VII.2 From Desktop to Plant Room: Development of an innovative system for mapping and assessing trap seal vulnerabilities in building drainage systems – lessons from the field.

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Abstract

The use of the *reflective wave technique* has been shown to be an effective method of mapping and detecting water trap seal vulnerabilities in building drainage systems. Research in sanitation engineering must however be about more than theoretically proving the efficacy of a particular technique, it is an integral part of the process to implement the introduction of such methodologies in a practical sense, particularly in our world of rapidly changing needs, in order to show both the importance of such research and to provide real solutions to serious problems.

Site based validation of the theoretical methodologies is key to the acceptance of any innovation in building drainage and has been placed at the centre of the development of the *reflected wave technique* right from the very beginning. This has proved immensely effective since site validation of theoretical results not only provides confidence in the theoretical approaches, but in turn, informs the theoretical advances in a virtuous cycle of *development, validation and review'.* This approach to implementing innovative ideas in building drainage has been carried out in five major studies leading from the relative simplicity of a university laboratory to a complex hospital environment in constant use.

The introduction of a conceptual framework for the development of this system is presented here which highlights the benefits of using an iterative and incremental approach to problem solving complex testing techniques in building drainage systems.

Keywords

Site testing, results validation, confidence building, conceptual models.

1. Introduction

This research charts the process of moving from the theoretical to the practical and highlights the difficulties along the way. The acceptance of end-users and building management personnel is of vital importance in this respect and gaining their confidence provides a significant milestone for the industry as a whole. The integration of a new technology into a sometimes rather rigid regulatory framework poses another challenge. Integrating academic rigour with technological development isn't new, however there are many pitfalls and finding a conceptual model to cover this process is an important element in the development process.

There are many methodologies [1] for charting progress and streamlining the innovative process. The field of software engineering has considered this to be essential in complex system analysis and design. A brief look at some of the methodologies used in that area of engineering shows several potentially useful conceptual models for development of a technology for application to the detection of defective water trap seals since there is a considerable software component to the system. The brevity of this paper precludes a lengthy discussion of these methods here however several have been chosen for a brief introduction as follows;

- The Waterfall method – This method is a top down methodology whereby a design is produced from a system brief which is implemented, tested and verified. This is a rigid system and is only suitable for a mature technology where a reasonably accurate brief can be produced.

- The Shashimi method – This again is a top down system based on a rigid brief, however allowance is made for some refinement of the brief during the development phase. The methodology is still rigid and again suitable for mature technologies.

- Iterative and incremental development – In this approach a cycle of 'brief', design, implementation, testing and review are all performed in a cyclical manner to fine-tune a design to the required outcome in an iterative and incremental way.

These methods are all features of complex software system design where many elements coalesce to form an integrated whole. A critique of these systems in the context of a system with elements of software, hardware and a complex pressure wave tracking methodology leads to a conclusion that the iterative and incremental development model is more appropriate to this field of interest, since there are many unknowns in the field. The 'top down' waterfall method requires prior knowledge of the eventual operation of the system, which is absent from a development such as the DETIS at its inception. The Shashimi method includes an element of iteration since there are overlapping elements leading to a process of feedback to the waterfall method, however it is still a 'top down' system. The iterative and incremental provides the best chance of producing a robust design in an iterative process best suited to applications in building drainage systems.

2. A Conceptual framework for development.

A conceptual framework for the evaluation and development of an innovative technology provides a useful insight into the way in which systems can be developed, particularly if the initial concept has a root in theoretical engineering in an academic setting. Figure 1 below illustrates the 'development cycle' and shows the elements of design and review which need to be included if a technology with a useful, practical application is to be developed. The conceptual framework is a modification of the development and iterative method discussed above and provides enough feedback and checks in order to highlight deficiencies and inefficiencies.

