une membrane et scellées. Les prototypes se sont suivis rapidement, d'abord pour éprouver le concept, puis pour mettre au point un appareil portatif pouvant être utilisé sur un chantier de construction.

À la **Phase 1** de l'étude, entreprise dans le cadre du Programme d'encouragement à la technologie du bâtiment résidentiel, l'évaluation et la sélection des composants de l'appareil ont permis de réaliser le modèle fonctionnel définitif qui est maintenant parvenu à l'étape de la conception industrielle.

Lors de la **Phase 2**, des essais sur des chantiers de Winnipeg ont été menés tant en construction neuve qu'en rénovation. L'efficacité de l'équipement a également été mise à l'épreuve à Montréal sur un assemblage constitué de plaques de plâtres extérieures fixées sur une ossature d'acier dont la membrane recouvrait le périmètre de toutes les fenêtres ainsi que les joints des plaques de plâtre, lesquelles agissaient comme pare-air. Les essais en service ont été extrêmement concluants, tant pour la capacité de l'appareil à détecter les fuites que pour l'effet psychologique sur les installateurs de pare-air. L'appareil permet de trouver les fuites et de les réparer sur-le-champ. Non seulement l'appareil est très efficace pour confirmer l'étanchéité des attaches à maçonnerie, mais il donne aussi d'excellents résultats pour les recouvrements, les joints et les agrafures des membranes ainsi qu'à la jonction des murs et des fenêtres. En outre, l'appareil a permis, sur deux chantiers, la mise au point d'une méthode différente pour assujettir les fixations en Z du bardage métallique. En effet, l'architecte en a changé la conception pour que les chercheurs puissent procéder aux essais.

Des membranes de couverture ont aussi été mises à l'essai et on a découvert que, tout comme pour les murs, on pouvait déterminer l'efficacité et l'étanchéité des recouvrements, des joints et des agrafures pendant la construction.

Quatre essais en laboratoire ont été réalisés, à savoir trois essais visant à déterminer la durabilité et le taux de performance de l'appareil et un essai destiné à comparer la méthode envisagée à la technique habituelle. L'appareil a offert une meilleure performance que la méthode habituelle qui consiste à utiliser un gaz traceur pour repérer les fuites, et les essais de durabilité ont confirmé que les composants et les paramètres de fonctionnement étaient conformes aux caractéristiques requises d'un appareil d'essai in situ.

Les chercheurs s'attendaient à ce que la question de la «fuite admissible» soit soulevée, mais personne n'a allégué, durant les essais en service, qu'un taux de fuite donné pouvait être toléré dans certaines zones. La méthode d'essai et de correction des défauts est très rapide et n'interrompt pas le cheminement critique des travaux. Il n'est donc pas logique de s'attendre à ce que le total des fuites excède les recommandations. Dès le début des travaux, quand on s'apercevait que des éléments entraînaient des fuites à répétition, on changeait les méthodes de mise en oeuvre.

Les résultats obtenus lors de cette étude prouvent que les composants de l'appareil, appelé *P.A.C.T.S.*, sont durables et permettent une mise en oeuvre supérieure des pare-air sans nuire au cheminement critique du calendrier de construction.

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4. BACKGROUND

The construction industry has been faced with the need to confirm air tightness of air barrier system/membrane installation *during* the construction period, when the only opportunity to correct deficiencies is available. A very small window of opportunity exists when the air barrier system/membrane is left exposed, prior to being covered by insulation and finishing materials. Designers provide the plans and specifications, manufacturers produce materials to meet all requirements, but the installers are the key component in the delivery of an effective system. Therefore, to provide the installer with a meaningful test method to confirm the installation with a "pass/fail" result that is easy to register and does not interfere with the critical path of the construction schedule, is essential.

The upcoming National Building Code 1995 Appendix references a recommended leakage rate for air barrier systems. The problem this creates in the evaluation of air barrier systems during construction is one of how to accumulate and measure leakage throughout the entire building. Quantified tests such as ASTM E283 can provide confirmation of a small section of the building, but they cannot be used throughout due to the cost and time involved to conduct the tests. If a section of wall is found to be leaking, the individual deficiencies may not be able to be located. Smoke trace tests can be performed by isolating a section of the structure by tenting and pressurizing while introducing a trace smoke element. This can identify the point of deficiency, but again, it is a timely exercise and the procedure is far too expensive in time and labour to perform to the entire building. Post-construction testing by measured air flow (blower-door) or by mechanical pressurization can confirm whether the structure has been built to recommendations, but it does not locate the specific deficiencies and is too late then to correct them.

At this time in the development of the testing equipment, the goal was to provide a tool and method for the confirmation of the installation of air barrier membranes that would allow quick confirmation of installation performance. The testing method must not be affected by any climatic condition to which it might be exposed (i.e., temperature, wind, humidity) and must also not prove detrimental to the components being tested. Most problems occur at junctions of components: laps and joints within the membrane, junctions with windows and expansion joints must prove to be testable. Test methods must accommodate all the materials and design configurations involved. The test must be able to be performed to a wall that is not a part of a completed structure, as this is the condition that the industry faces during the construction period. The testing equipment must be small enough to enable the worker to use it efficiently while on scaffold or swing-stage and to withstand exposure to construction site activity, without compromising the results. To meet these criteria, confirmation and durability testing are required to ensure the product can withstand the demands placed on it by on site use.

The impact on the construction industry would be the ability to deliver a better sealed structure to the owner. Potential energy savings promised by the better building performance of an inspected system is a consideration for success in this product's development. The liability and risk of building failure due to deficiencies in the air barrier system will be reduced. Initial cost of an installed air barrier membrane will increase due to the higher labour content required for an inspected system over a non-inspected system. This additional cost at the time of construction is insignificant when compared to the cost of premature building envelope failure. The most recent reported cost of repair to structures suffering premature building envelope failure is approximately $500,000,000 per year in Canada, and a proportion of this can be attributed to failed air barrier systems (NRC report as per J.Rousseau, Project Manager, CMHC).

5. OBJECTIVES

The specific objectives of this project are as follows:

1) Development of a working model prototype suitable for field testing.

2) Field testing to numerous conditions and construction types.

3) Testing the performance and durability of chosen components.

4) Comparative testing of P.A.C.T.S. machine against other methods of evaluating air tightness of air barrier systems.

6. PHASE I: PROTOTYPE EVOLUTION

Background up to HTIP involvement

Prototype 1

The first prototype constructed to test for air leakage was a small plastic flask with a rubber seal and an offset vacuum pump. See Photos A, B, and C. A soap solution was applied around the test detail. Bubbles forming indicated air moving from behind the detail to the test surface, under the pressure differential created within the flask test chamber. See Photo B. This soap solution was developed under I.R.A.P. assistance by a student from the University of Winnipeg, and a chemist from the N.R.C. This proved that the idea worked. The differential pressure created inside this chamber was so great that it lifted the membrane within the perimeter of the flask away from the substrate.

Problems with Prototype 1:

The vacuum pump had to be plugged in, requiring available electricity and extension cords.
The vacuum pump creating the pressure differential was heavy, not sufficiently portable.
Not all configurations and sizes of ties could be accommodated by the small test chamber.
The pressure differential created was too great, enough to damage the test site, so testing at this level is not realistic as representative of actual field conditions.

Goals for next iteration:

Construct a lightweight, battery-operated, one-piece tester.

Prototype 2

The second prototype of the Pressure Activated Chamber Test System or *PACTS* machine was constructed with a small, hand-held vacuum cleaner and a plastic dome. PACTS has been adopted as the working acronym for the testing machine, pending a marketing trade name. This machine was a dismantled, battery-operated vacuum cleaner, with a plastic dome-shaped chamber attached to the fan and motor casing. See Photo D. The chamber was small and therefore limited in the details that could be inspected. Brick tie systems are often up to 10" in depth from the wall demanding the construction of a larger chamber to successfully test this kind of detail. A gasket seal was installed to the open end of the chamber to facilitate the contours and irregularities of a wall. The original seal on the first prototype consisted of a bitumen-impregnated foam seal, which could accommodate the small steps and seams in the installed membrane.

Problems with Prototype 2:

The seal worked well in warm conditions but proved ineffective in cold weather, as the bitumen-impregnated foam seal became rigid and unworkable at low temperatures. An extension ring was installed to the open end of the chamber to test larger ties. However, the present width of the dome did not provide good visibility to the test area. Also, turbulence caused by air drawn from the test chamber resulted in the bubbles at the test detail bursting prematurely.

Goals for next iteration:

An all-weather seal must be found.
The size of the test chamber must be increased.
Visibility proved satisfactory in good light conditions, but in an enclosed or hoarded area with poor lighting, visibility was limited.
Install a light to illuminate the test detail.
An air baffle would reduce turbulence inside the chamber.

Prototype 3

H.T.I.P.'s involvement with the project began at this point. A third configuration of the PACTS machine was constructed using a larger plastic chamber. An open-cell, urethane foam seal was used on this model that worked well in cold weather conditions. A light was installed to the inside the chamber and activated by the on/off trigger of the PACTS machine.

Problems with Prototype 3:

If the seal came into contact with the soap solution used to indicate leaks with bubbles, foam and small bubbles formed around the seal, giving a possible incorrect result to the test. Pressure inside the test chamber was measured and found too high for a realistic test.

Goals for next iteration:

Design an airtight seal that maintains the all-weather applicability of the open cell urethane.
Develop a means of regulating and measuring the pressure to facilitate achieving required levels.

Prototype 4

This fourth PACTS machine was constructed using the same open cell urethane seal, but the foam was coated with silicone caulking to overcome the forming of bubbles. See Photo 2. This appeared to work satisfactorily, as the soap no longer came into contact with the open cells of the foam. The previous lighting system was again installed (see Photograph 6 for location of light). A wire-wound the pressure differential, as required. A pressure differential switch was installed which indicated when the desired test pressure differential was attained, with the addition of a signal light to confirm required levels.

Problems with Prototype 4:

The plastic chamber used proved to be very weak and prone to cracking.
The silicone caulking remained tacky to the touch and dirt stuck to the surface of the seal (see Photograph 5).
The offset location of the light made illuminating the test detail awkward. Constant light was not required for illumination while the test was performed, particularly if lighting was adequate. Constant light would prematurely drain the battery.
The speed-control voltage regulator was temperamental, not maintaining a constant fan speed after being set. It also was mounted on the outside of the casing, making it hard to operate and cumbersome.
The pressure differential switch was side-mounted, and the center of gravity was shifted away from a comfortable position.

Goals for next iteration:

High-impact, plastic dome required.
Improved closed-cell foam seal.
New light location to create better visibility.
Find a compact, speed-control mechanism to install within the casing.
Relocate the pressure differential light switch to improve operator comfort.

Prototype 5

A polycarbonate chamber that was tough and lightweight was used for this model. A friction-fit trim was installed to the edge of the chamber to protect the seal and the rim of the chamber. See Photo 3. The new seal was made of closed cell neoprene (see Photograph 7). The ergonomic factors of the design were considered. The pressure differential switch was relocated to the rear of the machine handle that improved the balance and ease of use. The speed control trigger was installed in the location of the on/off switch on previous models. This trigger was to be operated with the fore finger, on the underside of the hand-grip. The light was mounted at the rear of the chamber, inside the collar of the handle attachment. This new positioning improved visibility of the test area, being directly above the test detail.

Problems with prototype 5:

The speed control trigger proved difficult to operate.
The hand-grip on the PACTS machine offered limited room for operating the trigger and a gloved hand will not fit at all.

Goals for next iteration:

Change the location of speed-control trigger to improve operation.
Alleviate cramped space for gloved hand in hand grip.

Prototype 6

The speed control trigger was moved to the top of the hand grip, to be operated by the thumb. This proved easier to operate than the finger trigger. New location of trigger improved hand grip by making more space inside. See Photo 4. The red switch directly below the speed control trigger, is an on/off switch for the light inside the chamber. The light may then be used only when required, increasing the life span of the battery. A new, one-piece seal was developed and installed making easier replacement should the seal be damaged while in use (see photograph 8).

Improvement Evolution from Prototype 1 through Prototype 6:

- One piece, lightweight tool
- Balanced for easy, comfortable operation of the PACTS machine
- Impact-resistant, durable chamber for all-weather use
- Seals satisfactorily to many surfaces (see Photograph 7)
- Effective control of motor speed and pressure differential
- High visibility of test area (see Photograph 7)
- Illuminated test detail

PHOTOGRAPH LOG

Equipment Development

A) Container with soap solution; Prototype 1, offset vacuum pump and clear flask; Test performed on brick tie, air barrier membrane mounted on plywood

B) Test sample showing signs of bubbling at leak point

C) Prototype 1, offset vacuum pump and clear flask; Test sample on masonry block

D) Prototype 2, hand-held vacuum with clear dome

1) Prototype 3, hand-held

2) Prototype 4, addition of variable speed switching and pressure differential switch and indicator.

3) Prototype 5, variable speed trigger.

4) Prototype 6, relocate for ergonomics/ thumb trigger.

5) Prototype 4, urethane open cell gasket seal.

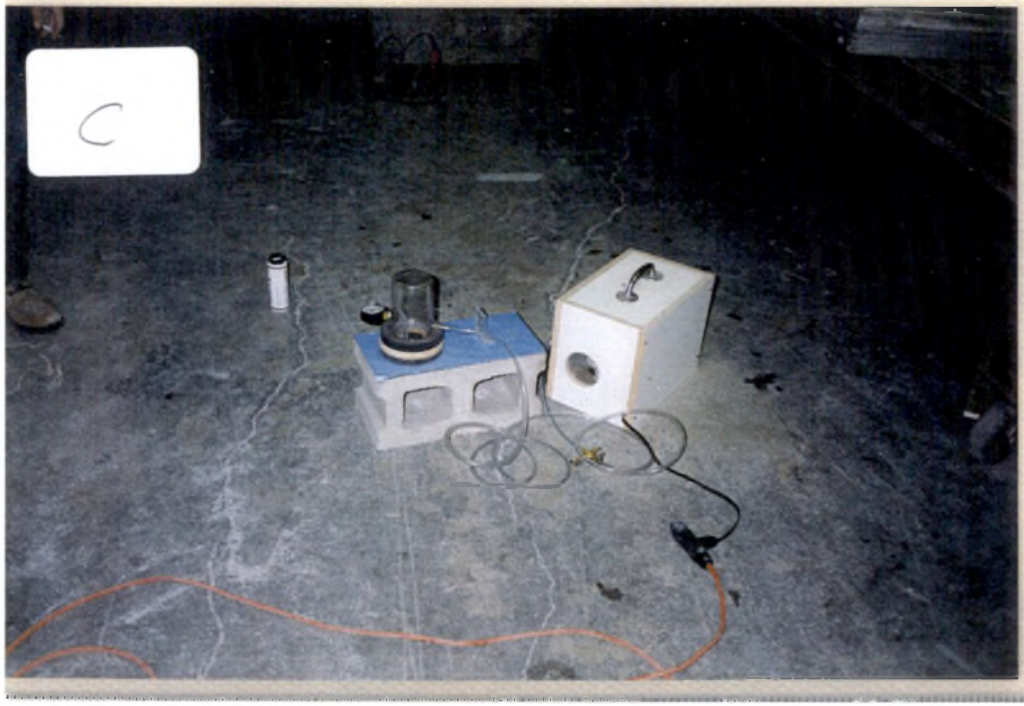
6) Prototype 4, light and air baffle, gasket seal coated with silicon.

7) Prototype 5, new hollow ridged closed cell neoprene rubber seal, separate from finished trim.

8) Prototype 5, new closed cell neoprene rubber seal and trim, manufactured in one piece.


A


B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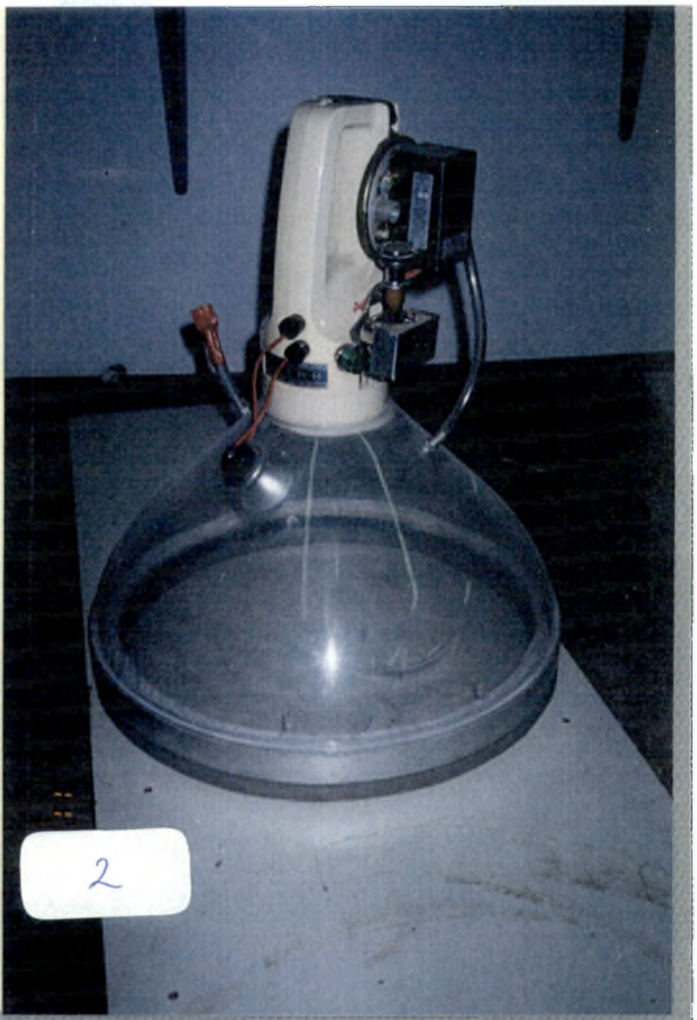
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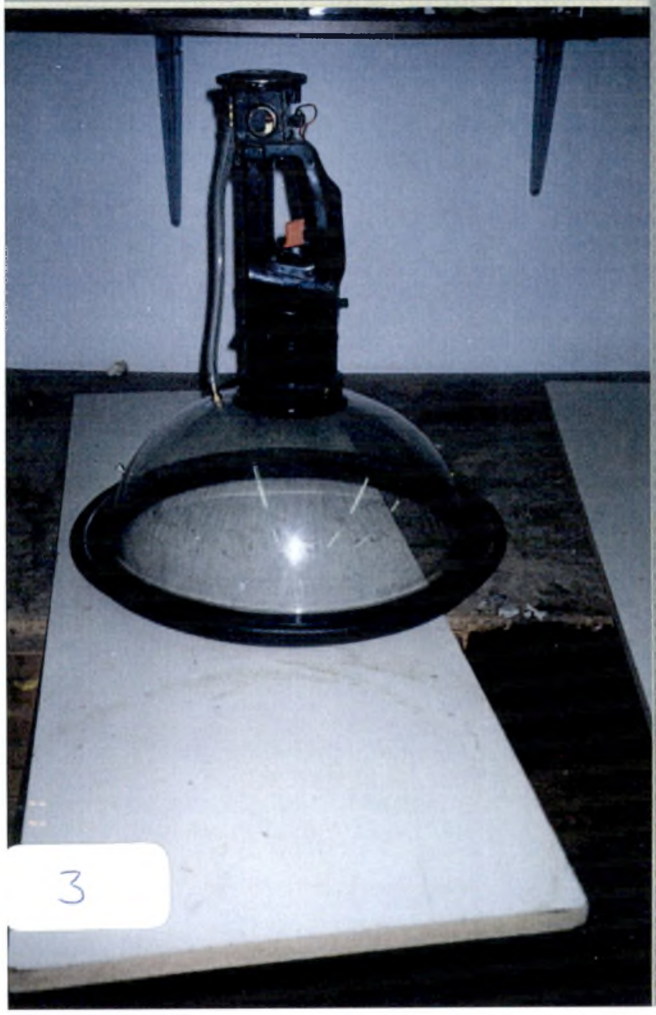
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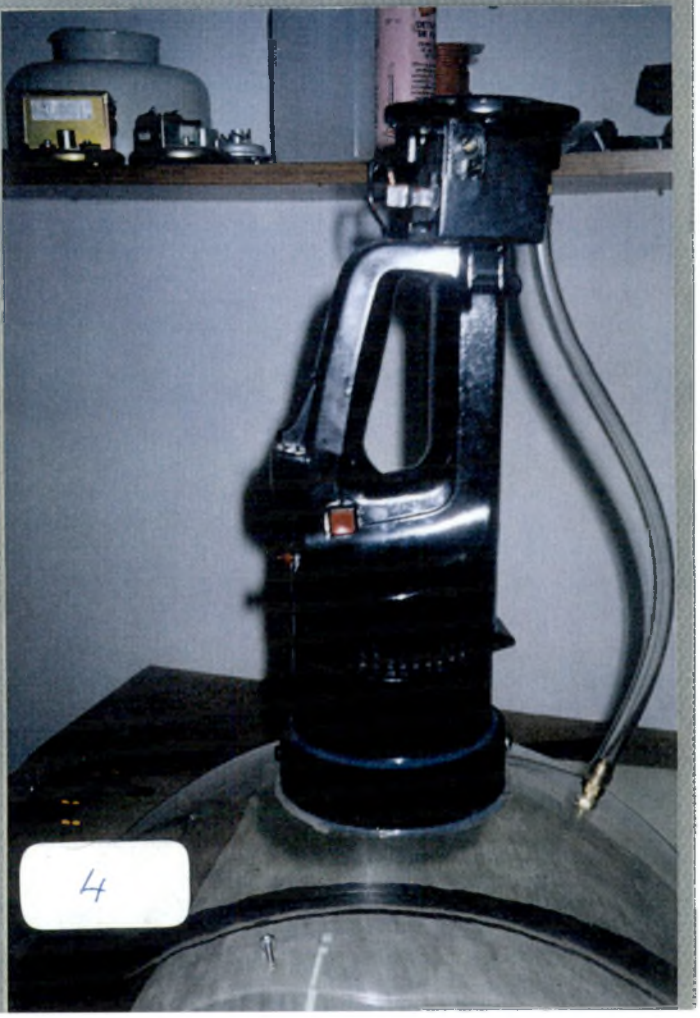
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7. PHASE II

7.1 Field Testing - Winnipeg

During contracted inspection of air barrier systems, the developed testing prototypes were used with owners' permission at the following projects.

7.1.1 Swimming Pool Retrofits A and B

Description of Construction

The air barriers tested were on two identical swimming pools undergoing complete retrofits of the building envelope. Existing building envelopes consisted of concrete block backup wall, a trowelled-on synthetic rubber based insulation adhesive, closed-cell extruded polystyrene foam insulation and clay face brick or steel panel. The retrofits consisted of removing the existing face brick, steel panels and insulation. The substrate was then prepared by scraping the existing insulation adhesive flat and applying a solvent based primer. New self-adhered membrane was then applied to the backup wall. Brick ties and mounting brackets for the steel siding were surface-mounted with screws to the backup wall through the air barrier membrane.

The roof retrofit consisted of applying a self-adhered membrane directly to the existing wood deck. Vertical and horizontal wood nailers were screwed to the wood deck through the vapour barrier to hold in place rigid insulation.

Testing of air barrier details took place during the construction. Testing with the PACTS was undertaken on membrane joints, seams, and penetrations at brick ties and mounting brackets. The penetration due to screws in the wood nailers on the roof could not be tested with the PACTS apparatus.

Observations

The PACTS prototypes used on this project were relatively easy to use. Some problems were encountered with the visibility of certain coloured lights for the pressure switch were identified. Although the apparatus is not heavy (approximately 2.3kg), the centre of gravity is forward of the handle due to the weight of the dome, which results in strain on the wrist. Better balance of the equipment can be achieved in the design. A carrying strap would be desirable when working from scaffold or ladders.

The PACTS apparatus was able to detect leaks at seams and penetrations in the membrane on relatively flat surfaces. The perimeter seal on the dome of the prototypes could seal minor irregularities on the test surface, such as occur at overlaps of membrane and mortar joints. However, inside and outside corners, surfaces with large irregularities and junction of membrane with window and door frames could not be tested with the existing prototypes. The development of domes with different profiles could facilitate the testing of these details.

The bubble solution used with the PACTS was effective when used to find small leaks in the membrane. On larger holes, the bubbles often popped too rapidly to be noticed. However, these larger leakage paths could often be identified visually by an experienced inspector. The effectiveness of the apparatus can be increased by slowly increasing the speed of the motor until the pressure switch operates the light. Also, applying the bubble solution by thoroughly wetting the test surface rather than dabbing the surface leaving a foamy film, increases the effectiveness of the apparatus on large leakage paths. The development of a bubble solution that would be more effective on larger leakage paths would be desirable.

The amount of bubble solution used was highly dependant on the user and on the size of the details tested. The amount varied between 1.1 and 2.7ml per tie (84 to 206 ties per 227ml bottle) for the 2" (~50mm) ties used in the project. It was noticed that the solution became contaminated with dust and other impurities with continued use from one bottle. The contamination is a result of applying the solution with a dabber. The presence of impurities in the solution may result in reduced performance of the solution. Applying the solution from a spray applicator would alleviate this problem.

The time to test a single tie averaged out to approximately 13.9 s/tie (259 ties/h) for two-operative testing, one person applying the bubble solution and one person operating the PACTS. This method is advantageous when testing long rows of ties from the ground or scaffold, as in this project.

From the beginning of the project the PACTS apparatus played an important role in the design of the air barrier details. PACTS tests on mockups indicated that a large percentage of the surface mounted brick ties and mounting brackets for Z-girts could be expected to leak around the screw holes if suitable attention was not paid to this detail. The testing with the PACTS indicated that a better air seal could be realized if mastic was applied behind the ties and brackets, therefore this procedure was undertaken on this project. Using this procedure, about 3% of the 795 ties tested on site were found to leak. None of the 14 mounting brackets tested were found to leak. Some of the leaks in the ties appeared to be due to a missing screw or a screw not driven in completely.

The effects of the testing on the quality of workmanship were apparent on this project. The test provides a positive visual indication of the presence of leaks, eliminating arguments from the trades involved. At the onset of site testing with the apparatus, T-joints in the membrane were often found to leak. T-joints occur in roof and wall membranes where a sheet of membrane overlaps a vertical joint on the adjacent membrane. This resulted in the trades involved paying particular attention to the T-joints. T-joints were rolled or had mastic applied, which resulted in achieving the desired seal. Where flutes occurred over junctions of membrane, the trades applied mastic or re-rolled the membrane.

7.1.2 Swimming Pool Retrofit C

Description of Construction

The air barrier tested was on a swimming pool undergoing a complete retrofit of the building envelope. The existing building envelope consisted of a concrete block backup wall, trowelled-on synthetic rubber, asphalt based insulation adhesive/vapour barrier, semi-rigid fibreglass, expanded polystyrene bead board insulation and fluted concrete block cladding. The retrofit consisted of removing the existing cladding and insulation. The substrate was prepared by scraping the insulation adhesive smooth and applying a solvent based primer to the backup wall. After the new self-adhered air barrier membrane was applied, brick ties were surface-mounted with screws through the membrane into the backup wall.

Testing of the air barrier details took place during construction. Testing was undertaken with the PACTS on joints and seams in the membrane and penetrations through the membrane at brick ties.

Observations

As with other projects on which the PACTS was used, the PACTS played an important role in the design of the air barrier details. Mastic was used behind the brick ties to ensure an airtight seal at the penetrations trough the membrane. T-joints and seams suspected as potential leak points were sealed with mastic by the trades because they were aware that they could be tested with the PACTS.

At the initial setting of 130 ties, 35 were found to leak (26%). These ties were all resealed using mastic. After the initial test, the tradesmen changed to another type of mastic and were more conscientious about their workmanship. On the following random tests undertaken, only 3 of 155 ties tested were found to leak (2%).

Several tests were undertaken to try to determine the amount of time required to test with the PACTS. The results suggested approximately 14.4s/tie (250 ties/h) when one person did the testing on the ground. When two persons did the testing on the ground, the time was approximately 7.1s/tie (507 ties/h). Working from a ladder, the time was about 17.2 s/tie (209ties/h). The results would vary for different persons, weather conditions, number of leaks found, reporting requirements and other factors.

7.1.3 Health Care Facility A

Description of Construction

The air barrier tested was on a mid-rise health care facility under construction. The backup wall in the areas tested was poured in place concrete. Torch applied membrane was installed onto the surface of the concrete. To seal to the windows frames, a self-adhered membrane flap built into the window frame was adhered to the torch applied membrane on the walls. Z-girts were screwed into the backup wall through the air barrier membrane to support aluminum panels.

Testing of the air barrier took place after the installation of the air barrier system. The PACTS was used to test seams and joints in the torch applied membrane and the self-adhered membrane surrounding the windows. The connectors penetrating the air barrier to support the Z-girts could not be tested with the existing PACTS prototypes as they were to large to fit inside the dome.

Observations

Few leaks were found on the seams in the torch applied membrane. The seams on torch-applied membrane are sealed by heated tar smoothed over the seam, providing an excellent air seal when done correctly. The concrete backup wall was also airtight in many areas. When a leak was found in the membrane with the PACTS, it was unknown whether the air was drawn through the wall or from air trapped between the membrane and the concrete backup wall. In the areas tested, many large unbonded areas of membrane existed. Therefore, there was the possibility that air could channel behind the membrane from a leak in the backup wall to a leak in the membrane. Where a hole existed in the membrane, it may not have been identified with the PACTS. The air could not be drawn through the concrete backup wall, however, since these holes do not extend through the entire building envelope. These should not create a leakage problem in the building envelope.

The PACTS was able to confirm leaks in the air barrier at window locations where the self-adhered membrane flap from the frame was adhered to the torch applied membrane on the backup wall. Some of the leaks around the windows were a result of torch-applied membrane being installed around the window after the installation of the self-adhered membrane flaps, resulting in burning the self-adhered membrane. Where the self-adhered membrane was not burnt and mastic was applied to the edges leaks were not found.

Some areas were tested from ladders with the PACTS. The installation of a carrying strap on the PACTS would make it easier and safer to climb the ladders and scaffold with the PACTS.

7.1.4 Health Care Facility B

Description of Construction

The air barrier tested was on a high-rise health care facility under construction. The building envelope consisted of a masonry, concrete or drywall backup wall, torch-applied air barrier membrane, insulation and clay brick cladding. The brick cladding was supported by shelf angles at each floor and brick ties, both surface-mounted and shear ties which are cast into the backup wall. Areas of the building envelope that were curtain wall were joined to the air barrier with a metal flashing. Self-adhered membrane was used to join the torch applied membrane on the backup wall to the metal flashing on the curtain wall.

Testing of the air barrier with the PACTS took place during construction. Testing with the PACTS was undertaken at joints and seams and penetration through the membrane at brick ties.

Observations

Few leaks were found at seams and junctions in the membrane. Leaks were found at the junction of the curtain wall to the air barrier on the masonry backup wall, which resulted in the air barrier contractors being required to apply mastic at the seams. Approximately 33% of the 456 shear ties tested were found to leak, a significantly larger proportion than the surface mounted ties tested on other projects. In some groups tested, as little as 10% and as much as 60% of the ties leaked. The quality of the installation dropped when the air barrier installers were rushed by the finishing trades. Sections of wall where a large percentage of leaks were found the air barriers contractors were instructed to redress the ties.

The approximate number of ties a PACTS with a fully charged battery could test before a recharge was required was determine on this project. Over a period of 16 days, 335 details were tested with the PACTS before the PACTS became unusable. As in pressure differential versus running time tests undertaken, the performance of the PACTS dropped of suddenly. Using a 15-second average test time, the 335 details translate into approximately 1.5 hours of test time. More tests of this type will be carried out in the future on production prototypes.

7.2 Field Testing - Montreal

With the owner's permission, confirmation testing of the efficiency of the testing equipment was undertaken.

Description of Construction

The seven-storey building, plus a penthouse, consisted of a main elevation facing south with two wings on the east and west elevations. These wings connected back to an existing three-storey building, forming an open courtyard to the centre of the structure. The construction consisted of: concrete frame, steel stud in-fill from the inside, interior drywall, poly vapour barrier, batt insulation between studs, exterior drywall, semi-rigid fibreglass insulation fastened back to steel stud, and masonry veneer. Bakor's Blue Skin self-adhered and torch-grade membrane was used at all junctions of the drywall, floor studs and perimeters of vinyl windows. Exterior drywall functioned as the air barrier system. Masonry ties were an 'L'-shaped bracket fastened with one screw (Deckfast) through the drywall to the steel stud.

A review of construction details was conducted and procedure for the utilization of our apparatus was decided. At the time of our visit, the ground floor of the south elevation had been completely covered with masonry. The west side of the south elevation to the second floor had also been completed with masonry. The east side of the south elevation had been covered with insulation. The east elevation was completed to the point where the exterior drywall was installed, the windows were in place, and the air barrier was installed to the third floor. Interior insulation was not yet installed. The west elevation exterior drywall was completed to the third floor and insulation was installed to most of the first floor. Air barrier and windows were installed. The courtyard area was completed to the third floor with exterior drywall, windows and air barrier. Insulation was installed to the second floor with masonry commencing at ground level. The test was to be carried out on the south, east and west walls, to the exposed exterior drywall where the air barrier material had been installed.

Protocol for the Test Apparatus

To date, all testing had been performed either on bituthane membranes (both self-adhered and torch-grade) or sheet metal liners. The task was to assess the testing equipment to an exterior airtight drywall system.

Procedure

The first tests were performed at a designated location on un-insulated wall. From observations made of the installation of the air barrier, it was obvious that deficiencies were present. Fissures, poorly bonded material, and taut membrane across corners, etc., were all seen to exist. On the first 2' of membrane tested, seven leaks were identified. Bubbles formed easily both at laps, joints in adjoining membranes, and where the membrane terminated on the face of the exterior drywall. A small proportion of soap suds was noted to be absorbed by drywall.

Expansion/compression joints at floor levels proved a challenge due to the continuous channel made by the compression joint. The problem for the PACTS machine was easily surpassed by installing small blocks of foam rope at the point where the test chamber covered the compression joint.

Small holes were observed in the drywall where unsuccessful attempts had been made to locate steel studs with drywall screws. This condition proved slightly more challenging to identify a positive leak. Absorbtion of the soap/suds solution by the exterior drywall required a quick response, with the test equipment after thee application of the soap. Also, when the device was removed or the fan switched off, the bubble collapsed due to the hole in the drywall being directly open to the interior of the building. A very small pressure differential (40 Pa) provided best results at this deficiency. The PACTS tester already operated with a variable speed trigger, allowing different pressure differentials to be achieved.

Some laps and seams formed extremely large openings to which it was impracticable to apply the soap suds solution, and simple visual inspection was sufficient under these conditions. Ten masonry ties were installed, and the test apparatus identified leaks to nine of them. Bubbles formed at all times to the right hand side of the screws. This could be attributed to the installer being right handed, forming a bias in the pressure of the screw penetrating the drywall.

The test apparatus proved extremely effective at leaks to the wall-side of the membrane at the window detailing, but could not perform tests to the membrane adhered to the leading edge of the window. This test could be carried out with a differently profiled chamber and warrants investigation. The air barrier material had failed to seal the open mullion and corner extrusions of the window units at some locations. This also proved not to be a testable detail due to the profile required and does not warrant any further development, as the deficiencies are obvious and easily identified by visual inspection.

The deficiencies described were identified and communicated to the appropriate project personnel for rectification.

PHOTOGRAPH LOG

Field Testing - Montreal

1) West Elevation.

2) East Elevation.

3) South Elevation - West end.

4) South Elevation - East end.

5) Court Yard - East Elevation.

6) Court Yard - West Elevation.

7) Court Yard - North Elevation.

8) Court Yard - North Elevation.

9) Test apparatus in use on West Elevation - ground floor.

10) Results of test. Leaks identified by bubbles.

11) Detailing at window prior to testing. West Elevation, second floor.

12) Test at detailing of window. West Elevation, second floor.

13) Test at detailing of window. West elevation, second floor.

14) Leak found at junction at floor slab. West Elevation.

15) Suspected leak in drywall where screws missed stud etc. West Elevation, second floor.

16) Test in progress.

17) Visible bubbles, confirming leak.

18) Masonry ties on South Elevation, prior to testing.

19) Masonry ties - test in progress.

20) Test results showing leak in screw fixing.

General Detailing and Visual Inspection

21) Torch-grade membrane installed at junction in drywall seam. Bond of membrane deficient and leak found at junction of membrane.

22-26) Details not testable with PACTS machine. Visual inspection adequate to determine deficiencies.


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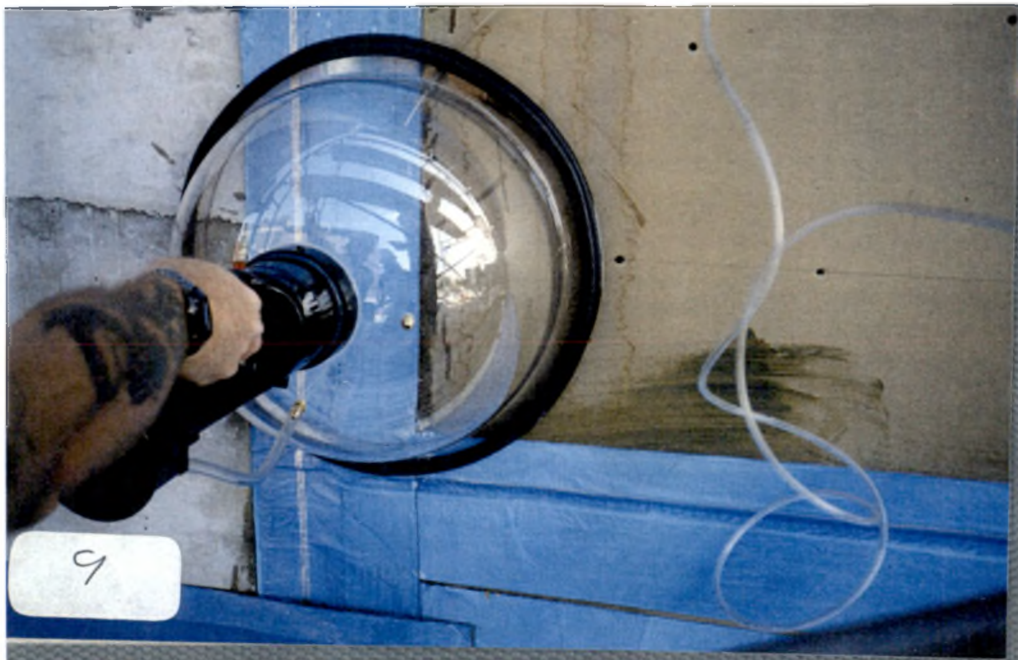

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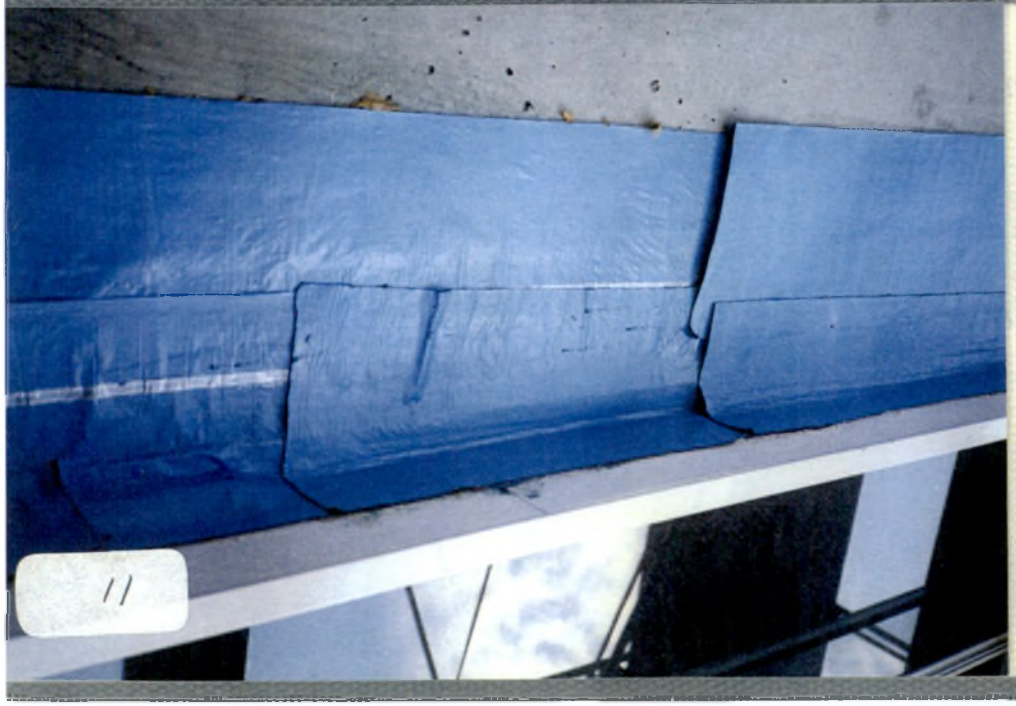

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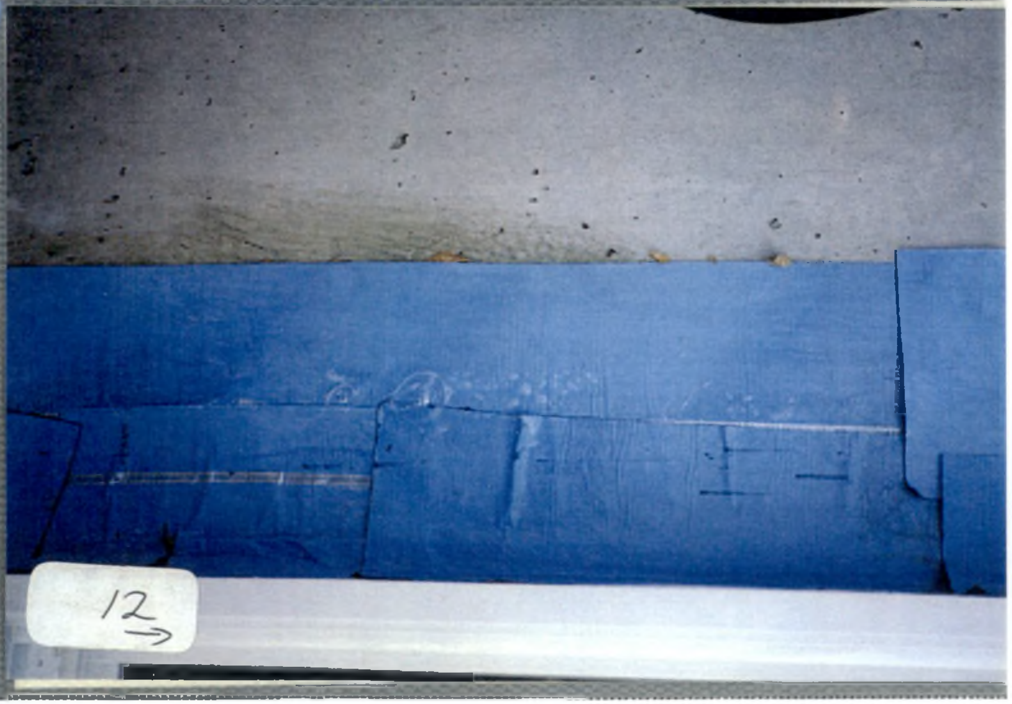