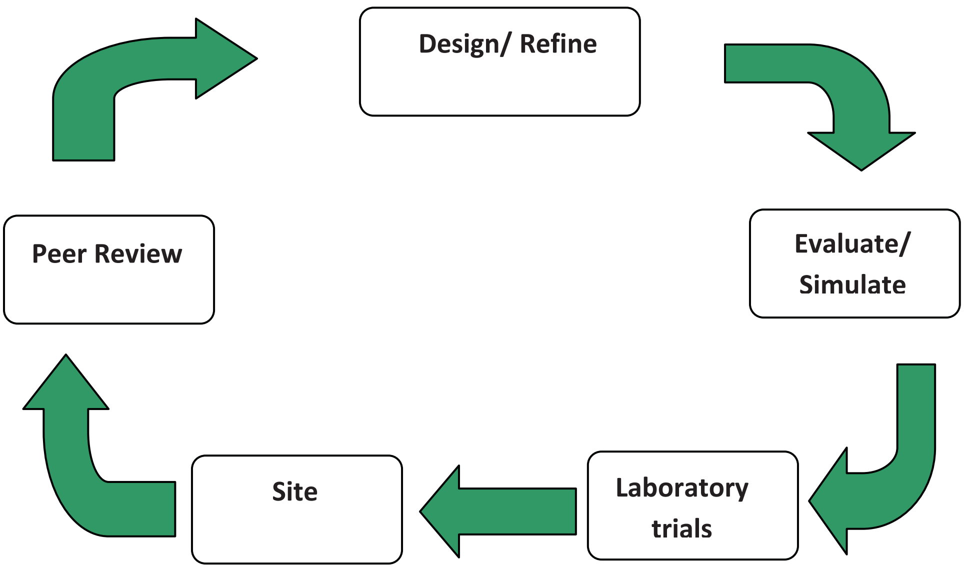

Figure 1 A conceptual framework for design based on theoretical, laboratory and site investigation, based on a modification to the *iterative and incremental development* method as applied to complex software system design.

The elements of the process are obvious in many cases however it is useful to be reminded that each of these steps is important to produce a robust design. The elements are described in more detail below.

Design/ Refine

This is the initial design and subsequent refinement. The motivation for the design may be a concept based on a known need or a response to a perceived need in the field.

Evaluate/ Simulate

Central to the work of academic engineers is the evaluation of system design and performance. Linked to this, although often separate, is the modelling of system operation using mathematical, numerical and computer techniques to allow fast evaluation of conceptual designs and subsequent changes/refinements in realistic modelling environments. The power of this element of the process lies in the ability to evaluate without having to instigate costly and time-consuming laboratory or site evaluations on embryonic designs, the process is thereby speeded up considerably.

Laboratory Trials

Modelling and simulating operation cannot however highlight some of the nuances of system performance, particularly if the system under consideration is new with limited data sets of usage information from which to drive the models. Laboratory investigations highlight the first practical issues in any development process, as well as providing useful data on actual performance from which the models can be refined

Site Trials

One of the criticisms often aimed at academics is an inability to operate in real situations, as professionals in industry have to. The instigation of site trials is therefore very important in the development cycle since it not only provides more practical application information and additional performance data to drive the simulation models, but provides the first real critique of the system from professionals in the field. This critique is invaluable. Professionals, particularly in the building drainage field, have a sense of what can work, what building managers and authorities will accept and how the system will be viewed by the profession at large.

Peer Review

The production of research papers for peer reviewed academic journals and relevant conferences provide an academic integrity to the development process. It is often considered inappropriate to publish details on innovative technologies because of intellectual property (IP) issues, however, if these IP issues can be overcome the benefit of expert opinion and criticism is of immense value to any development process. If handled properly the ‘peer review’ part of the process should feed into the conceptual framework for design and enhance the overall outcome.

These elements are not exhaustive and indeed there are ‘loops within loops’ within this process, however overall these are considered the main elements required to produce a robust technology with every chance of succeeding since the iterative process has the effect of ‘weeding out’ inefficiencies and promoting best practice in both academic and industrial spheres of interest.

3. Case Study

3.1 Introduction

In order to illustrate the effectiveness of this conceptual framework for design and development, a case study will be considered. The system under consideration is the defective trap identification system (DETIS). The purpose of the discussion is not to explain how the system works, that has been dealt with elsewhere both at CIBW62 symposia and in peer review journals,[2],[3],[4] but rather to consider how changes, refinements and improvements have been made possible by application of the methodology set out in the conceptual framework above. The iterative process of ‘passes’ around the cycle is further enhanced by an increase in complexity in the site trial phase. It is the site trial element which forms the focus of the case study.