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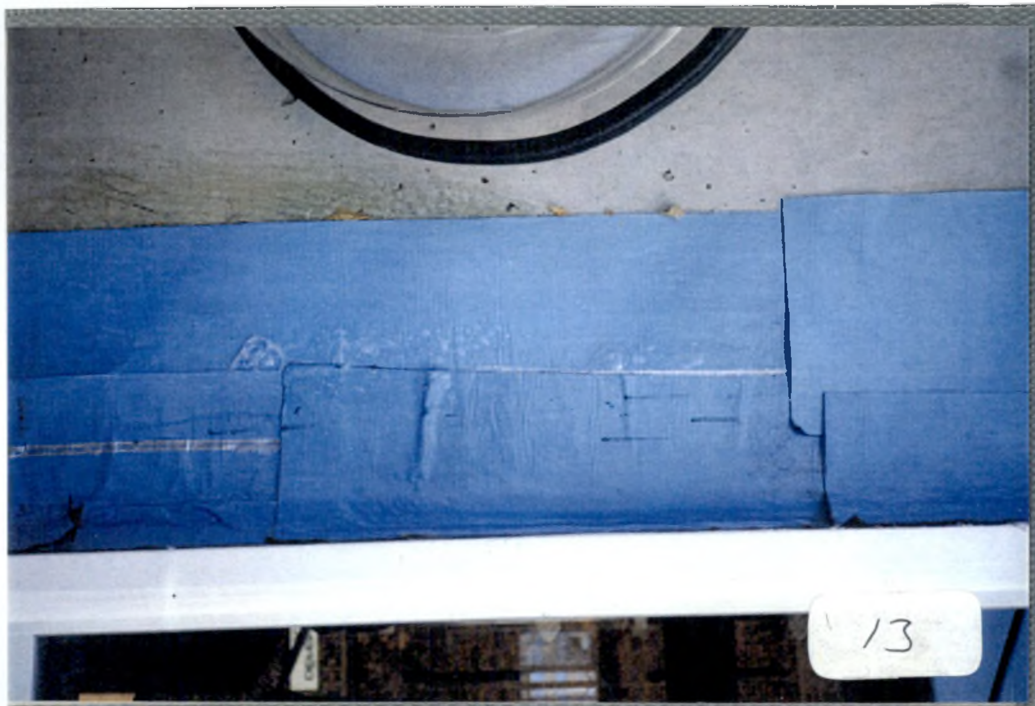
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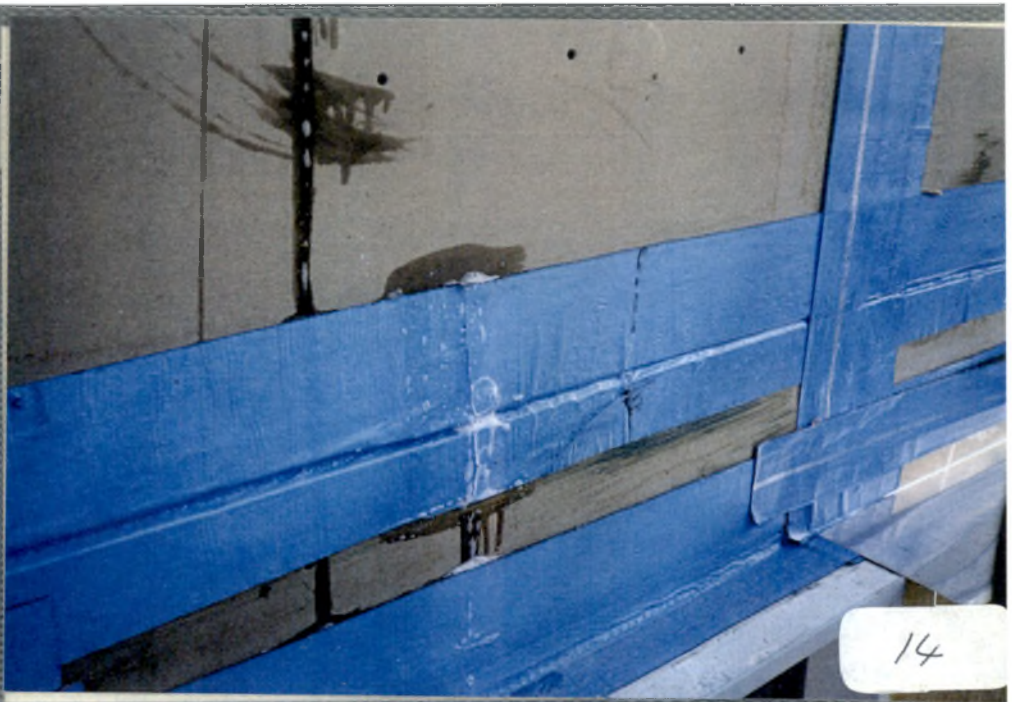
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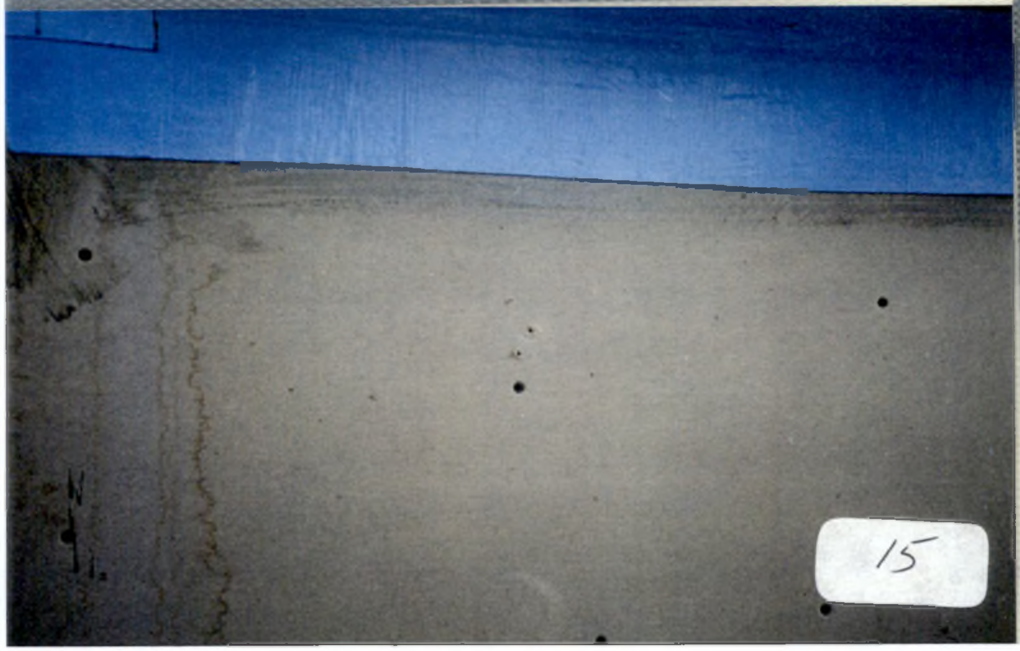
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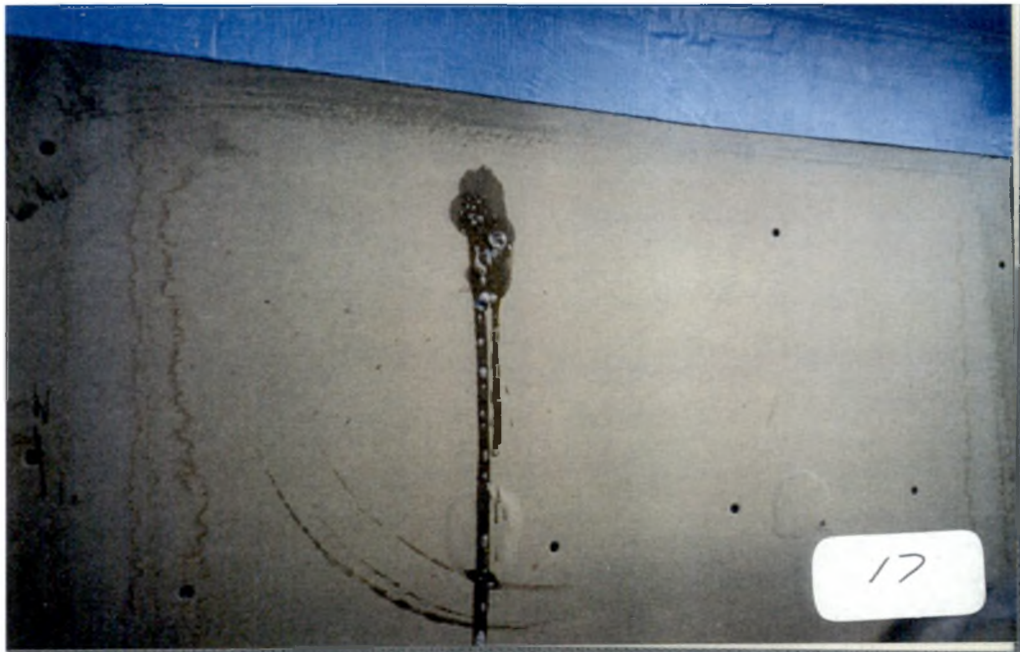

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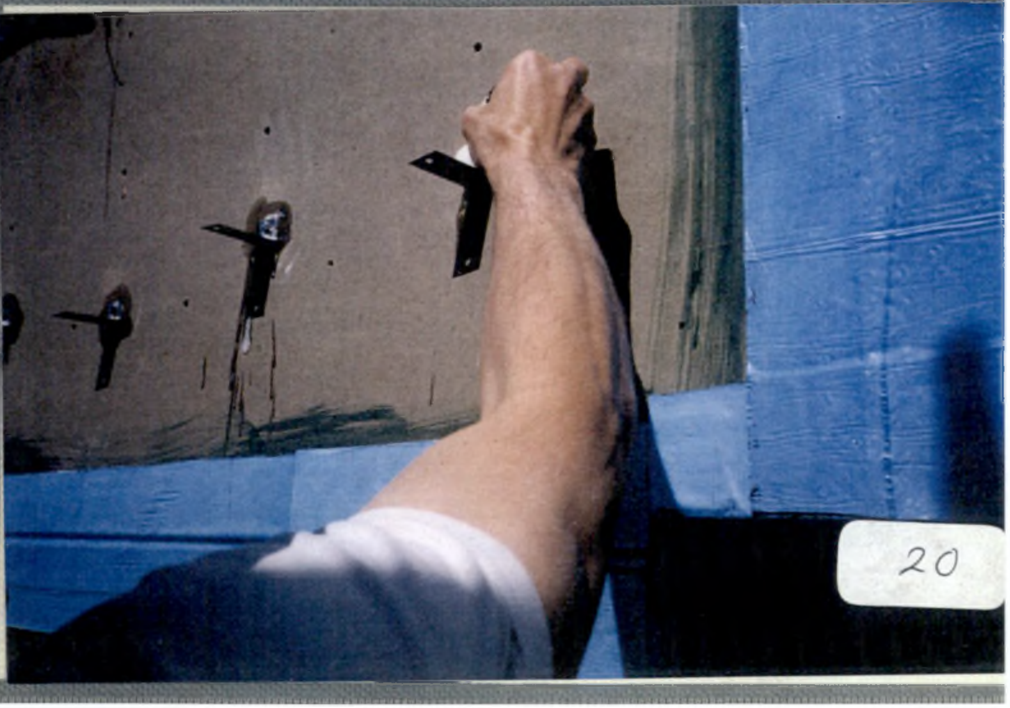

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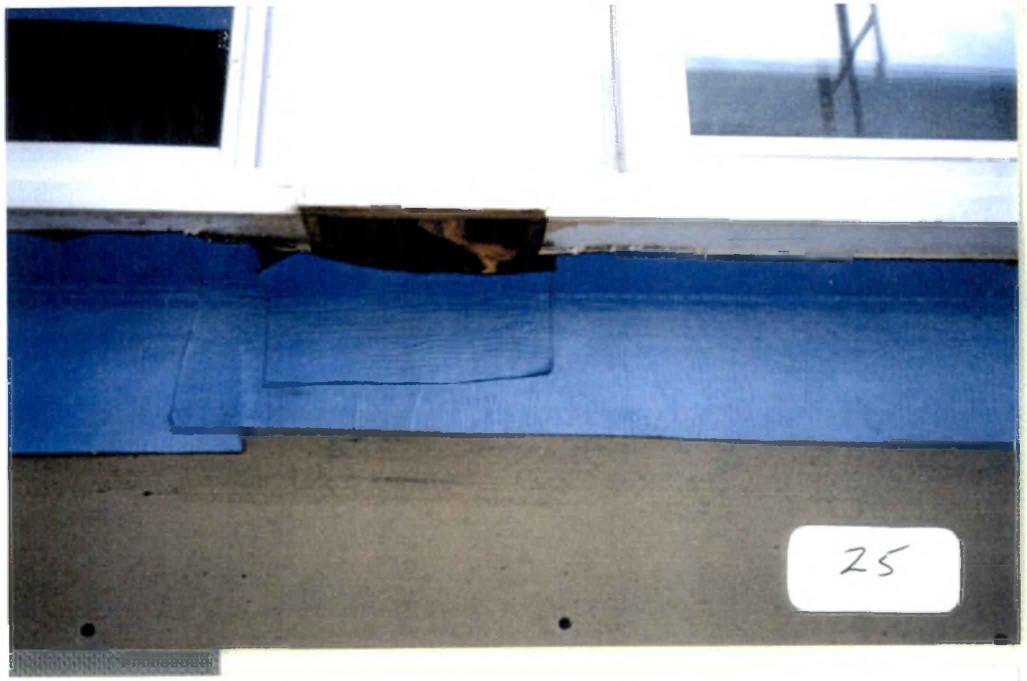

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7.3 Comparative Testing: PACTS versus Smoke Trace

Objective and Scope

Objective

The objectives of the testing was to compare the effectiveness of the PACTS device to smoke testing as a means of identifying air leakage points through air barrier systems.

Scope

Smoke testing and testing with a PACTS prototype was carried out on two test chambers. The test chambers incorporated various types of wall construction, air barriers and brick ties typical of construction in commercial buildings. These were tested using both smoke trace method and the PACTS device to determine the airtightness of the details.

Apparatus and Method

Masonry Chamber Test

The masonry test chamber constructed for the tests is shown in Figure #1. The masonry test chamber is approximately 7.2ft (2.18m) long by 8ft (2.44m) high by 3.1ft (0.94m) deep. The front face used in the testing is a twelve course concrete block wall. One half the front face is covered with self-adhered membrane and the other half with torch applied membrane. The back portion of the chamber is an cavity enclosed by steel stud supported drywall. The edges were sealed with air barrier membrane so the chamber was reasonably airtight. Several ports were provided into the cavity for the purpose of taking pressure readings and connection of hoses for pressurizing the chamber and injecting smoke.

The masonry test rig contains five rows of five ties each which are typical of the types commonly used in concrete masonry supported brick veneer construction. The top row of ties are surface mounted ties which were mounted with two screws each through the air barrier into the concrete block. The next two rows are shear truss ties which were set into the block wall. The air barrier was fitted around the ties and sealed with a mastic on self adhered membrane. On torch applied membrane the area around the ties is was torched and worked with a trowel to seal around the ties. The bottom two rows are ladder ties which were placed between two courses of concrete block. Similar to the shear ties, the air barrier was installed around them and sealed with a mastic on the self adhered membrane and worked with a torch and a trowel on the torch applied membrane. The test rig also contains four sections of angle mounted with two screws each through the air barrier which are typically used for mounting girts for metal cladding. The test chamber contains approximately 36ft (11m) of seams.

Pressure differentials were measured using a Dwyer Series 475-4 Mark 2 digital manometer with a range of 0-5kPa (0-20in. of water) and a resolution of 0.01kPa (0.4in of water) and a water filled U-tube manometer with a range of 0-12in. of water (0-3kPa) in increments of 0.2in. of water (0.05kPa).

The chamber was pressurized to 0.60in. of water (150Pa) with a variable speed fan and a dense white smoke was injected. The areas which leaked as indicated by a stream of smoke were recorded. The test was repeated at a pressure of 4in. of water (1000Pa).

Following the smoke tests a local journeyman mason (the inspector) who is independent of the project was shown briefly how to use the PACTS and asked to check each tie and other seams and areas he felt necessary. The leaks detected, indicated by bubbling of the soap solution, were recorded.

Drywall Chamber Test

The steel stud- drywall test chamber constructed for the tests is shown in Figure #2. The chamber is approximately 8ft (2.44m) long by 8.33ft (2.54m) hight by 2.5ft(0.76m) deep. The front face used in the testing was covered with self-adhered membrane. The remaining portion of the chamber was also steel stud supported drywall. All edges were sealed with air barrier membrane so the chamber was airtight and Several ports were provided for the purpose of taking pressure readings and connection of hoses for pressurizing the chamber and injecting smoke. Pressure differentials were measured with the same equipment as used in the test on the masonry test chamber.

The test rig contains four rows of five ties each which are typical of the types used in stud wall supported brick veneer construction. The top two rows are various types of surface mounted ties connected with either one or two screws through the air barrier and drywall into a steel stud. The bottom two rows of ties were clipped onto the side of the steel stud before the air barrier is installed. The air barrier was sealed around the ties with a mastic. The test chamber contained approximately 43ft (13m) of seams.

The chamber was pressurized to 0.60in of water (150Pa) with a variable speed fan and thick white smoke was injected into the chamber. The areas which leaked, indicated by a stream of smoke, were recorded. The test was repeated at a pressure of 2.81in of water (700Pa).

Following the smoke tests, the inspector checked all the ties and the seams with the PACTS device. The leaks detected, indicated by bubbling of the soap solution, were recorded.

Observations

Masonry Chamber Test

Figure #3 and Figure #4 show the results for the smoke test on the masonry test chamber at 0.6in of water (150Pa) and 4in of water (1000Pa) respectively. The leaks found are marked with an 'X'.

Figure #5 shows the leaks detected with the PACTS by the inspector. The pressure indicator light was set to switch on at 1.8in of water (460Pa). The circles mark areas which were tested and no leak was found. All ties, which are indicated by the squares, were tested by the inspector. The leaks marked with a 'U' indicate that the inspector thought it unlikely that detail would leak based solely on a visual inspection. The leaks marked with a 'E' indicated that the inspector expected that the detail would leak based on visual inspection..

Figure #6 show all leaks found by all three tests. The 'B' indicates the leak was found by both the smoke trace and the PACTS, the 'V' indicates the leak was found only by the PACTS device, and the 'S' indicates that the leak was found only by one or both of the smoke tests.

Table #1 shows the comparison of the smoke and PACTS tester results on the masonry test chamber. As can be seen, the PACTS found a greater percentage of the total number of the leaks. The results of the smoke tests indicate that more leaks are found at a greater pressure. Of the leaks found with the PACTS, in the inspector's judgment about 70% were unexpected based on visual inspection.

Drywall Test Chamber

Figure #7 and Figure #8 show the results of the smoke test on the drywall test chamber at 0.6in of water (150Pa) and 2.81in of water (700Pa) respectively. The leaks found are marked with an 'X'.

Figure #9 shows the leaks detected with the PACTS tester by the inspector. The indicator light switched on at about 1.76in of water (440Pa).

Table #2 shows the comparison of the smoke and PACTS tester results on the drywall test chamber. As with the masonry test chamber, the PACTS again detected a greater percentage of the leaks than the smoke tests. Of the leaks found with the PACTS, in the tester's judgement 30% were unexpected.

Discussion

As shown in Table #1 and #2, the PACTS tester detected a greater percentage of the total number of leaks than the smoke tests on both the masonry test chamber and the drywall test chamber. One explanation for this observation is that the larger leaks tended to drown out the smaller leaks in the smoke tests. Another explanation is that small leaks are hard to see with the smoke trace because not enough smoke is forced through the opening to make the leak easily visible. However, with the PACTS, small leaks may still cause the soap solution to bubble. A third reason is that only a small amount of air movement rapidly diffuses a smoke trace, making the source difficult to see. Since the PACTS device uses a relatively small, isolated testing area, air movement outside the dome of the PACTS does not affect the visibility of the results.

The variability of the results based on the inspector's judgement was apparent from the tests. In both cases, the inspector's judgment based on visual inspection was not a very reliable indicator of the airtightness of a detail, although on the drywall test chamber better results were obtained than on the masonry chamber. Visual inspection results would be expected to vary to a large degree based on the experience of the inspector and thoroughness of the inspection.

On the masonry test chamber, leakage was detected on two ties with the smoke testing which were missed by the PACTS device. Both ties were retested at a later time with the PACTS and the leaks were detected. They were likely missed because the soap solution did not cover the deficiency in the membrane completely and thus a bubble did not form when the pressure differential was induced across the membrane.

On the drywall test chamber, leakage was detected at two ties and one other location (not at a tie or a seam) which were not detected by the PACTS. Both ties which were not detected had large openings which the bubble solution would have to span, and as a result, it was difficult to induce a bubble at these details. The other location which was not detected was not one of the area tested by the inspector. When tested later with the PACTS the leak was detected. The leaks missed by the smoke testing were small leaks.

Conclusions

1) In both these tests, the PACTS device detected more leaks than the smoke tests.

2) The importance of proper application of the bubble solution was noted in these tests.

3) The bubble solution had difficulty spanning large openings in the membrane. The development of a better solution can improve the effectiveness of the testing system. This also indicates that visual inspection is an important component of the inspection process.

4) Visual inspection alone was unreliable in determine the airtightness of many details.