3.2 First iteration – proof of concept

Prior to going on site for the first time the process began with a concept based on well known and understood pressure wave propagation techniques. The first iteration involved a truncated version of the framework above involving only the design, simulation and laboratory investigation elements. This is usual in the very early stages of design however it is important to highlight the iterative process even at this early stage. The proof of concept went through several stages of this process using only very simple laboratory test rigs, increasing in complexity as the extent of the capability of the DETIS became apparent.

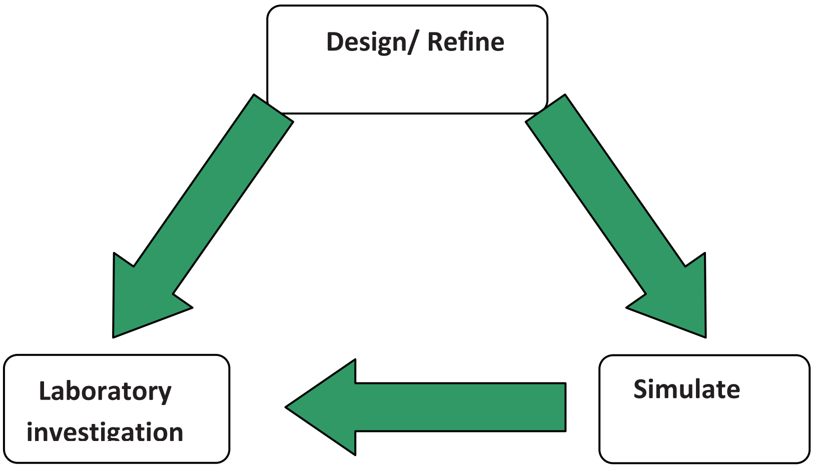

Figure 2 Initial Proof of Concept

The initial proof of concept was carried out on the laboratory test rig at Heriot-Watt University (HWU) as shown in Figure 3. The simple 'single shot' piston transient generator was used to prove that any empty water trap seal could be located using the reflective wave technique. This system was also used in the initial simulations using AIRNET. This iteration proved that the methodology worked, that any termination could be detected and that the system produced a unique 'signature' which could be used to effectively assess if any given system had a defect.

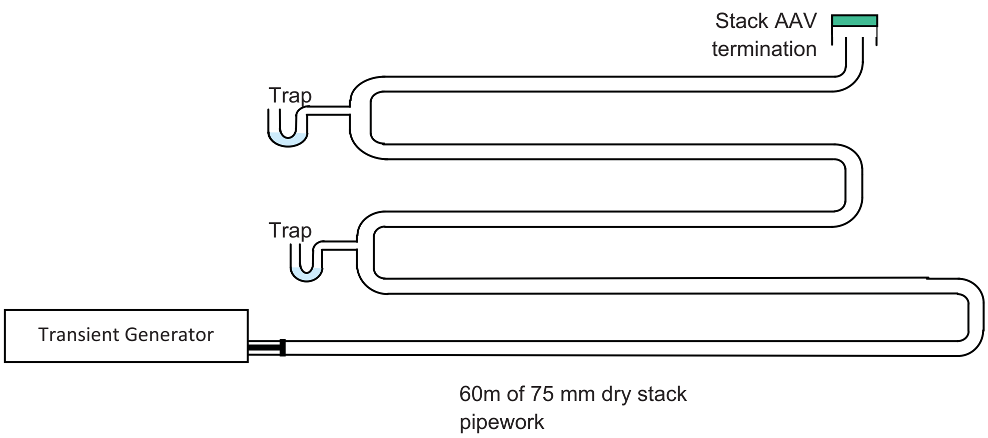

Figure 3 Laboratory test rig used for initial 'proof of concept' iteration.

3.3 Second iteration – Site trial housing block, Dundee.

The first site trials were carried out in a 14 storey building in Dundee Scotland. The results of this trial have been discussed in previous CIBW62 papers [4] and on the whole the trial was very successful. In terms of application of the *iterative and incremental conceptual framework* this trial raised several important issues which did not emerge in the laboratory or simulation phases, however they were verified afterwards by another pass of the simulation/laboratory investigation phase. The main issues raised were:

1. The single pulse methodology used successfully in the laboratory may actually cause water trap seals to be displaced in certain circumstances. This was an invaluable discovery and one which instigated some research on non-steady friction in water trap seals in response to high frequency air pressure waves [5] [6]. This led to the development of the sinusoidal wave technique, a non-destructive method of testing.

2. While it was well known that waves divided at junctions [7] the implications for this application weren't fully appreciated. The dimensions of the input junction in relation to the main stack height are critical, as is the location of the device itself.

These issues were addressed in the laboratory, in modelling and the outcomes reported in conference papers and peer reviewed journals.

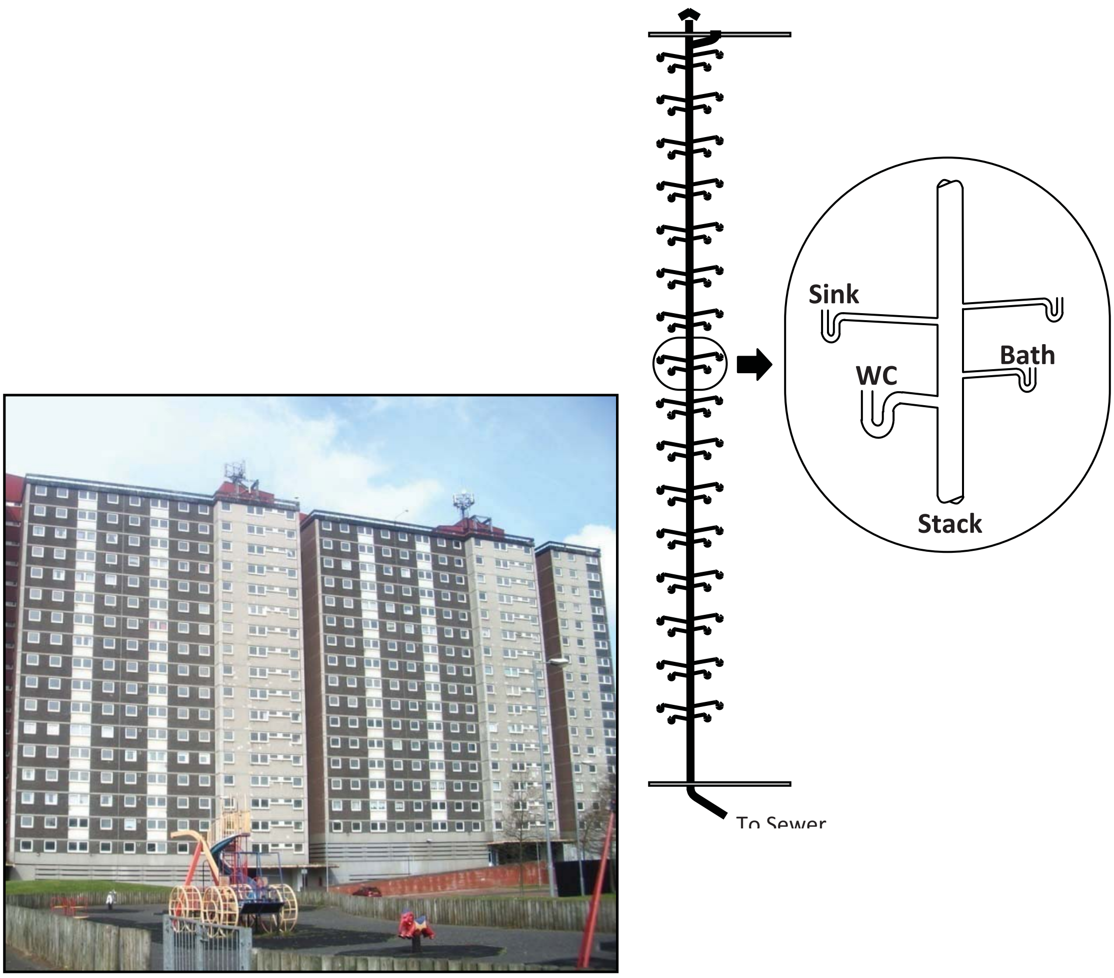

Figure 4 Housing Block in Dundee used in first real site trial.