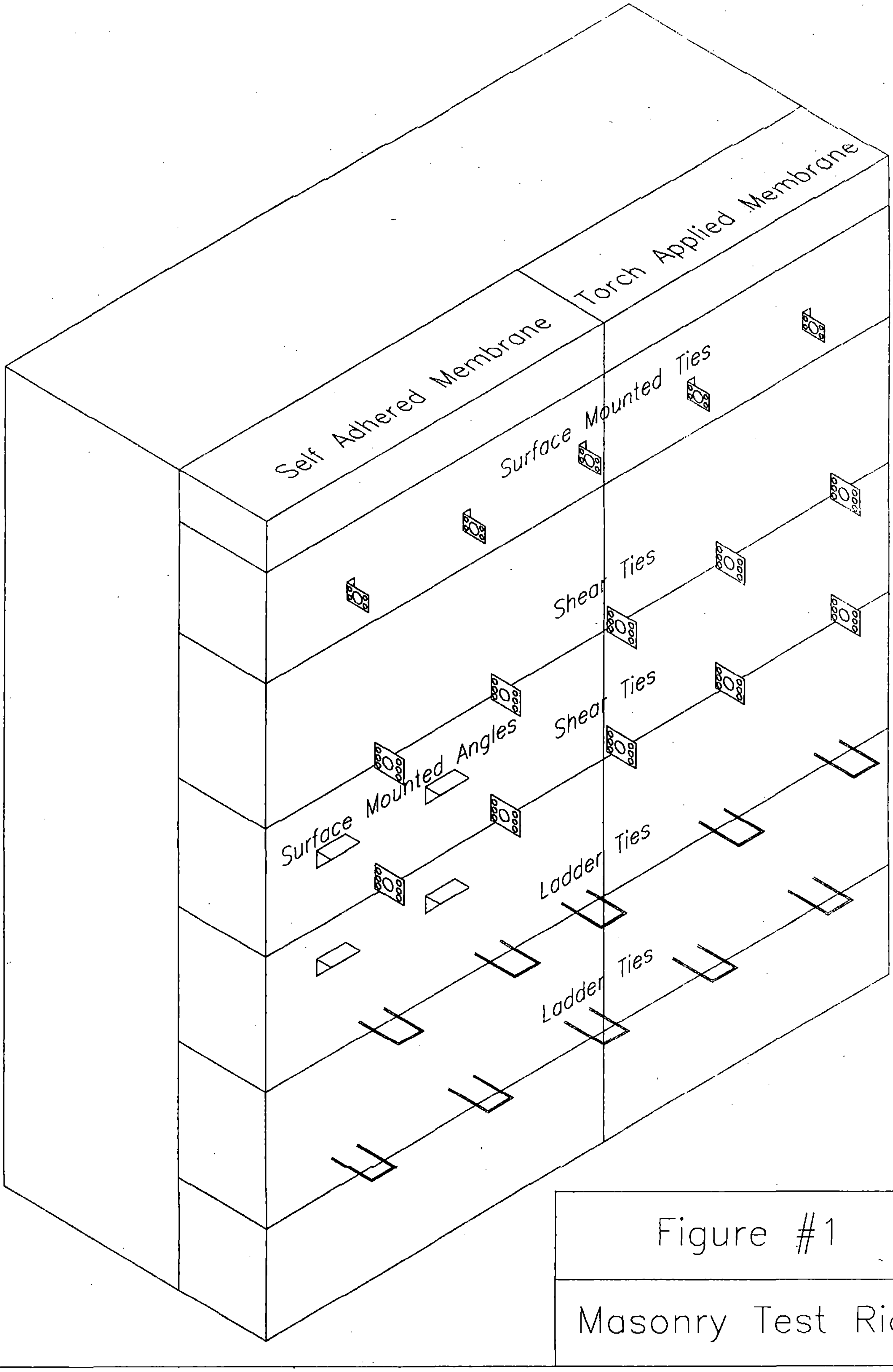


Figure #1

Masonry Test Rig

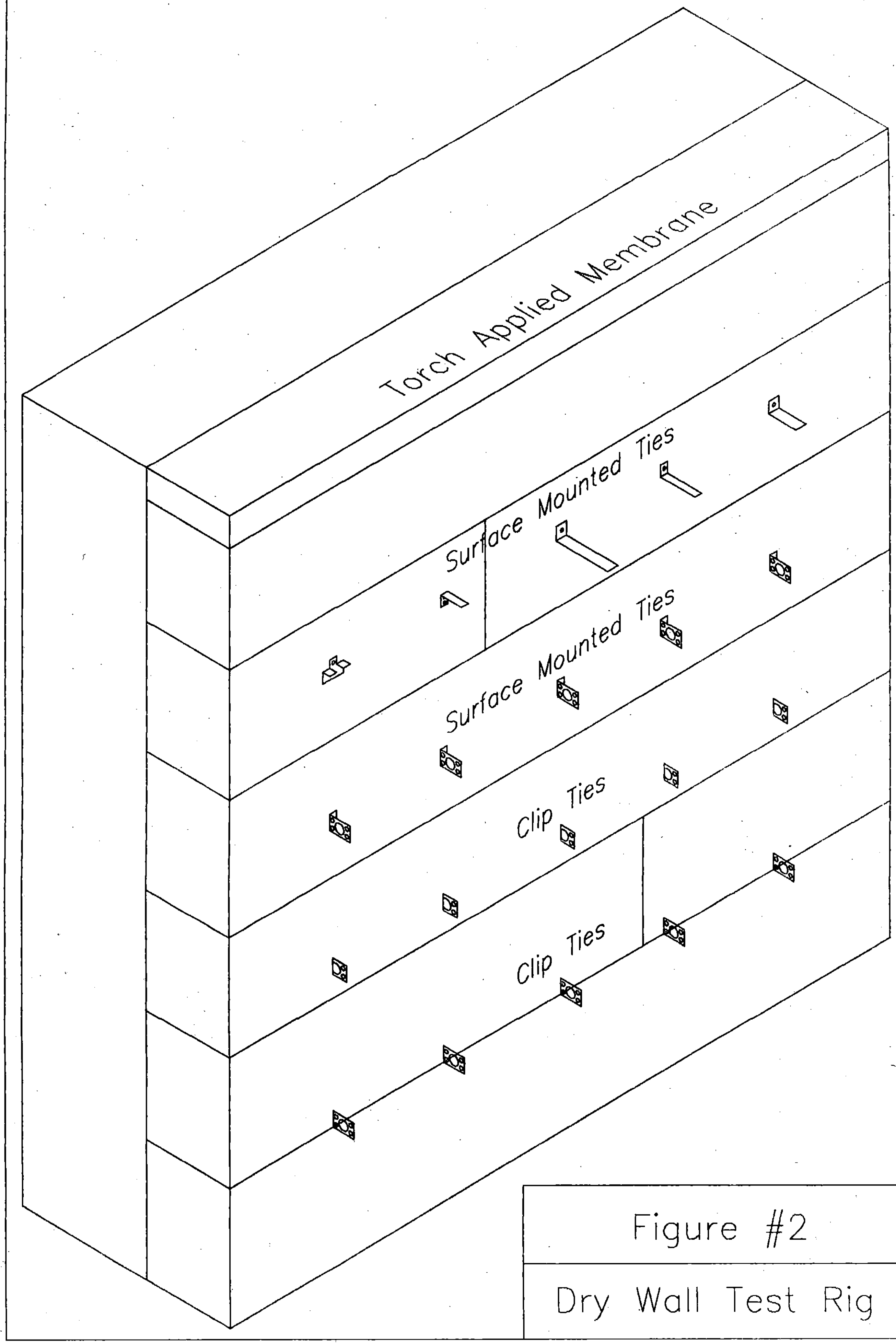


Figure #2

Dry Wall Test Rig

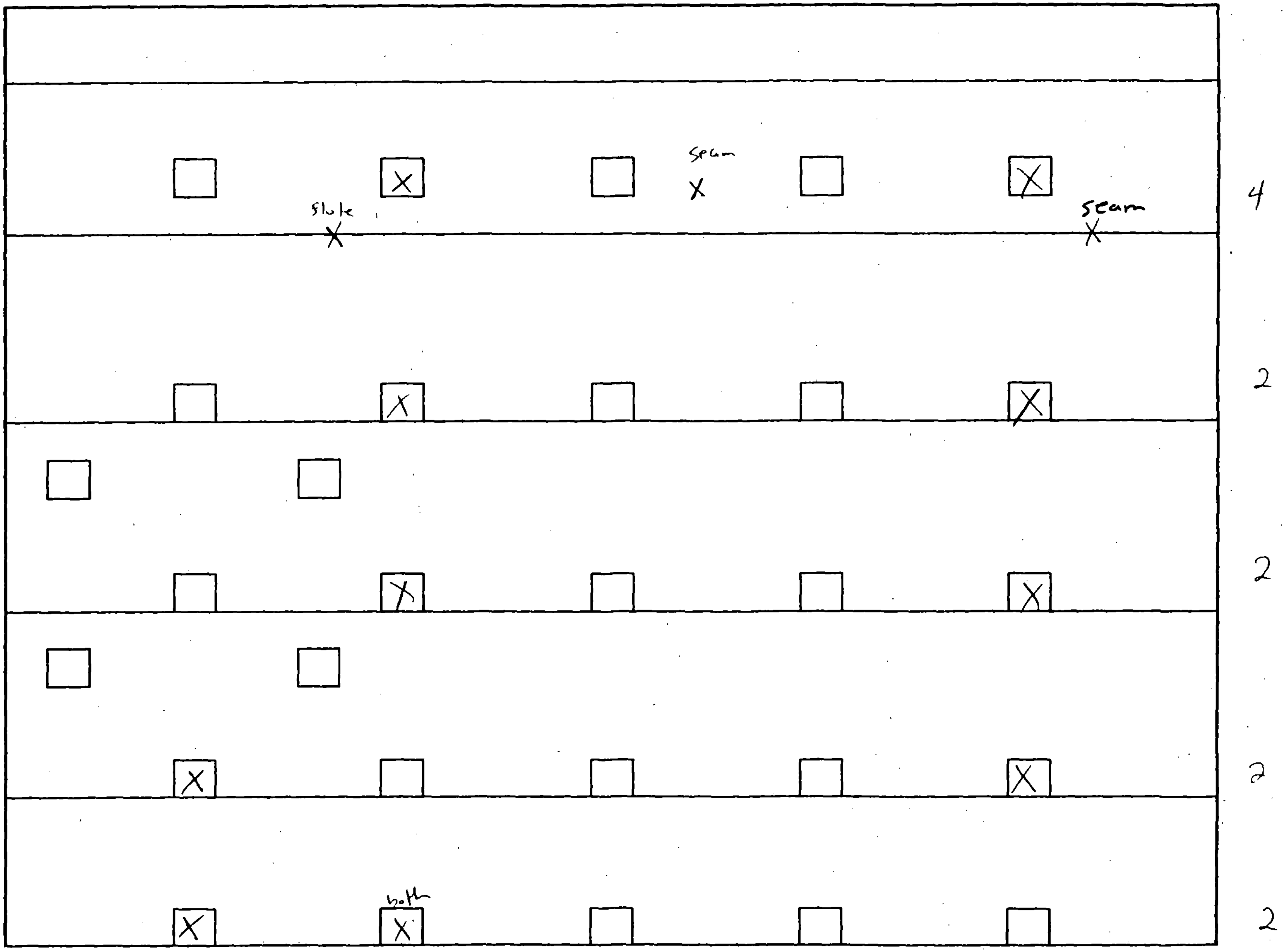
Table #1: Masonry Test Rig Results

	Leaks Found		Leaks Missed	
	Number	Percentage	Number	Percentage
Found by Vacts Tester (460Pa)	17	89%	2	11%
Found by Smoke (150Pa)	12	63%	7	37%
Found by Smoke (1000Pa)	15	79%	4	21%
Total Found by Smoke	15	79%	4	21%
Total Number of Leaks Found	19	100%		

Table #2: Drywall Test Rig Results

	Leaks Found		Leaks Missed	
	Number	Percentage	Number	Percentage
Found by Vacts Tester (440Pa)	10	77%	3	23%
Found by Smoke (150Pa)	9	69%	4	31%
Found by Smoke (700Pa)	10	77%	3	23%
Total Found by Smoke	10	77%	3	23%
Total Number of Leaks Found	13	100%		

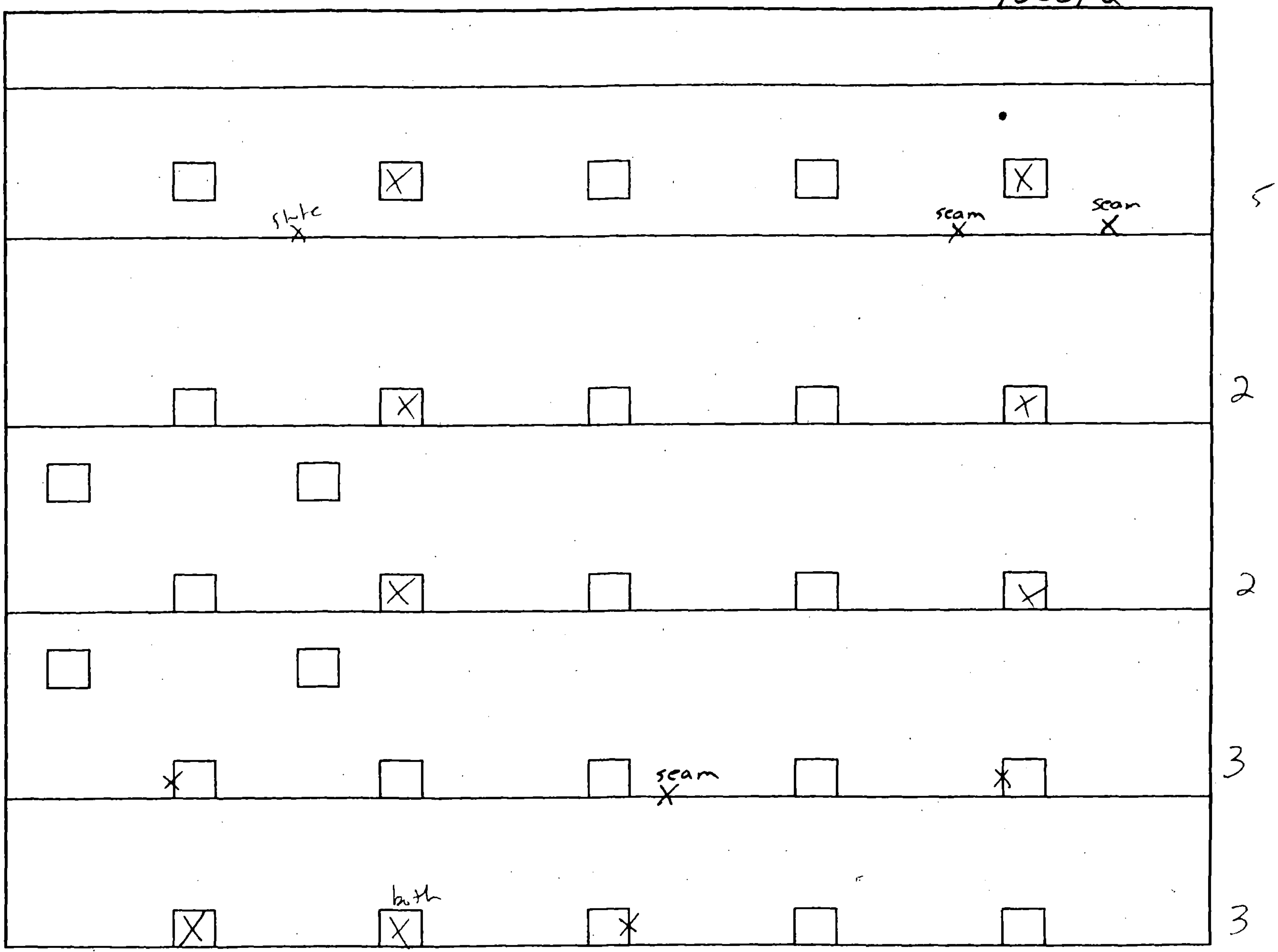
Smoke Test Result for Masonry Test Rig Figure #3 **11May 95** 150 Pa



Identification of Deficient Detailing/Leaks

Smoke Test Result for Masonry Test Rig Figure #4 **11May 95**

1000Pa



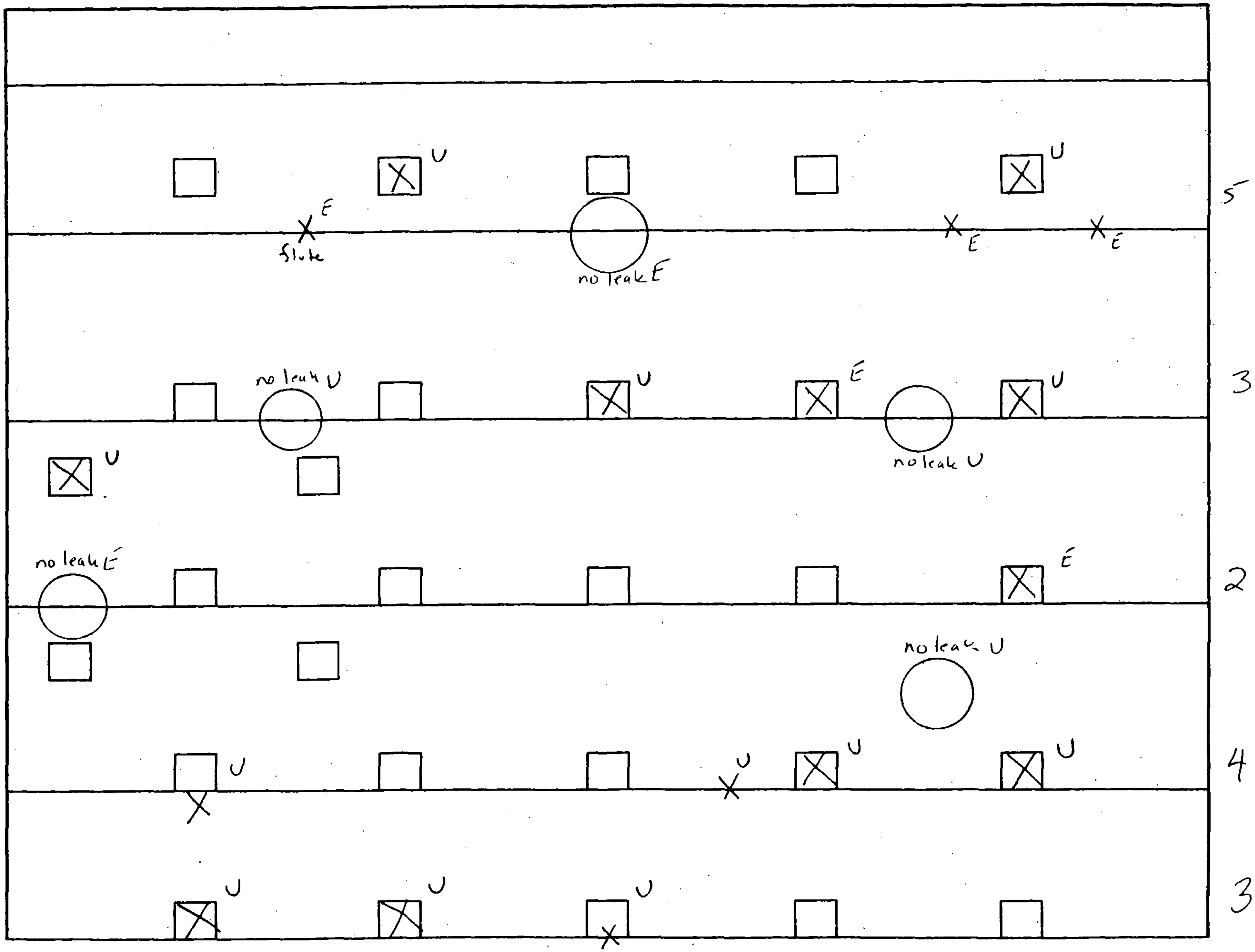
Identification of Deficient Detailing/Leaks

Vacts
Smoke Test Result for Masonry Test Rig

Figure #5

11May 95

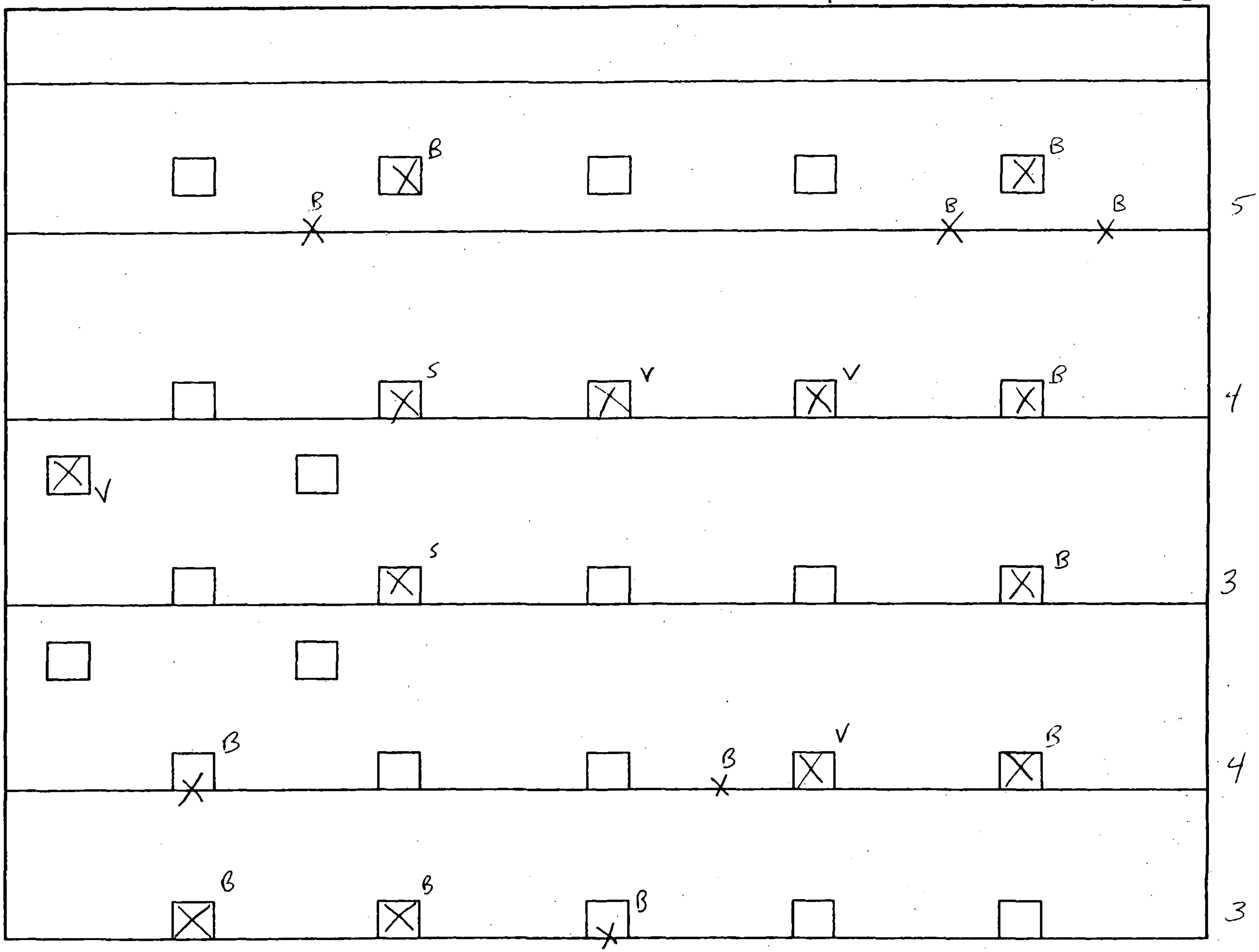
460 Pa



Identification of Deficient Detailing/Leaks

Smoke Test Result for Masonry Test Rig Figure #6 **11May 95**

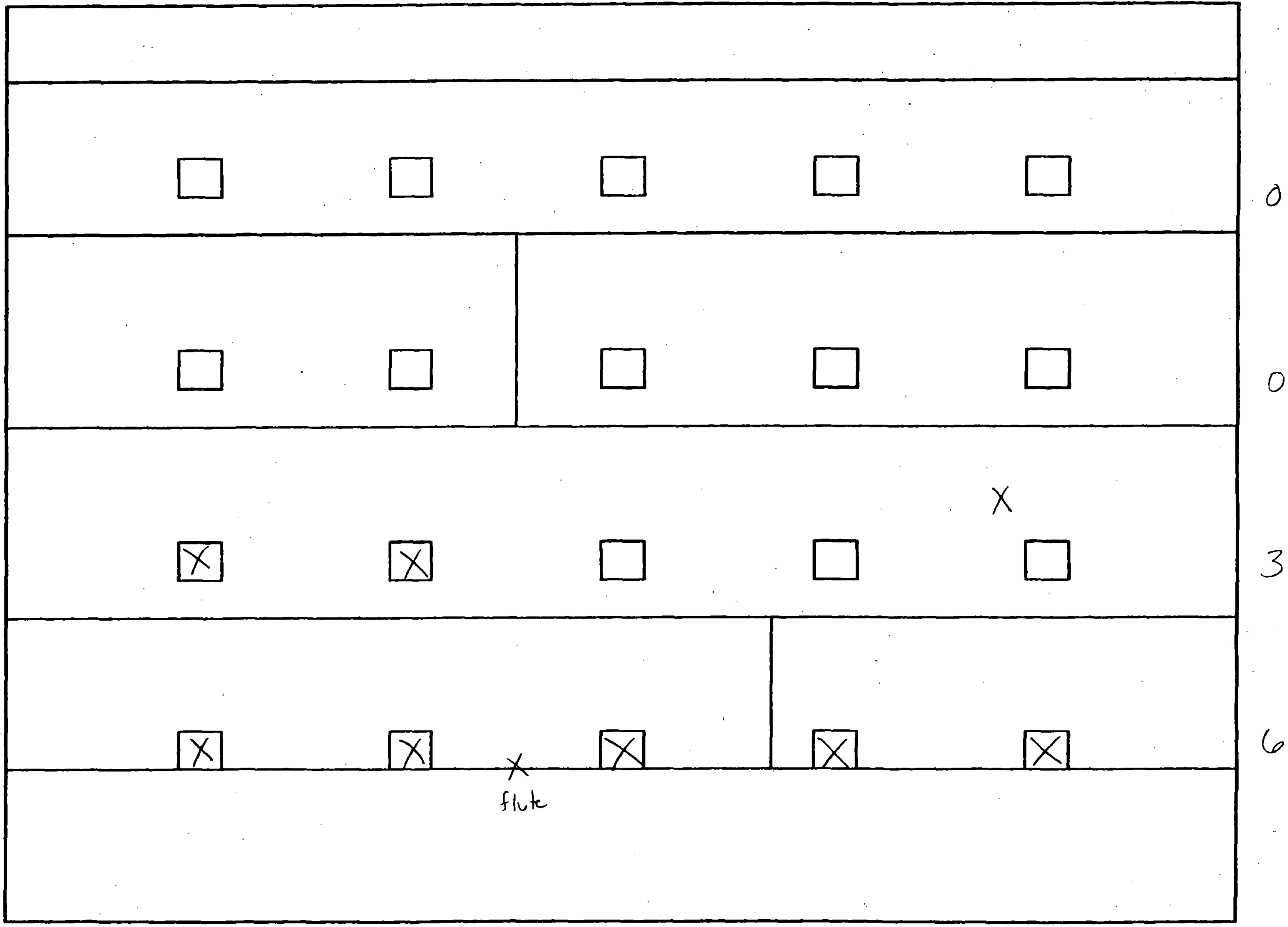
Total Leaks - Smoke ; Vacts



Identification of Deficient Detailing/Leaks

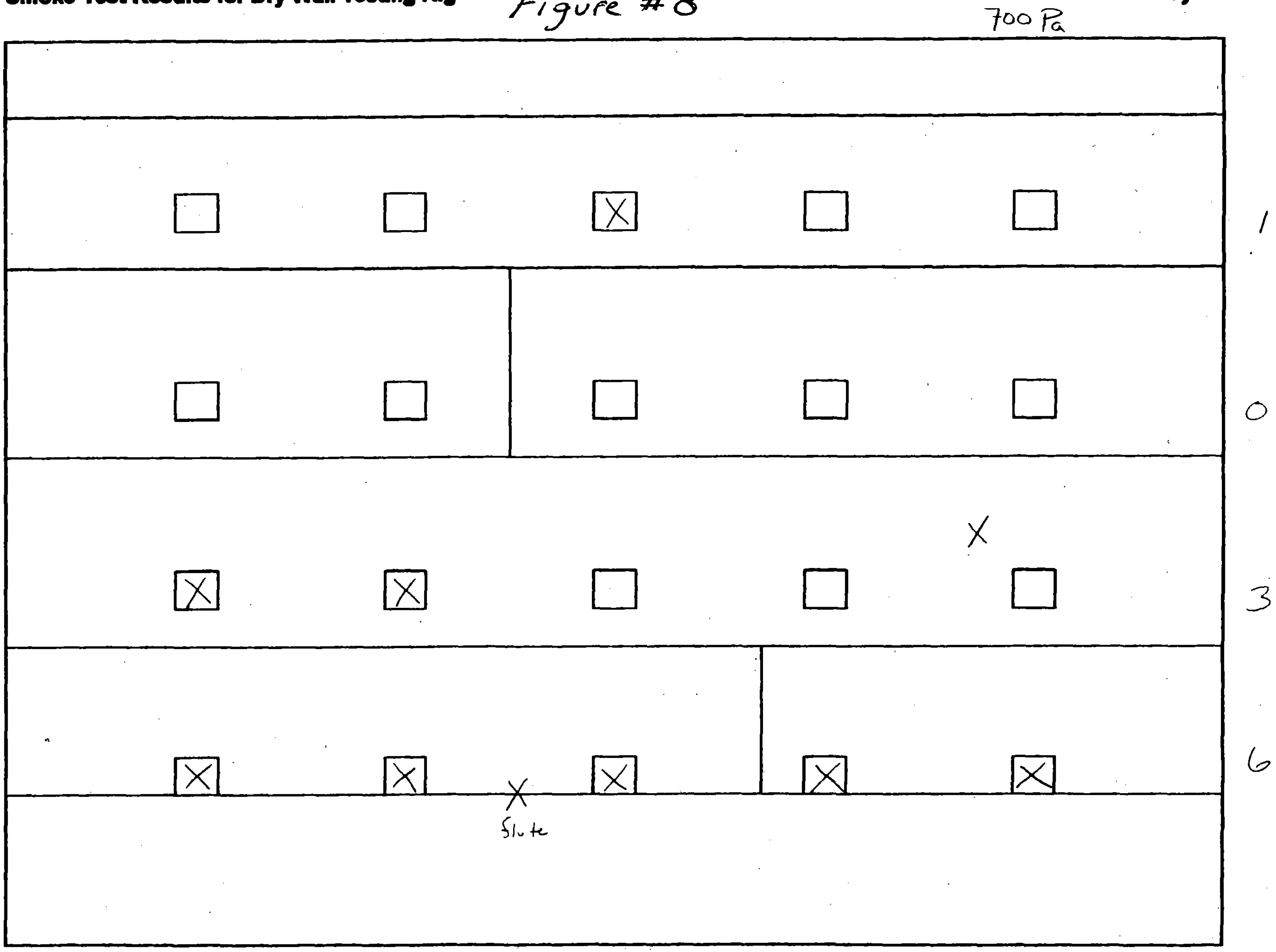
Smoke Test Results for Dry Wall Testing Rig Figure #7 11May 95

150 Pa



Identification of Deficient Detailing/Leaks

Smoke Test Results for Dry Wall Testing Rig Figure #8 **11May 95**



Identification of Deficient Detailing/Leaks

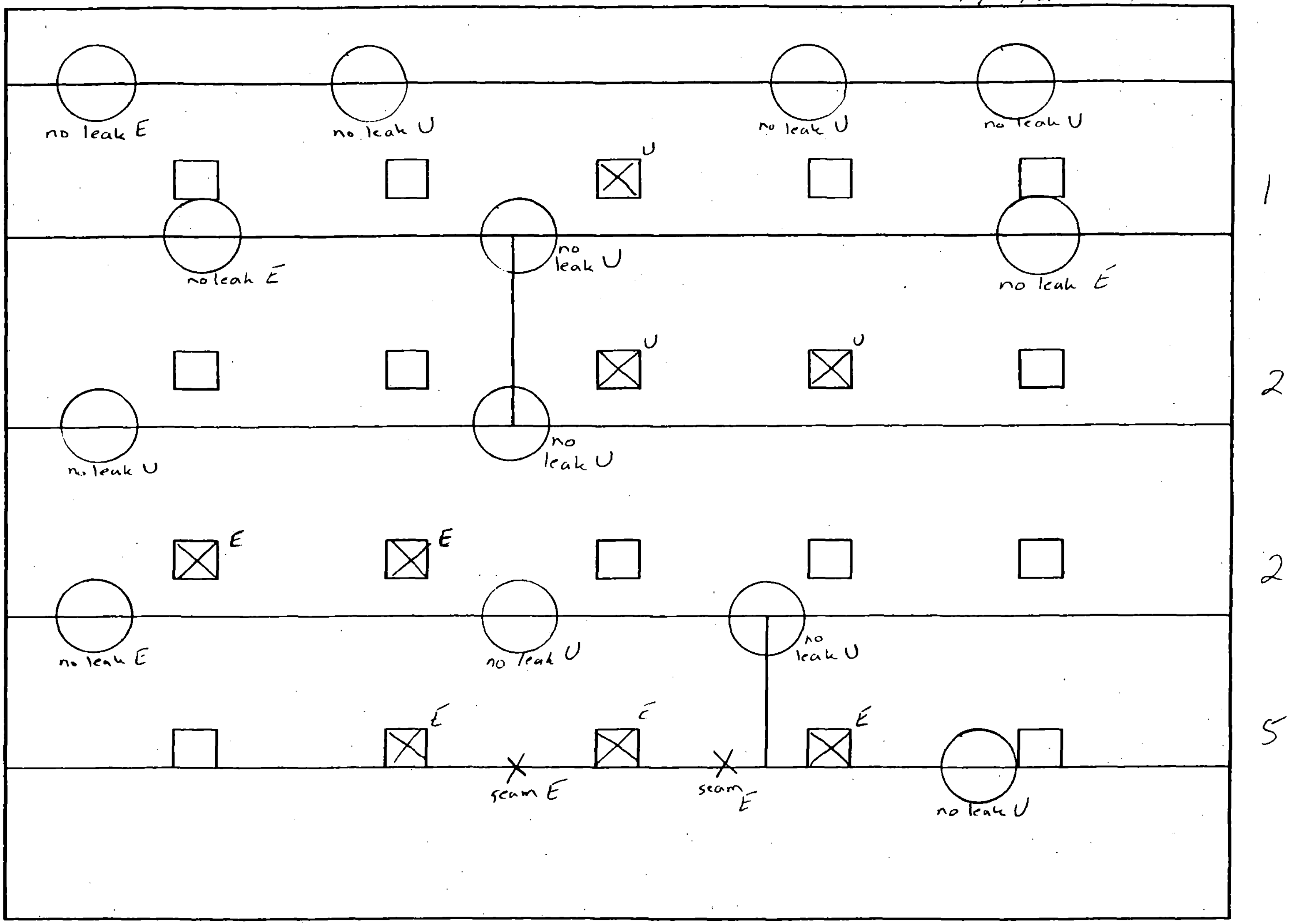
Vacts

Smoke Test Results for Dry Wall Testing Rig

Figure #9

11May 95

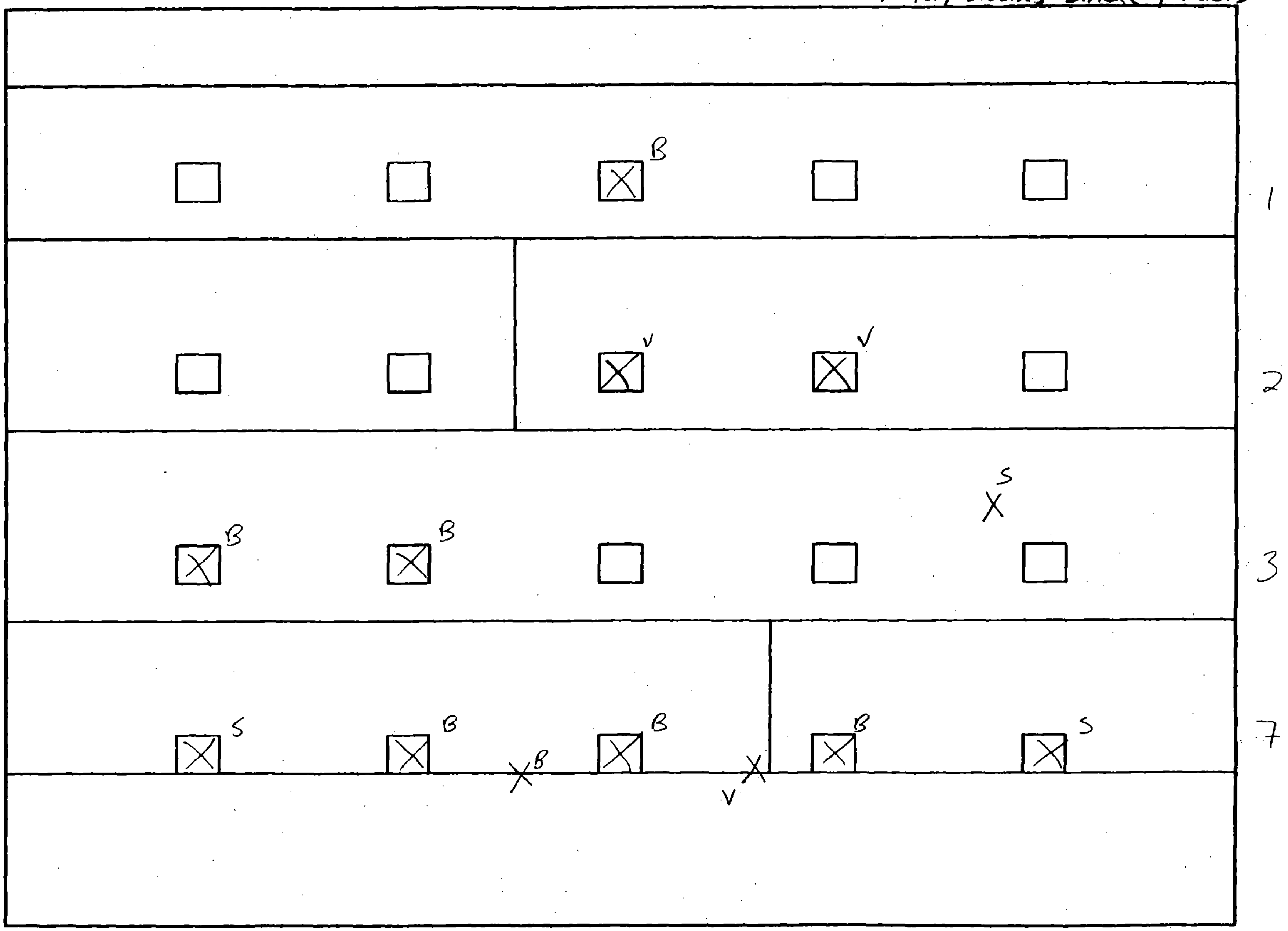
440 Pa



Identification of Deficient Detailing/Leaks

Smoke Test Results for Dry Wall Testing Rig Figure #10 **11May 95**

Total Leaks - Smoke & Vacts



Identification of Deficient Detailing/Leaks

7.4 PACTS Fan Performance Testing

Objective and Scope

Objective

The primary objective of the fan tests was to evaluate the pressure and airflow characteristics of the PACTS prototype for comparison of alternate components considered in the production model. A secondary objective is to determine if the pressure and airflow performance is affected by the use of the illumination light and the age of the batteries used in the PACTS apparatus.

Scope

Testing was carried out according to ANSI/AMCA 210-85. It should be noted that precise airflow and pressure measurements are not required to fulfil the objectives of the test.

Apparatus and Method

Apparatus

To fulfil the requirement of the test objectives an ANSI/AMCA 210-85 inlet test chamber was built. The test chamber was smoke tested at approximately 2.5kPa to ensure there was no detectable leakage in the chamber. A diagram of the chamber is shown in Figure #1. At the pressure measuring plane, one pressure tap was installed into each side of the box. All four taps were interconnected to average the four readings over the pressure measuring plane.

The pressure differentials were measure with an Air Instrument Resources Ltd. MP6KD digital micrometer covering the range 0 to 6kPa in 0.01kPa increments. Variable air supply and airflow measurement was provided by a Can-Best Model 283 A 200 window air leakage tester. The rotometers on the Can-Best tester are calibrated for flows from 0.1 to 10cfm (0.05 to 5l/s). The new and the old batteries used in PACTS for the tests were Makita 7000, 7.2V nickel-cadmium. The batteries were fully run down and then charged for two hours prior to each test.

Method

In total, eight fan tests were done on the PACTS device using the same prototype PACTS device. To determine the impact of battery age, tests were done with an old and a new battery. To determine if the illumination light has a significant effect on the device, half the tests were done with the light on and half with the light off. All tests done were repeated to give an indication of the consistency of the results battery performance. The eight tests performed are as follows:

1) New battery, illumination light off.
2) New battery, illumination light on.

3) Old battery, illumination light off.
4) Old battery, illumination light on.
5) New battery, illumination light off.
6) New battery, illumination light on.
7) Old battery, illumination light off.
8) Old battery, illumination light on.

The PACTS device was held against the test chamber as shown in Figure #1. Vaseline was used around the gasket on the dome of the PACTS device to minimize extraneous leakage. The PACTS device was run at full speed. Airflow into the ANSI/AMCA chamber was varied from 1cfm to 14cfm (0.47l/s to 6.61l/s) using the Can-Best. Corresponding pressure measurements were taken at each airflow rate. The duration of each test was kept to less than 10 minutes.

Observations

Figure #2 and #3 shows the results of the four tests run using the new and old batteries respectively.

Discussion

Figures #2 and #3 show that the fan curves obtained in these eight tests are approximately linear. Fan curves are not usually linear, but over the small range of airflows in this test a linear approximation seems to be reasonable. To obtain the full fan curve for the device, the use of a flow measuring device that is calibrated for higher airflows than the rotometers in the Can-Best window tester will be required.

The data shows a certain degree of scatter as is evident in the Figure #2 and #3. However, a decrease in performance due to the use of the illumination light is not apparent. It is also appears that the older Nicad battery's performance is similar to that of the new battery. This suggests that the battery will have a longer service life than the PACTS itself, therefore demand for replacement batteries for this equipment will be small.

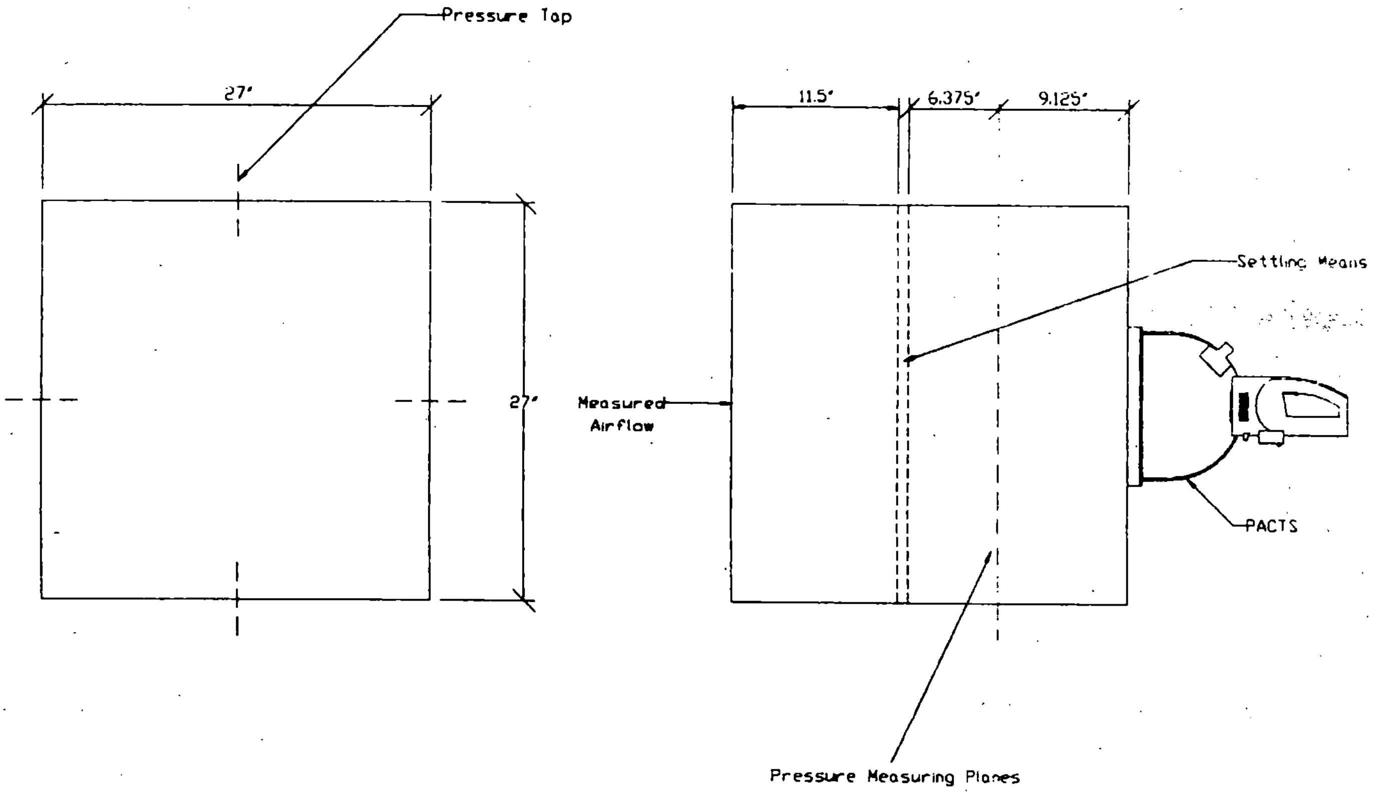
Also of interest is the performance of the PACTS device at lower temperatures. This testing is more feasible to undertake during the winter months.

Conclusion

1) No significant decrease in performance of the PACTS tester was evident due to the use of the illumination light.

2) No significant decrease in performance was apparent due to the use of an older Nicad battery as opposed to the use of a new battery.

3) Further testing is required to determine the low temperature performance and the performance throughout the full range of airflows the PACTS device is capable of operating in.