3.4 Third iteration – HWU School of the Built Environment building

The lessons learned from the second iteration were implemented in the third iteration and the second real site test. The site was chosen because access was available for continuous observation and because it is in a busy campus; these facilities are in constant use. At face value the system appears simpler than the Dundee test however there were unforeseen complications with this system which produced valuable insights. This, again, highlights the importance of the iterative and incremental approach. The main findings from this research iteration were:

1. The sinusoidal wave technique was verified as non-destructive, repeatable and reliable, even in the busy campus building.
2. It was difficult to ascertain a defect in water traps at the ends of the branches, again this is due to the division of waves at junctions and the cumulative effect of this phenomenon. Further investigation and simulation of the system using AIRNET produced a solution whereby additional transducers were required on branches in order to produce the required resolution.
3. This research also highlighted the unusually high rate of evaporative depletion of water trap seals used to collect condensate from boilers, a cause for concern.

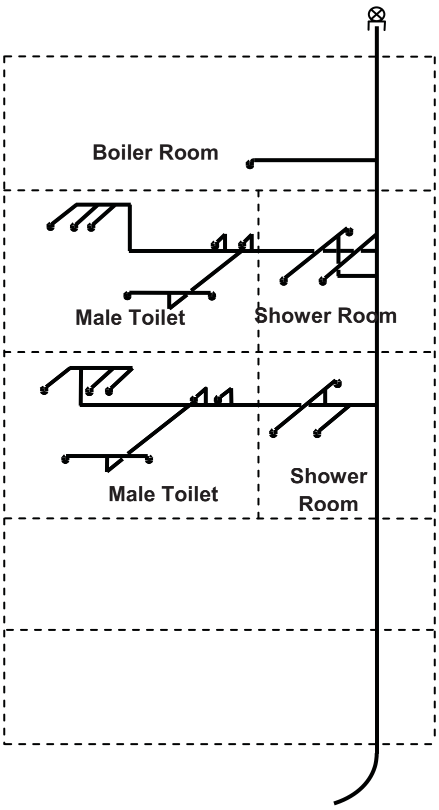

Figure 5 Site Trial at Heriot Watt University

3.5 Fourth iteration – RBS building, Glasgow

Armed with the valuable insights from the HWU trial another building was procured for a field trial. The Royal Bank of Scotland kindly allowed the Drainage Research Group from HWU to trial the system in a building in Glasgow. The building was 7 storeys tall and was a busy commercial office block. The field trials in this building provided more invaluable insights into the extent to which the technology could be applied. The main findings were;

1. The test methodology was robust, repeatable and non-destructive. Tests were carried out when the building was occupied without disruption to normal building operation.

2. It was found that more than one vertical stack could be tested using a single input point for the air pressure wave. The installation of addition pressure transducers on every stack was sufficient to locate defects on any given stack. This expanded the reach of the device to any stack directly connected to a collection drain.

3. A phenomenon of apparent time delay on the reflected wave return time was observed in this installation. The increased range of the identification system amplified this phenomenon to the point where the previously accepted method of calculating defect location broke down. Extensive model simulation and laboratory investigation of this phenomenon highlighted the need for a means of calibration to overcome the apparent delay phenomenon. This was included in the system control programme due to Kelly [4] known as 'Tracer'.

The iterative and incremental methodology employed in this phase of the research was a powerful means of overcoming considerable challenges in the field.