Fan Testing Chamber

Figure #1

Figure #2

Fan Curve for Test on New Battery

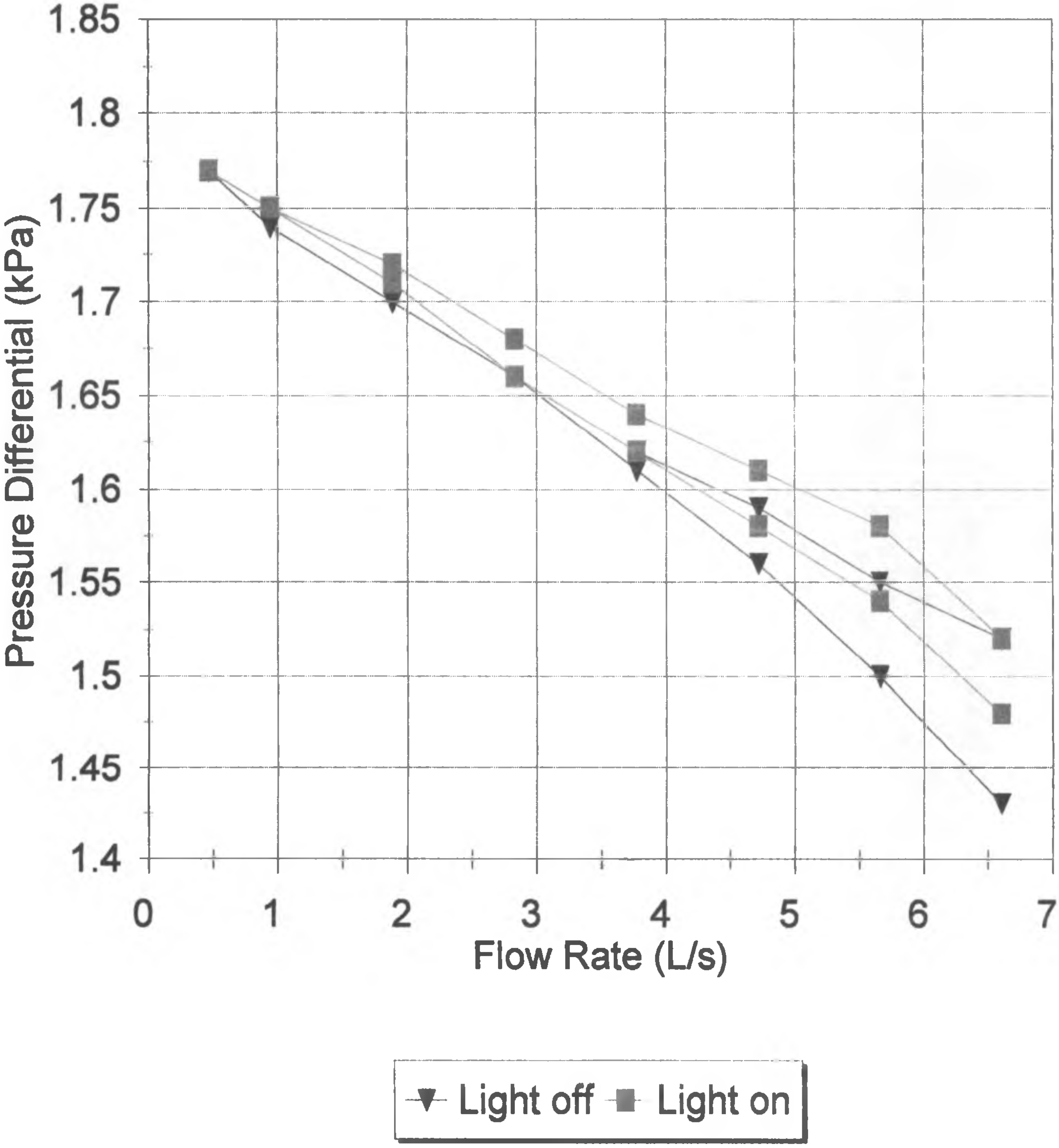
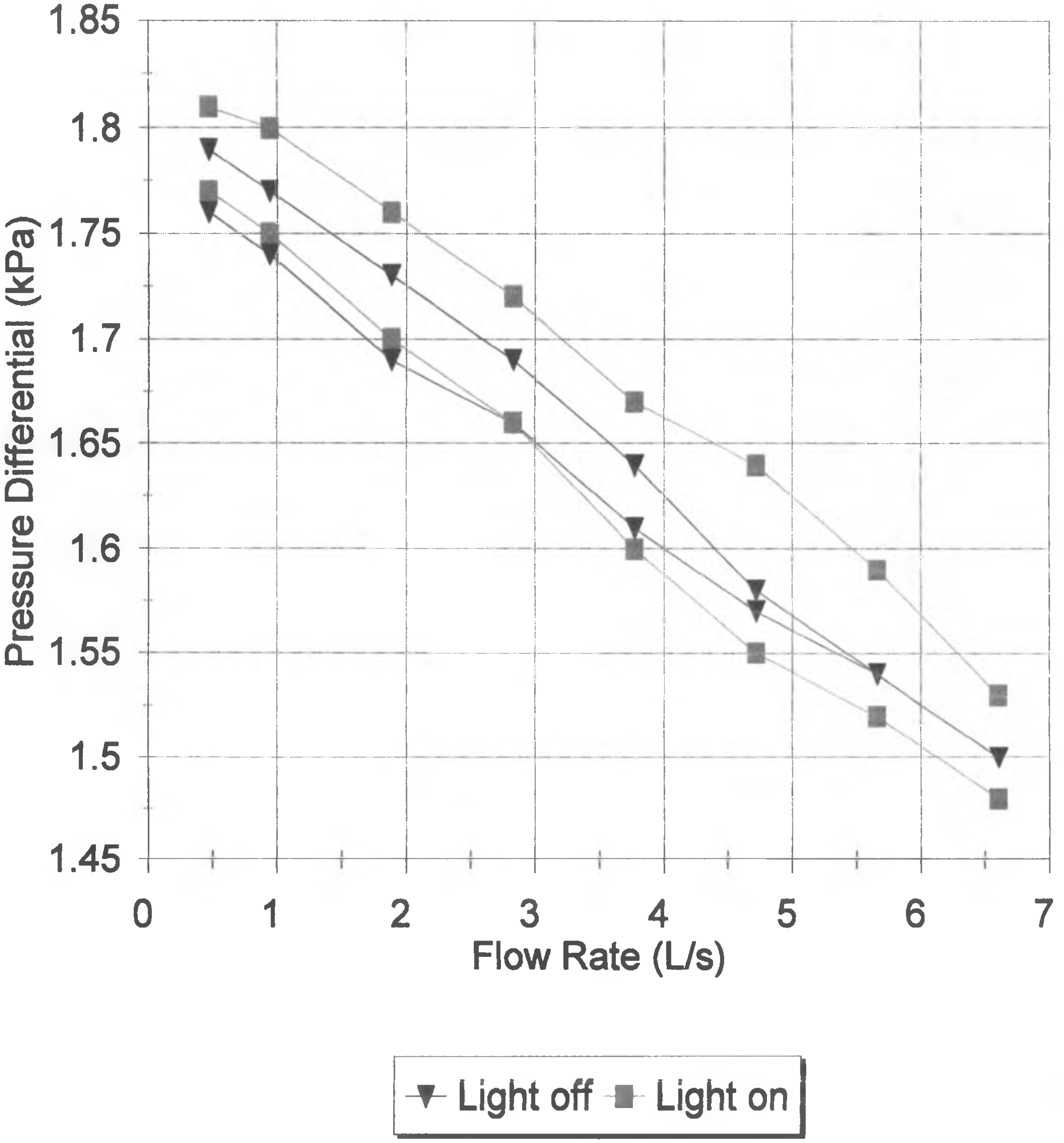


Figure #3

Fan Curve for Test on Old Battery



7.5 Pressure Differential Versus Elapsed Running Time Test

Objective and Scope

Objective

The objective of the tests was: to evaluate the impact of the battery charge time, illumination light operation, battery age and the load on the fan on the PACTS performance.

Scope

Testing was carried out by running the PACTS at full speed with a small opening into the dome of the PACTS and measuring the pressure differentials achieved against elapsed running time.

Apparatus and Method

Apparatus

A hole, approximately 5/16" in diameter, was drilled in a piece of sheet steel. The selection of the size of the hole was arbitrary. The dome of the PACTS device was sealed to the sheet using the existing gasket around the dome. Vaseline was applied to the gasket to minimize extraneous leakage. Pressure differentials were measured with a Dwyer Series 475-4 Mark2 digital manometer with a range of 0-5kPa and a resolution of 0.01kPa. A timer with a resolution of 1 second was used to measure the time interval between pressure readings. Both batteries used in the test were Makita 7000, 7.2V nickel-cadmium. The new battery was charged with a Makita Fastcharger Model DC7010. The old battery was charged with a Makita Fastcharger Model DC7100. Before charging, all batteries were run down completely in the PACTS device.

Method

In all, eight tests were done on the PACTS device. All testing was performed using the same prototype PACTS device. In seven of the test, the PACTS was run at full speed against the plate for the entire length of the test. The pressure differential was recorded every 2 minutes. The tests are as follows:

1) New battery, 1 hour charge time, illumination light on.
2) New battery, 2 hour charge time, illumination light on.
3) Same as test #2
4) New battery, 4 hour charge time, illumination light on.
5) New battery, 14 hour charge time, illumination light on.
6) New battery, 2 hour charge time, illumination light off.
7) Old battery, 2 hour charge time, illumination light on.

In Test #8, the PACTS was run at full speed in free flow (i.e., not against the plate). After 1 minute and 45 seconds the PACTS was placed against the plate and a pressure reading was taken. The pressure reading took 15 seconds to obtain. The fan was then stopped to remove it from the plate after which it was run in free flow again. Therefore, approximately 15 seconds was spent running the PACTS against the plate while the reading was taken and 105 seconds were spent running the fan in free air every two minute interval.

Observations

Table #1 shows the recorded results for the eight tests undertaken on the PACTS device. Figure #1 provides the comparison of a 1 hour and 2 hour charge. Figure #2 provides the comparison of a 2, 4 and 14 hour charge. Figure #3 indicates the effect of the illumination light on the performance. Figure #4 compares the performance of an old and the new battery. Figure #5 indicates the impact of the load under which the PACTS operates on its performance. Table #2 presents the elapsed running time in each test before the pressure differential fell to 500Pa. These values were obtained by linear interpolation between the closest points in each test.

Discussion

Based on the consistency of the results for Test #2 and #3 (2 hour charge) shown in Figure #1, it does not seem unreasonable to divide the performance curves into two ranges. The first range is characterized by stable or slowly decreasing pressure differential with elapsed running time. In Test #2 and #3, the pressure differentials in this range were between about 1500Pa and 1800Pa, well above the 500Pa minimum desired for field tests. The second range is characterised by exponentially decreasing performance. The beginning of the second range is signalled by a rapid decrease in performance, and a change in the tone of the motor (although it is not instantaneous, it is audible). This point may be the most appropriate to change the battery since the performance drops off rapidly. For Test #2 and #3 this knee in the curve occurs at about the 12 minute mark. The elapsed running times until they reached 500Pa were 15 minutes, 40 seconds and 15 minutes, 47 seconds for Test #2 and #3 respectively, a difference of only 7 seconds between the two.

Referring to Figure #1, it is apparent that in Test #1 (1 hour charge) the pressure differential deteriorated more rapidly once it had reached the knee in the performance curve compared to Test #2 and #3 (2 hour charge). The Test #1 curve exhibits the same general shape of Test #2 and #3 and the beginning of the rapid decrease in performance occurred at approximately the same elapsed running time, 12 minutes into the test. In the first range of Test #1, the pressure differential achieved by the PACTS was between about 1500 and 1900Pa. The drop in pressure differential at the beginning of the second range was more rapid in Test #1, as is apparent in Figure #1. Table #2 shows that in Test #1 the pressure differential fell to 500Pa at about 13 minutes and 35 seconds, while Test #2 and #3 averaged to 15 minutes and 43 seconds, a difference of 2 minutes and 8 seconds. It is roughly estimated this difference may account for between 50 to 80 details tested on the construction site.

Figure #2 shows the results of Test #2 and #3 (2 hour charge) and Test #4 and #5 (4 and 14 hour charge respectively). From the graph, it is evident that in the first range, the performance of the PACTS were fairly consistent. In the Tests #4 and #5 the pressure differential in the first range were between about 1500 and 1800Pa, as in Tests #2 and #3. The PACTS performance in second range show a degree of difference between Tests #2 and #3 and Tests #4 and #5. The differences, however, are small and of little interest. In all four tests, the rapid decrease began at about 12 minutes into the test. From Table #2, Test #4 and #5 ran for 15 minutes, 10 seconds and 14 minutes, 54 seconds respectively before the pressure differential fell to 500Pa. The difference between these and the average of Test #2 and #3 is 32 second for Test #4 and 49 seconds for Test #5.

To observe the effect of the illumination light on the performance, Test #6 was run with a 2 hour charge and the illumination light off. Figure #3 shows the comparison of the results of Test #6 to the results of Test #2 and #3 graphically. In the first range, the difference between the results were small. The pressure differentials for Test #6 were from about 1500 to 1800Pa as in Tests #2 and #3. However, with the light off the first range lasted approximately 2 minutes longer, 14 minutes as opposed to 12 minutes obtained in Tests #2 and #3. As shown in Table #2, with the light off the PACTS achieved a pressure differential greater than 500Pa for about 2 minutes longer than the average of the Tests #2 and #3.

Figure #4 compares the test results for the older battery (Test #7) to those of a new battery (Tests #2 and #3). As in previous comparisons, the differences in performance in the first range are not significant. The pressure differential achieved by with the older battery were in the range 1500 to 1800Pa in the first section of the curve. The beginning of the second stage of the curve was at about 12 minutes, as with the Tests #2 and #3. The PACTS with the older battery ran for 15 minutes and 4 seconds before the pressure differential decreased to 500Pa, 40 second less than the average of Test #2 and #3. These tests indicate that the old battery is as good as the new battery, which indicates that the battery life span will probably be as great or greater than the equipment.

Figure #5 compares Test #8, which was run at maximum airflow, to Tests #2 and #3. In the first range on Test #8, pressure differentials are in the range of about 1500 to 1800Pa as in Tests #2 and #3, well above the 500Pa minimum required. The rapid decrease in performance at the beginning of the second range starts before 8 minutes into the test, significantly below the 12 minutes obtained in Tests #2 and #3. At 10 minutes and 13 seconds the pressure differential was 500Pa, 5 minutes and 30 seconds less than the average of Tests #2 and #3. Therefore, it is obvious that the useful time for the PACTS device before battery change is required is significantly affected by the amount of air the fan is required to move. It is noted, however, that the tests run against the plate would more suitably represent the actual on-site use rather than Test #8, run with full airflow through the fan for the majority of the test.

Conclusion

1) The performance curves displayed a two stage behaviour. The first stage was characterized by slowly decreasing pressure differential with elapsed running time. In the second stage the pressure differential decreased exponentially with elapsed running time.

2) Pressure differentials in the first stage of PACTS operation were in the range of 1500 to 1800Pa.

3) A small decrease in performance occurred due to a one hour charge relative to a two hour charge.

Decrease in the elapsed running time before the pressure differential fell to 500Pa was approximately 14% for the one hour charge.

4) No significant change in performance was observed between tests with batteries charged 2 , 4 and 14 hours. The 500Pa pressure differential occurred about 15.5 minutes into the test.

5) When the illumination light was not used the elapsed running time before the pressure differential fell to 500Pa increased by approximately 12%.

6) The difference in performance between the old and the new battery is insignificant. Demand for replacement batteries is expected to be small.

7) The effective running time between battery charges for the PACTS varies with airflow rate. A 35% decrease in the elapsed running time before the pressure differential fell to 500Pa was observed in the test run with free airflow compared to the tests with restricted airflow.

Table #1

Pressure Differential Versus Running Time Test Results

Running	Pressure Differential (kPa)							
Time (min.)	*Test: 1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
0	1.90	1.80	1.80	1.78	1.76	1.82	1.78	1.82
2	1.77	1.73	1.72	1.72	1.69	1.72	1.73	1.66
4	1.75	1.76	1.71	1.71	1.69	1.72	1.74	1.65
6	1.71	1.74	1.69	1.68	1.69	1.72	1.71	1.62
8	1.68	1.70	1.67	1.65	1.64	1.67	1.68	1.47
10	1.63	1.65	1.64	1.60	1.58	1.64	1.62	0.54
12	1.52	1.59	1.56	1.53	1.52	1.58	1.53	0.18
14	0.24	1.09	0.98	0.90	0.76	1.53	0.78	0.03
16	0.07	0.38	0.44	0.22	0.18	0.93	0.25	0.00
18	0.00	0.24	0.31	0.02	0.01	0.41	0.08	0.00
20	0.00	0.13	0.14	0.00	0.00	0.29	0.05	0.00
22	0.00	0.05	0.05	0.00	0.00	0.16	0.01	0.00
24	0.00	0.01	0.01	0.00	0.00	0.07	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table #2

Running Time Until Pressure Differential is at 500Pa

	Test Conditions	*Running Time Until 500Pa (min.)	Difference From Average of Test #2 and #3 (min.)	Percent Difference (%)
Test #1	new, 1hr., light on, restricted air	13.59	-2.13	-13.55
Test #2	new, 2hr., light on, restricted air	15.66	-0.06	-0.38
Test #3	new, 2hr., light on, restricted air	15.78	0.06	0.38
Test #4	new, 4hr., light on, restricted air	15.18	-0.54	-3.44
Test #5	new, 14hr., light on, restricted air	14.90	-0.82	-5.22
Test #6	new, 2hr., light off, restricted air	17.65	1.93	12.28
Test #7	old, 2hr., light on, restricted air	15.06	-0.66	-4.20
Test #8	new, 2hr., light on, free air	10.22	-5.50	-34.99

* Obtained by linear interpolation.

Figure #1

Comparison of 1 and 2hr. Charge

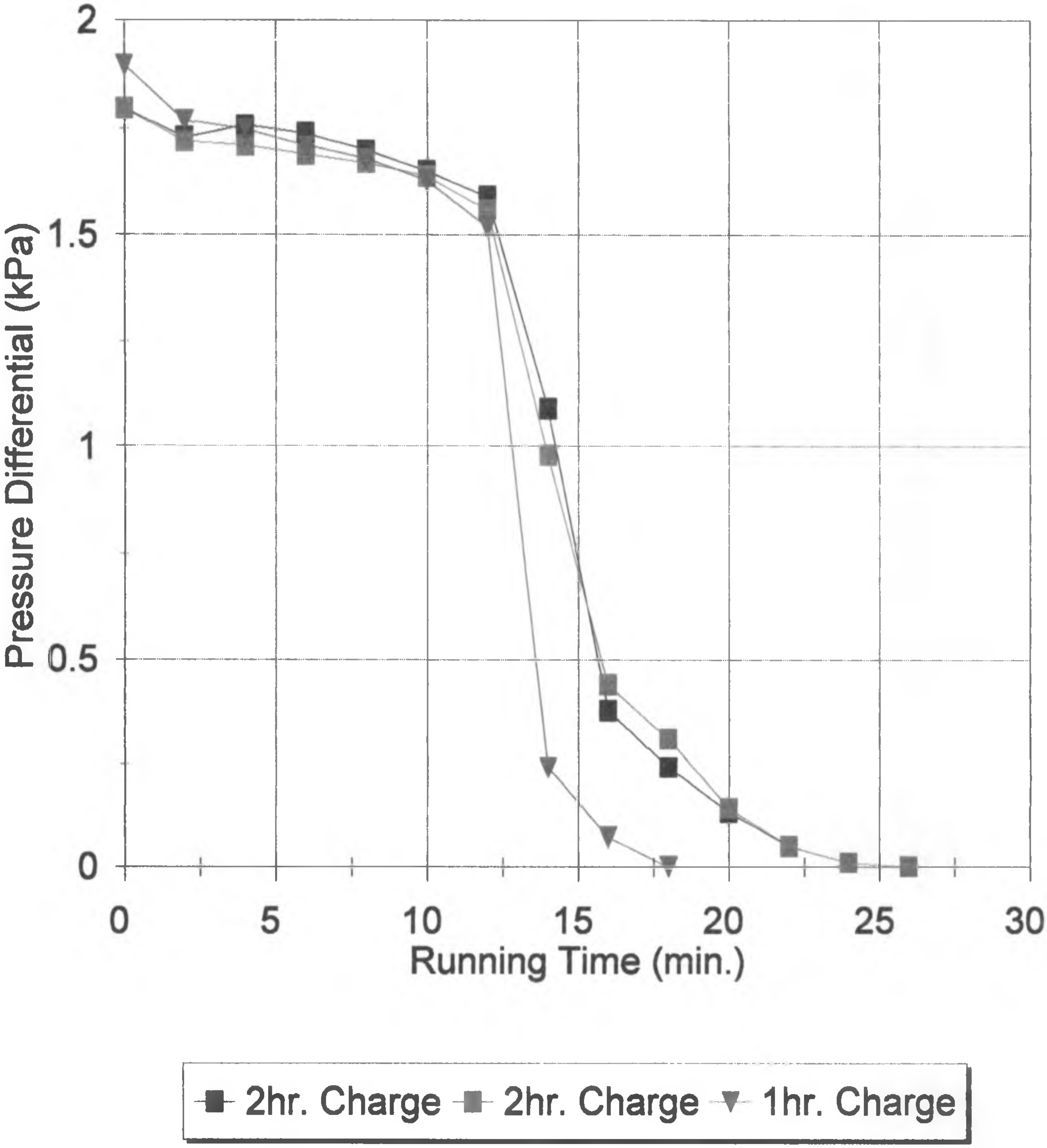


Figure #2

Comparison of 2, 4, and 14hr. Charge

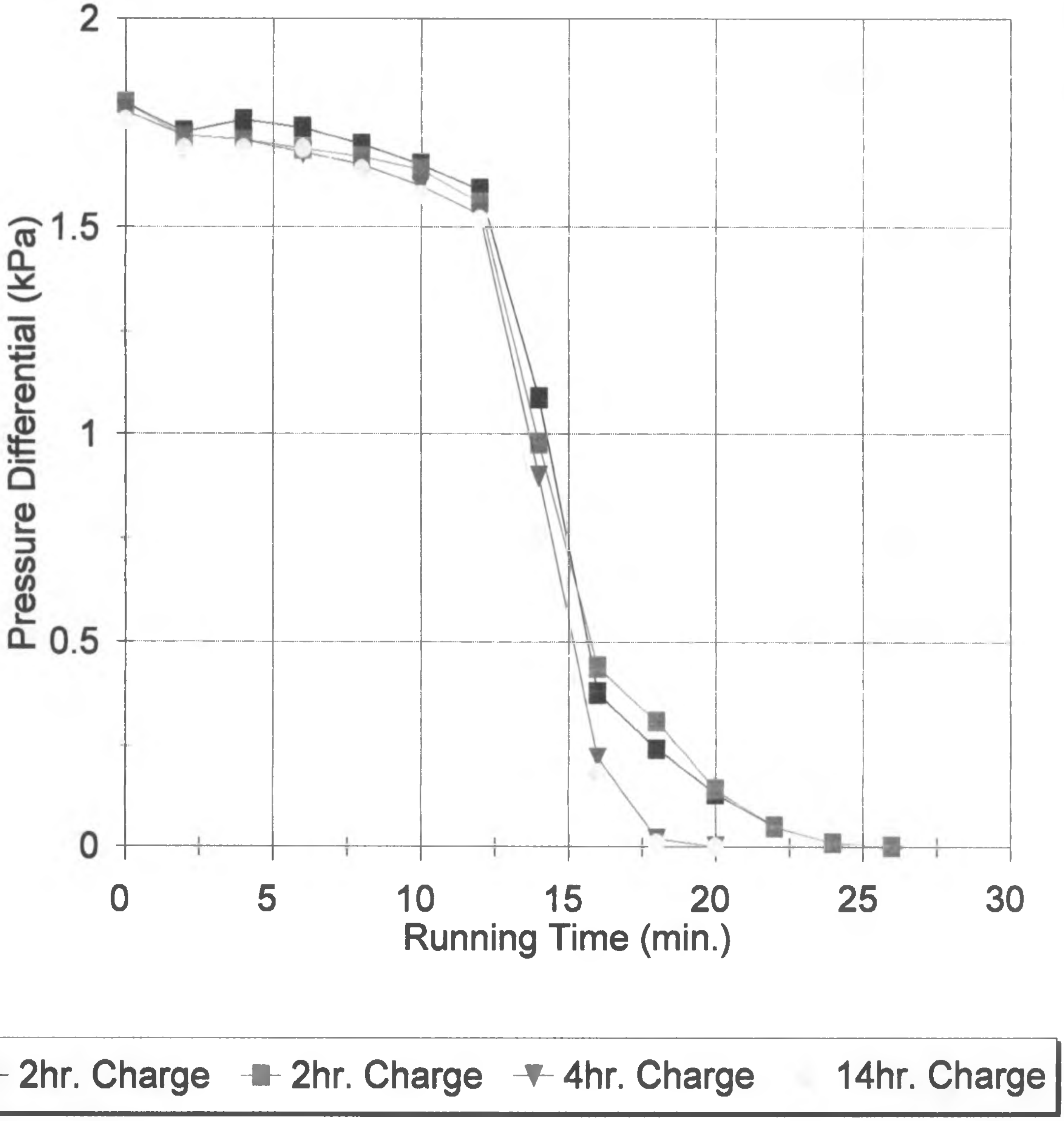


Figure #3

Effect of Illumination Light

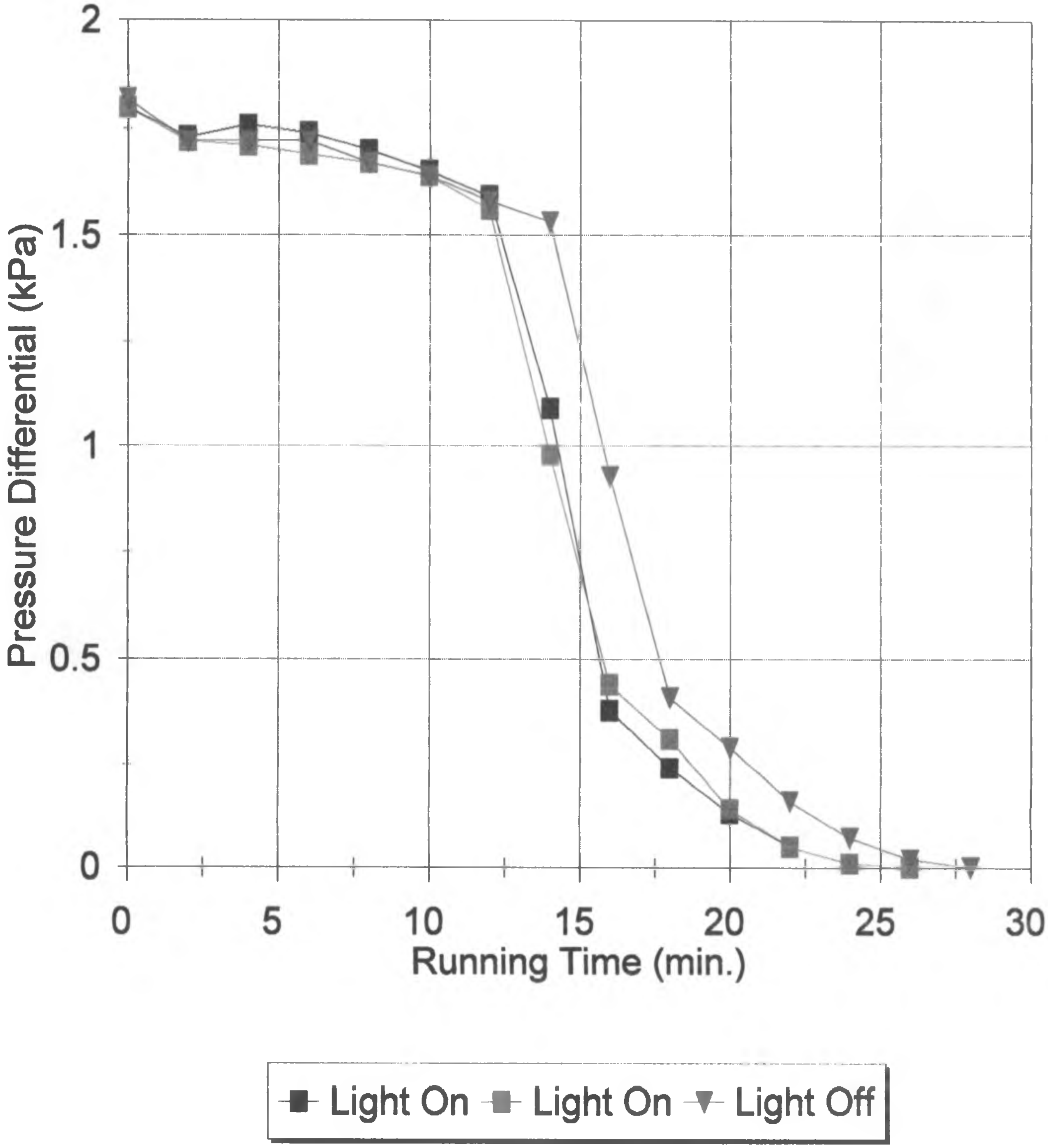


Figure #4

Comparison of Old and New Battery

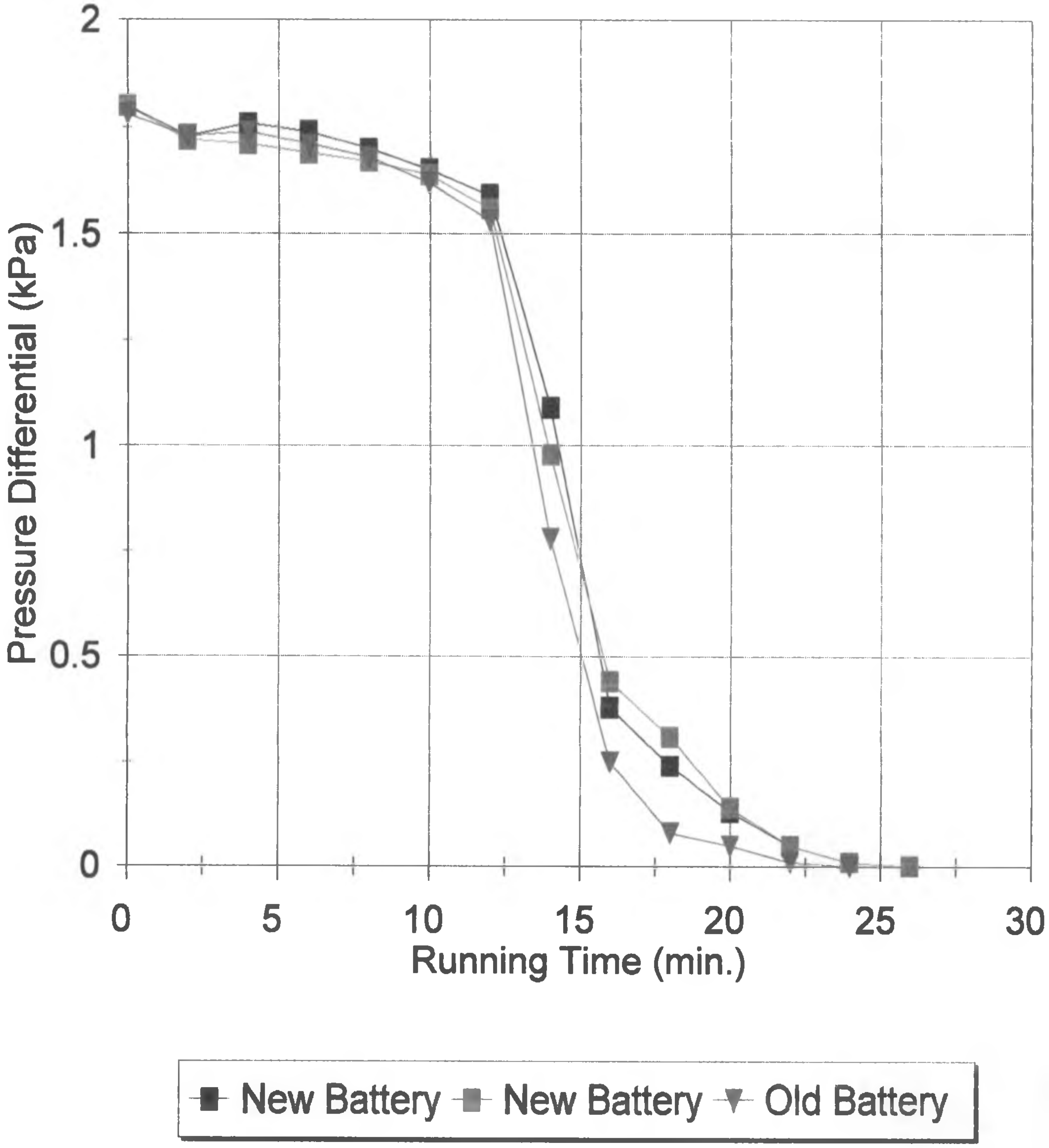
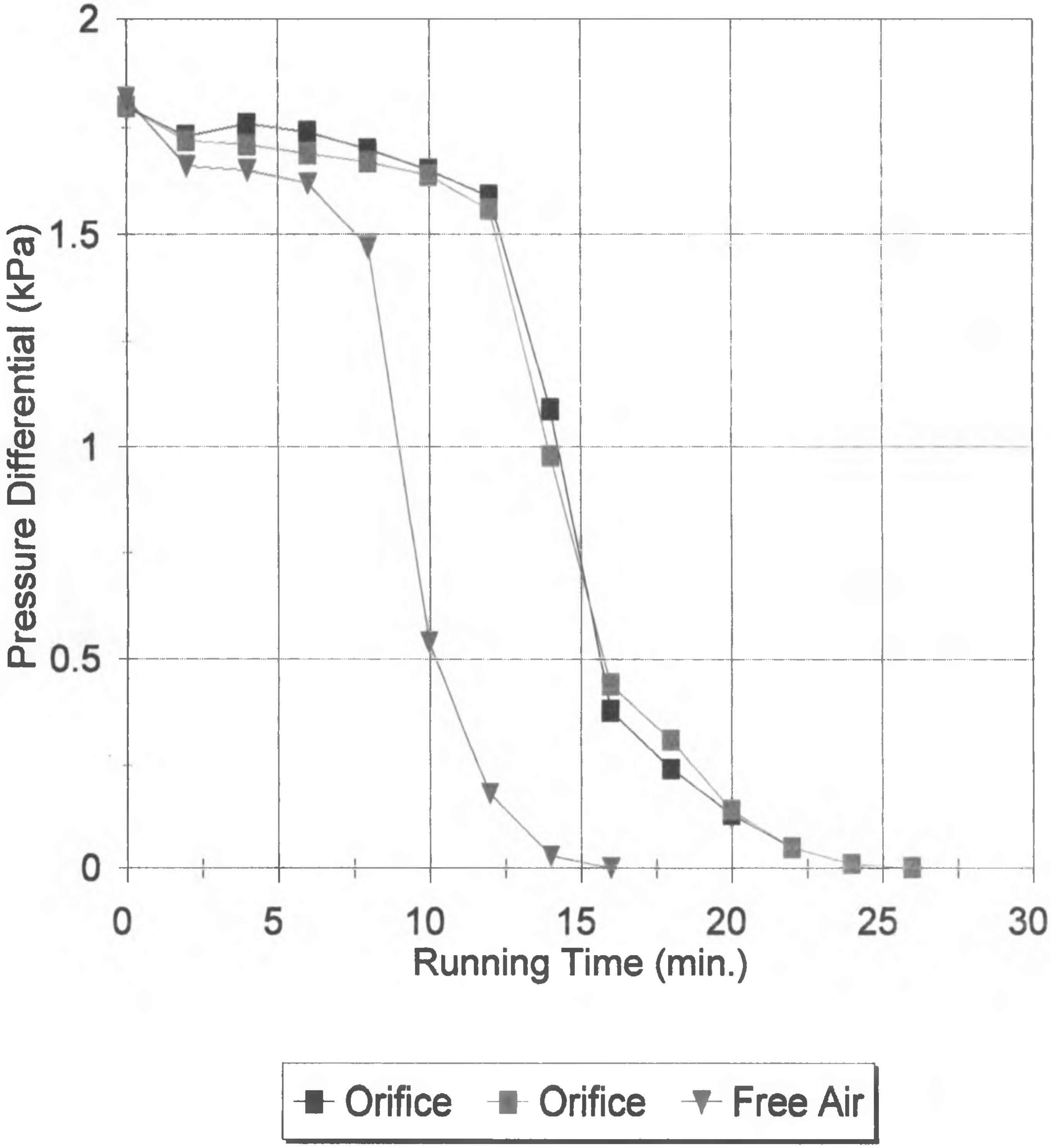


Figure #5

Comprison of Restricted & Free Airflow



7.6 Pressure Differential Versus Leakage Area Test

Objective and Scope

Objective

The objective of the test was to relate the pressure differential achieved by the PACTS apparatus to an actual leakage area open into the dome of the PACTS apparatus.

Scope

Testing was carried out by varying the size of a triangular orifice into the dome of the PACTS device and measuring the corresponding pressure differential between the inside and outside of the dome.

Apparatus and Method

Apparatus

The requirements for the test were that an area of an opening into the PACTS dome could be easily varied and measured while the pressure differential developed by the PACTS was measured. To facilitate these requirements, an aluminum sheet was fabricated with a V-notch. A second sheet of aluminum could be slid over the notch to vary the area, as shown in Figure #1. A Dwyer Series 475-4 Mark2 digital manometer (range 0-5kPa, resolution 0.01kPa) was connected to a pressure tap in the dome of the PACTS device to measure the pressure differential between the inside and outside of the dome of the PACTS.

The same battery, a new Makita 7000 -7.2V nickel-cadmium, was used in the PACTS for both test undertaken. The battery was run completely down in a PACTS and then charged for two hours prior to each test.

The dome of the PACTS device was sealed to the notched sheet of aluminum. Vaseline was applied between the notched sheet and the sliding sheet and around the gasket on the PACTS to minimize extraneous leakage during the test.

Method

The PACTS device was placed against the sheet and run at full speed. The height of the opening in the notched sheet was varied from 0.5cm to 15cm (0.196in to 5.906in) in increments of 0.5cm (0.196in), varying the area of the opening from 3.325mm^2 to 2992.5mm^2 (0.005154in^2 to 4.638in^2). The corresponding pressure differential achieved by the device at each setting were measured and recorded. The test was repeated with the same prototype PACTS and battery to provide an indication of the consistency of the results.

Observations

Table #1 shows the recorded results of the tests. Figure #2 shows the results of the test graphically.

Discussion

As shown in Figure #2, results of both tests were fairly consistent. Significant differences occurred at the low pressure differentials (high leakage area) end of the curve. This was likely due to differences in the initial charge of the battery and the length of time the individual tests were run. Note that the low pressure end of the range is off little practical interest in these tests.

Using linear interpolation between the closest points on both curves, the equivalent leakage area at which the device can no longer achieve a pressure differential of 500Pa (2.01in. of water) was estimated. A value of 838mm^2 and 799mm^2 (1.299in2 and 1.238in2) is obtained in the first and second test respectively.

The actual pressure differential achieved in a particular application depends on several factors, including the Reynolds number of the airflow through the opening(s) and the geometry of the opening(s). Therefore, in a on-site application of the PACTS, one would not expected that the actual area of leaks into the PACTS dome could be precisely predicted from the pressure differential achieved. This test could be used to provide an estimate of the leakage area (an equivalent leakage area), including extraneous leakage, corresponding to given pressure differential in an on-site application. Note that in the case of the existing PACTS prototypes, the pressure differential achieved also depends also on the state of the battery used in the device.

As shown in Figure #1, the relationship between the pressure leakage area and pressure differential is roughly exponential. The relationship between the leakage area and pressure differential can be estimated by an exponential regression equation, however, large relative errors between observed and estimated points occur in the low pressure (high leakage area) range of the curve.

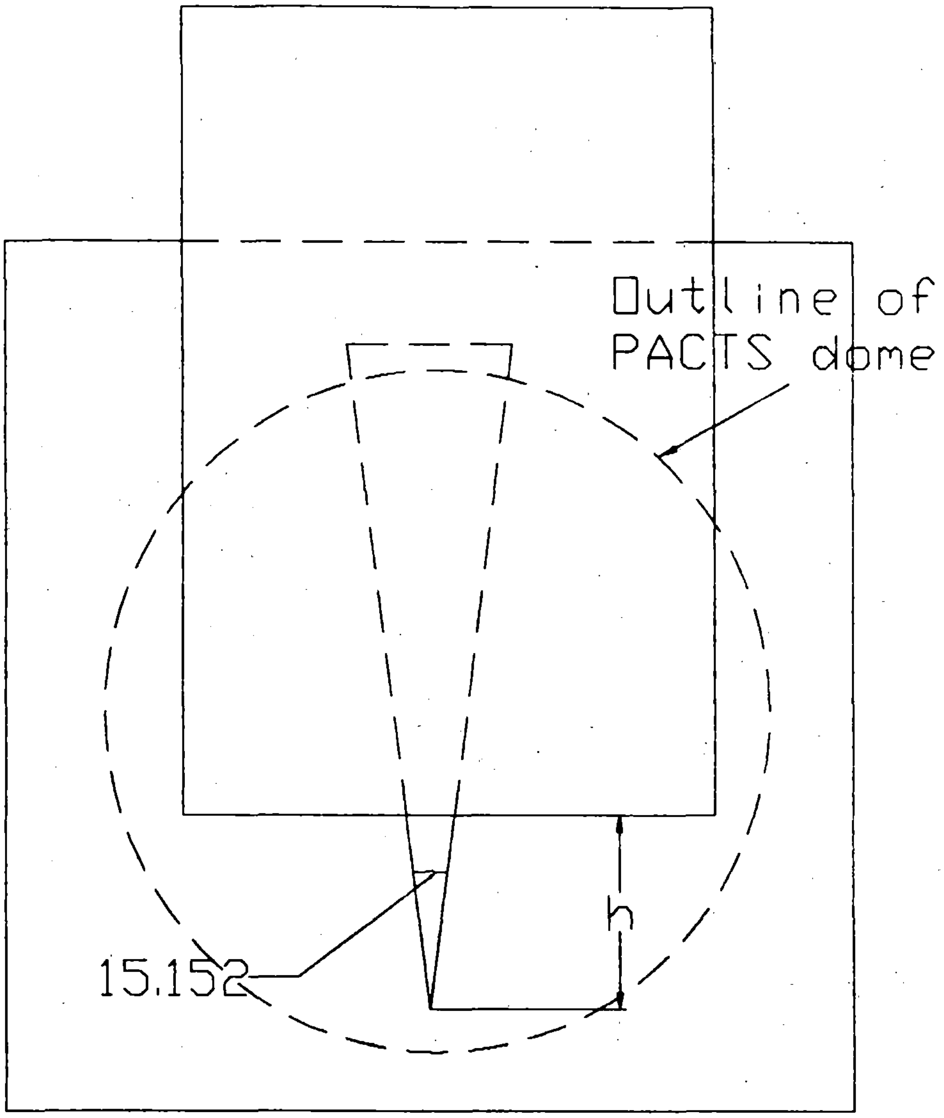
Conclusion

1) The leakage area at which the PACTS with a fresh battery device could no longer achieve a pressure differential of 500Pa (2.01in of water) was approximately 820mm^2 (1.271in^2), a substantial size of opening.

2) The actual area of an opening at which the PACTS device can no longer achieve a given pressure differential in an on-site application depends on several factors which are not easily quantifiable.

3) Using the PACTS and performance curves produced to accurately estimate the leakage area of a test detail is not feasible. This test method could be used to obtain an equivalent leakage area, provided that an acceptable relationship between the pressure differential and equivalent leakage area can be defined.

4) The relationship between leakage area and pressure differential is approximately exponential.



Area=hxhxtan(15.152)

Figure #1

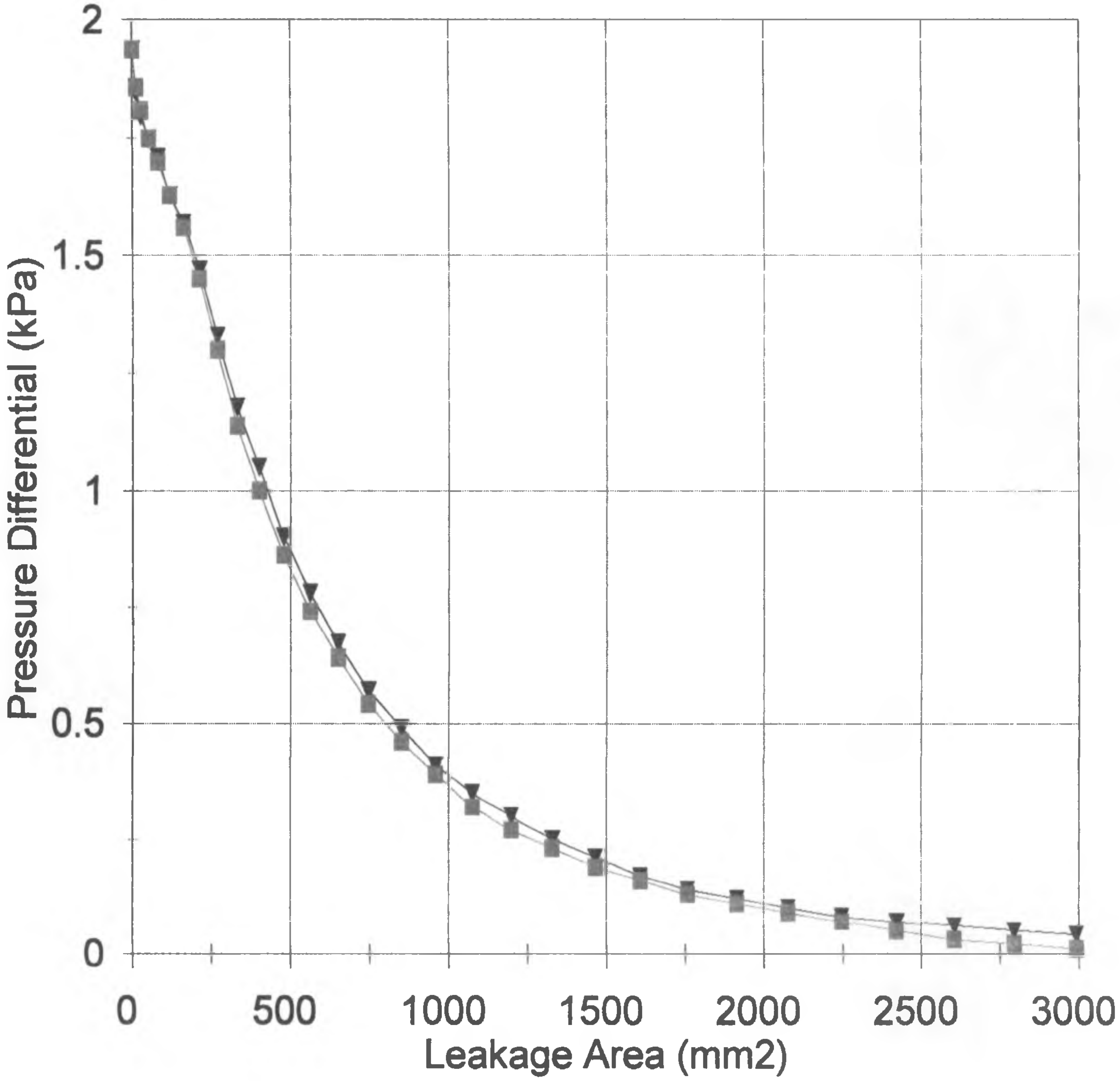
Test Apparatus

Table #1
Leakage Area Versus Pressure Differential

Height of Triangle (cm)	Equivalent Leakage Area (mm2)	Test #1 Pressure Differential (kPa)	Test #2 Pressure Differential (kPa)
0.5	3.325	1.94	1.94
1.0	13.300	1.85	1.86
1.5	29.925	1.80	1.81
2.0	53.200	1.75	1.75
2.5	83.125	1.71	1.70
3.0	119.700	1.63	1.63
3.5	162.925	1.57	1.56
4.0	212.800	1.47	1.45
4.5	269.325	1.33	1.30
5.0	332.500	1.18	1.14
5.5	402.325	1.05	1.00
6.0	478.800	0.90	0.86
6.5	561.925	0.78	0.74
7.0	651.700	0.67	0.64
7.5	748.125	0.57	0.54
8.0	851.200	0.49	0.46
8.5	960.925	0.41	0.39
9.0	1077.300	0.35	0.32
9.5	1200.325	0.30	0.27
10.0	1330.000	0.25	0.23
10.5	1466.325	0.21	0.19
11.0	1609.300	0.17	0.16
11.5	1758.925	0.14	0.13
12.0	1915.200	0.12	0.11
12.5	2078.125	0.10	0.09
13.0	2247.700	0.08	0.07
13.5	2423.925	0.07	0.05
14.0	2606.800	0.06	0.03
14.5	2796.325	0.05	0.02
15.0	2992.500	0.04	0.01

Figure #2

Test #1 and #2 Results



PHOTOGRAPH LOG

Equipment Testing

1, 2, 3 & 4)	Construction of Masonry Block Test Chamber for Comparative Testing against smoke trace
5, 6, 7 & 8)	Construction of Steel Stud and Drywall Test Chamber
9, 10, 11 & 12)	Inside and Outside Corner Test Chamber
13 & 14)	Independent Inspector Using PACTS
15& 16)	Smoke Trace Tests
17 & 18)	Fan Curve Test - ANSI/AMCA Standard 210-85.
	Equipment: CAN-BEST 283 A200. Flow meter. Air Instrument Resources Ltd. Micromanometer MP6KD.
21 & 22)	Pressure Differential versus Elapsed Running Time
23 & 24)	Pressure Differential versus Leakage Area
	Equipment: Air Instrument Resources Ltd. Micromanometer MP6KD.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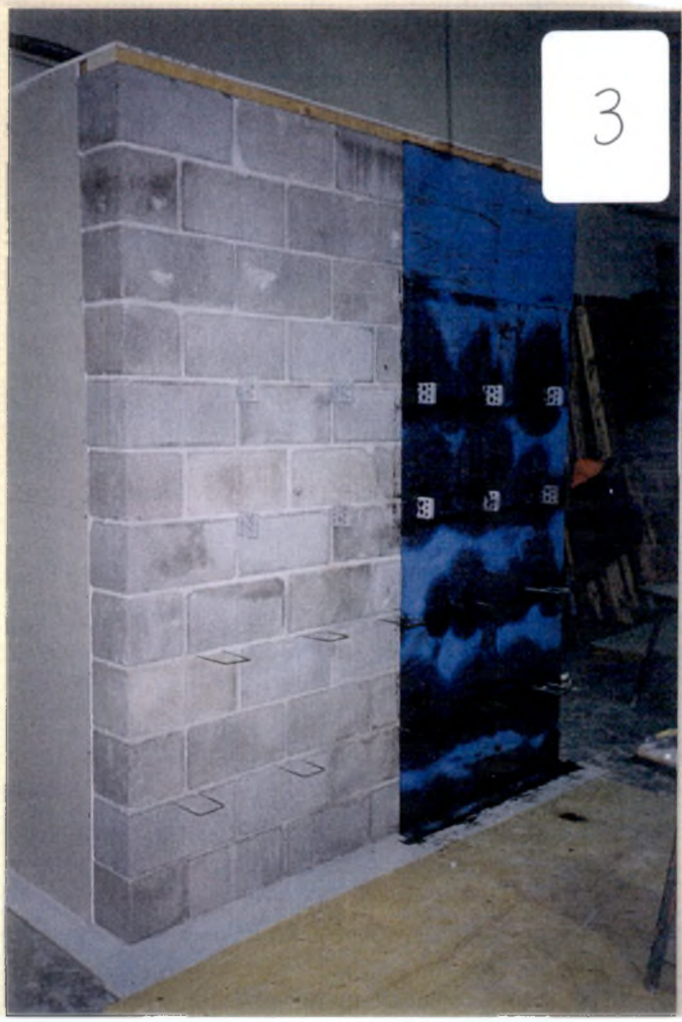
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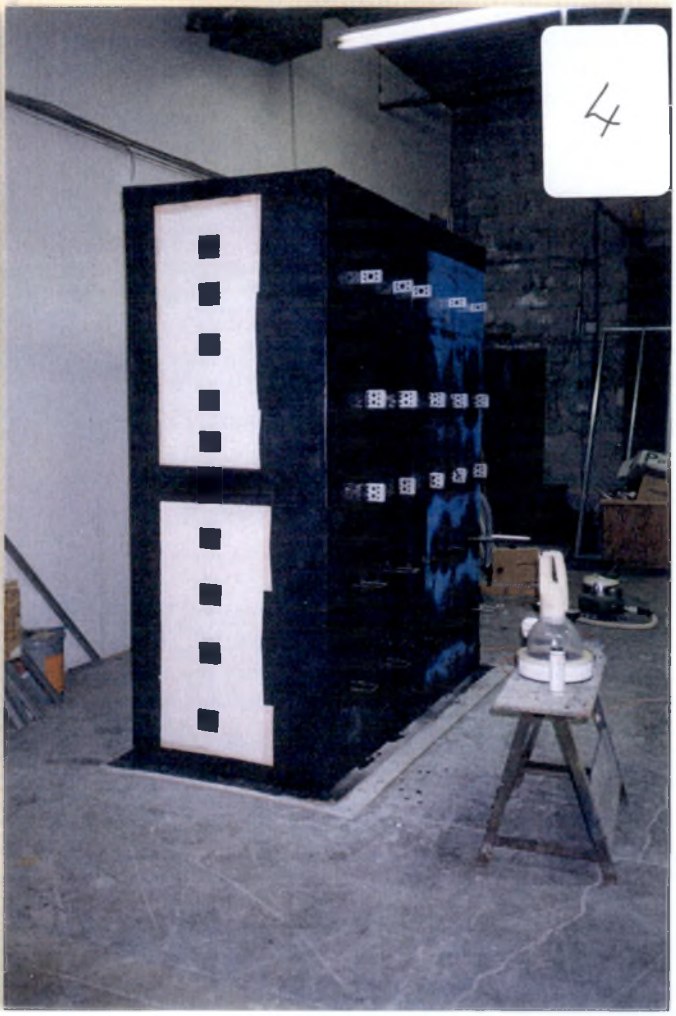
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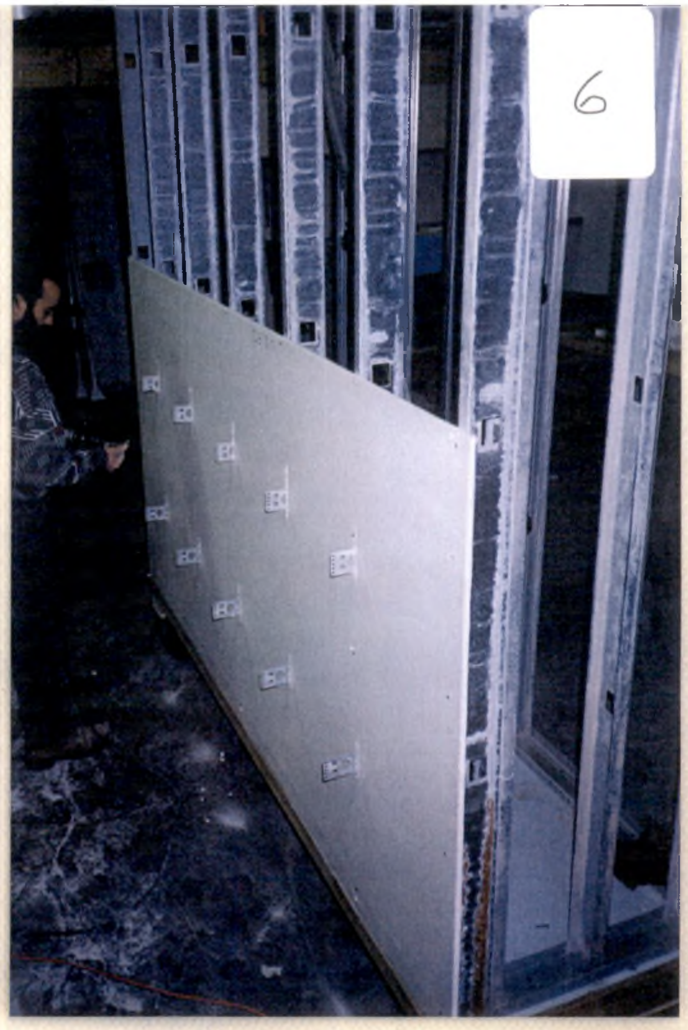
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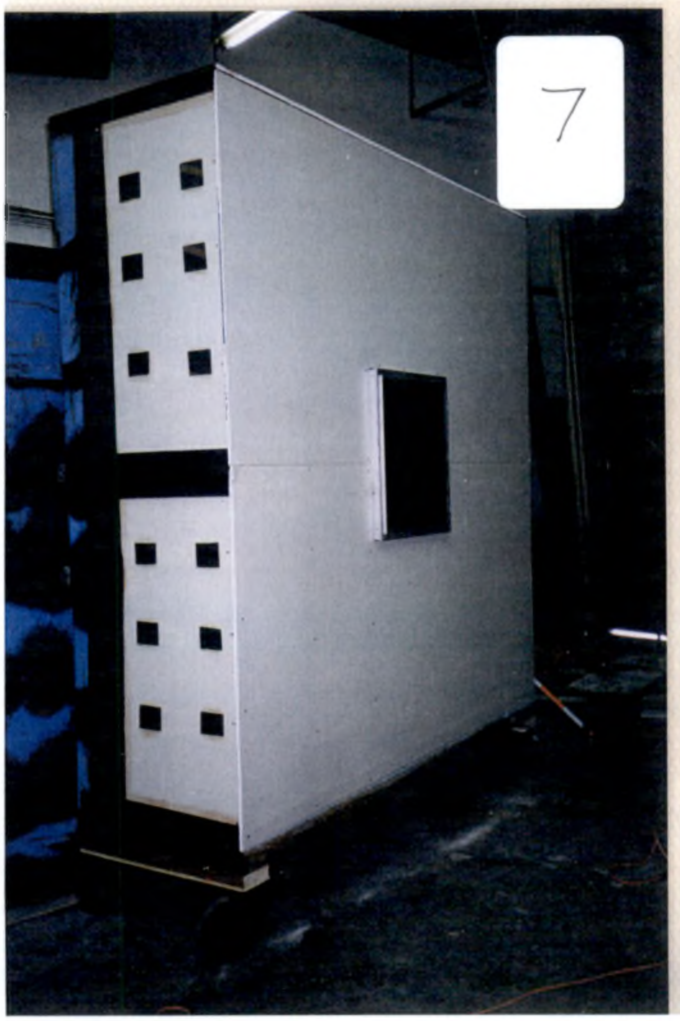
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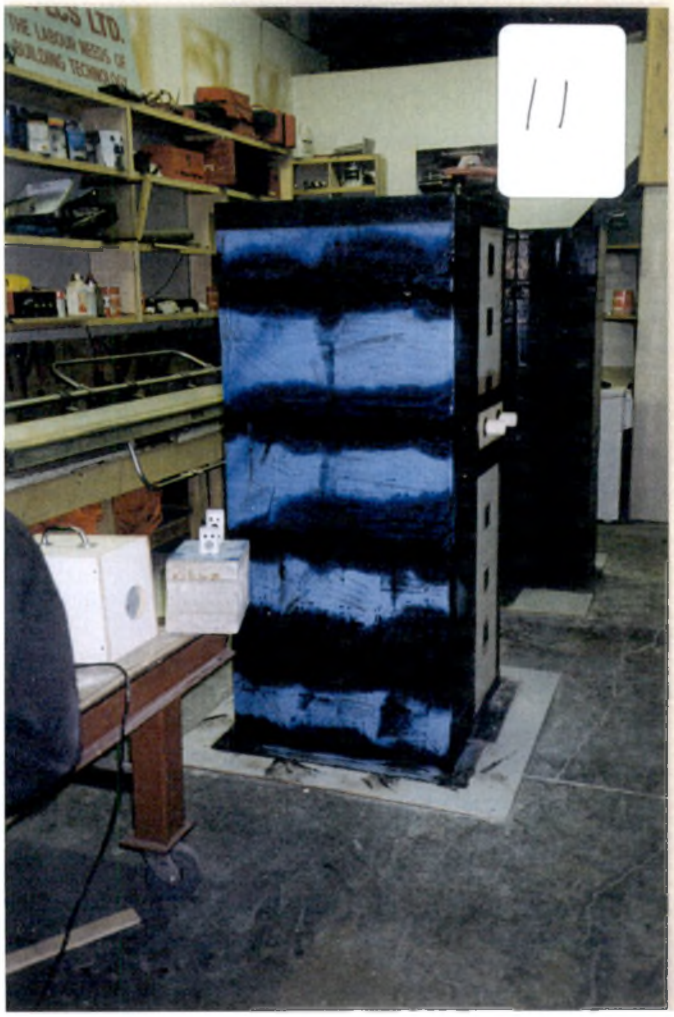
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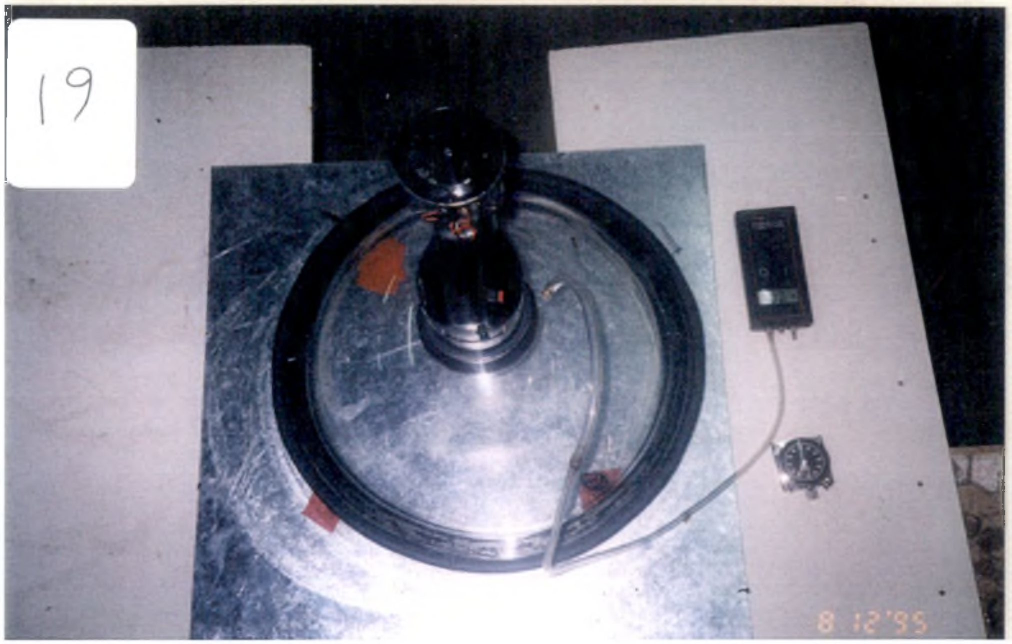

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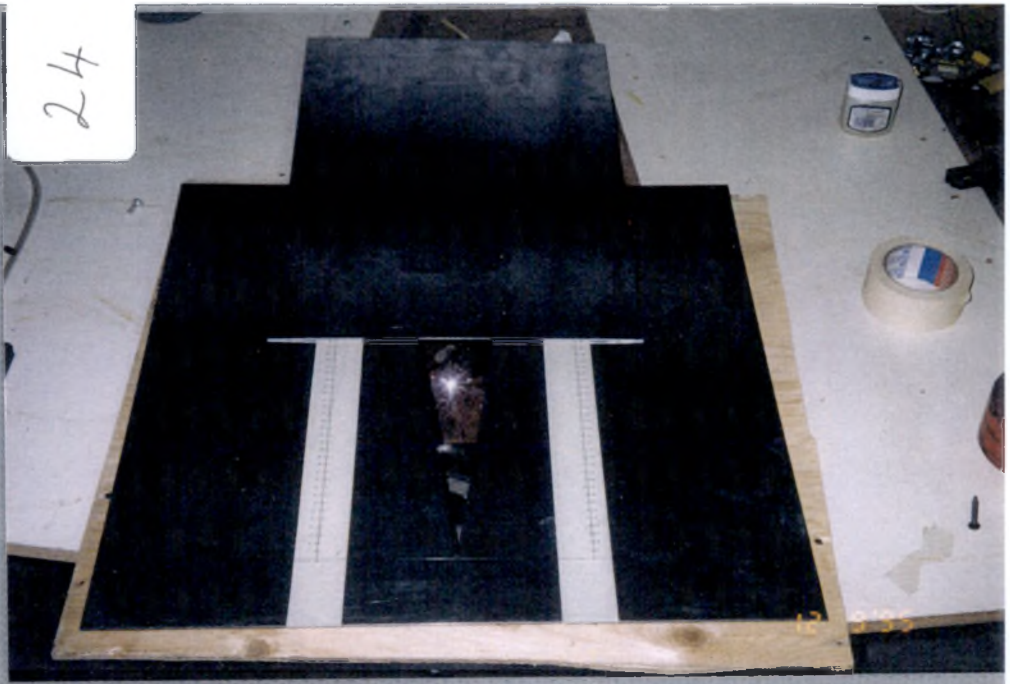

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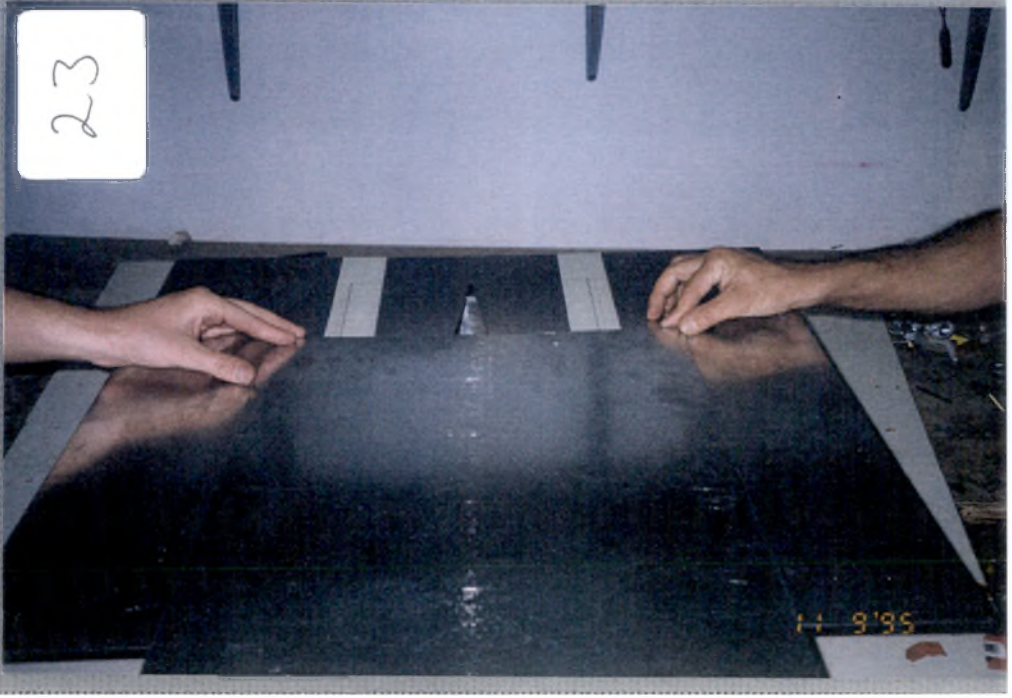

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8. CONCLUSIONS

1) The principle concept of the testing method and equipment has proven to be effective in both site and lab conditions. The test method supersedes existing methods in its efficiency in identifying leaks and in the time necessary to perform the tests. No impact to the critical path of the construction schedule has been noted, other than a slight delay in construction by the testing and the correction of the deficiencies. This situation should not be considered as a delay caused by the testing. Rather, it is the deficient work, previously ignored, and the time is invested in the correction of said deficiencies.

2) Lab tests have found the equipment in its prototype form to be durable and effective throughout the range of tests performed. It becomes obvious when either battery decay or extraneous leakage affect the test results. No special precautions have to be taken to monitor either condition.

3) Site testing has found certain conditions require additional preparation to the test area to make testing practical. These conditions are uncommon in general construction practice of installation of air barriers consisting of expansion joints, compression joints, or the like, where troughs in the air barrier system require additional blocking. Other site conditions can be addressed by various profiles to the plastic chamber that can address inside/outside corners, window edges, etc. Portions of the building that cannot be confirmed with the developed testing equipment should be considered for alternate testing methods, for instance, the smoke trace test.

4) The testing method has been embraced by all stakeholders. Architects, the spec writers, have viewed the method and equipment as a practical means of confirmation and lessening liability. General contractors now have a method of monitoring sub-trades, and the sub-trades can be confident that their workmanship has been improved to address today's requirements in airtightness of air barrier systems. Most importantly, owners and developers have recognized the impact of the introduction of the testing method as proving a critical component of their investment, the air barrier system, is more likely perform to the expected life span and improve the energy performance of their building, due to less leaking through the air barrier.