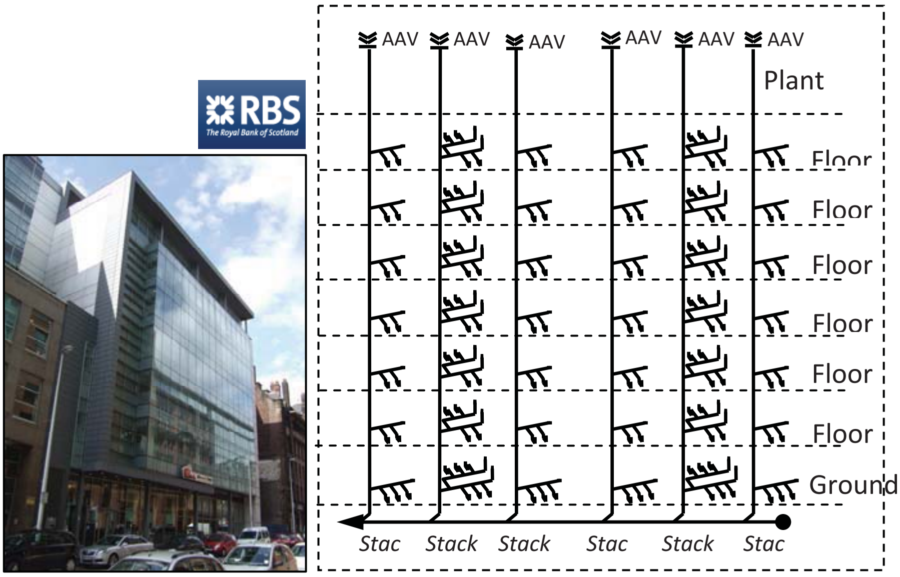

Figure 6 The installation at the RBS building in Glasgow

3.6 Fifth iteration : Royal Infirmary Edinburgh (RIE)

Overcoming previous challenges has produced a very robust technology defensible in any sphere of engineering development. The iterative and incremental approach has proved a powerful methodology and confidence is high that solutions to future challenges can be found using this method.

The next phase of this research will install a test system in the New Royal Infirmary in Edinburgh, a prestigious building owned by Consort Healthcare, operated by Balfour Beatty Workplace and used by the National Health Service (NHS) in Scotland. The hospital opened in 2003 at a cost of GBP£190 million. It has some 900 inpatient beds and the biggest maternity and reproductive health department in Scotland. It is also the teaching hospital linked to the University of Edinburgh. It is the centre for many specialist services including cardiac surgery, and kidney, liver, pancreas and bone marrow transplants. The RIE is home to the Scottish Liver Transplant Unit. The hospital is a centre of medical excellence and the trial of the DETIS has been allowed on the grounds of its potential for producing a reduction in spread of Healthcare Acquired Infections (HAI) such as C-Dif and MRSA, an issue high on the agenda of all healthcare professionals.

Figure 7 Arial view of the new Royal Infirmary Edinburgh. Building provided by Consort healthcare and Balfour Beatty workplace.

The drainage system in the RIE is very complex and extensive. A rough estimate gives a total of approximately 650 vertical stacks in the whole building. The stacks themselves are relatively straightforward in design and are easily testable individually however the scale of the installation and the complexity of the horizontal collection drain network are significant.

The approach taken in the proposed trial is to isolate a small area of the building for investigation. The context for the choice of trial area is simply to 'Protect Patients' therefore the stacks identified for the trial cover two significant ward areas in the hospital. The purpose of the trial is to prove that the system can work in a busy hospital building so a small area will prove this easily. The 'small area' is in fact bigger than the entire installation at the RBS building in Glasgow.

The application of the iterative and incremental methodology to this installation will be invaluable since the complexity of installation provides many challenges which require verifiable innovative solutions.

The extent of the challenges to be overcome can not be dealt with in this paper however the following summarises some of the issues;

1. The base of stacks are not all accessible.
2. Many of the collection drains are greater than 150 mm which will cause severe degradation of our signal and make measurements impossible using the methodology used in Glasgow.
3. Access to ward areas must be limited and planned.

Implementing the methodology to this installation produces an elegant solution to the problems associated with working with the collection drain system. Extensive simulations and the availability of plant room space produced the proposed installation methodology shown below in Figure 7.

The advantages of this system are;

- All testing and installation done in plant room, no need for costly works to drill holes in floor slabs and fire stop.
- Only one pressure transducer required, therefore fewer inputs are required on data acquisition system and fewer transducers required.
- The installation will be quicker and require less building operator input.
- Only one stack is tested at a given time thereby simplifying the test methodology and identification of traps.
- The system is upgradable i.e. any number of stacks can be added without changing the defect free data base of the whole installation.
- The calibration required is reduced since the apparent delay observed in the RBS building will be reduced.

The installation will be challenging however the simulation and laboratory tools available provide considerable backup in the event of encountering problems on site. The holistic approach taken to all these installations has proved effective and the implementation of all the elements described in section 2 above in the conceptual framework have been required to reach this point in the research successfully.

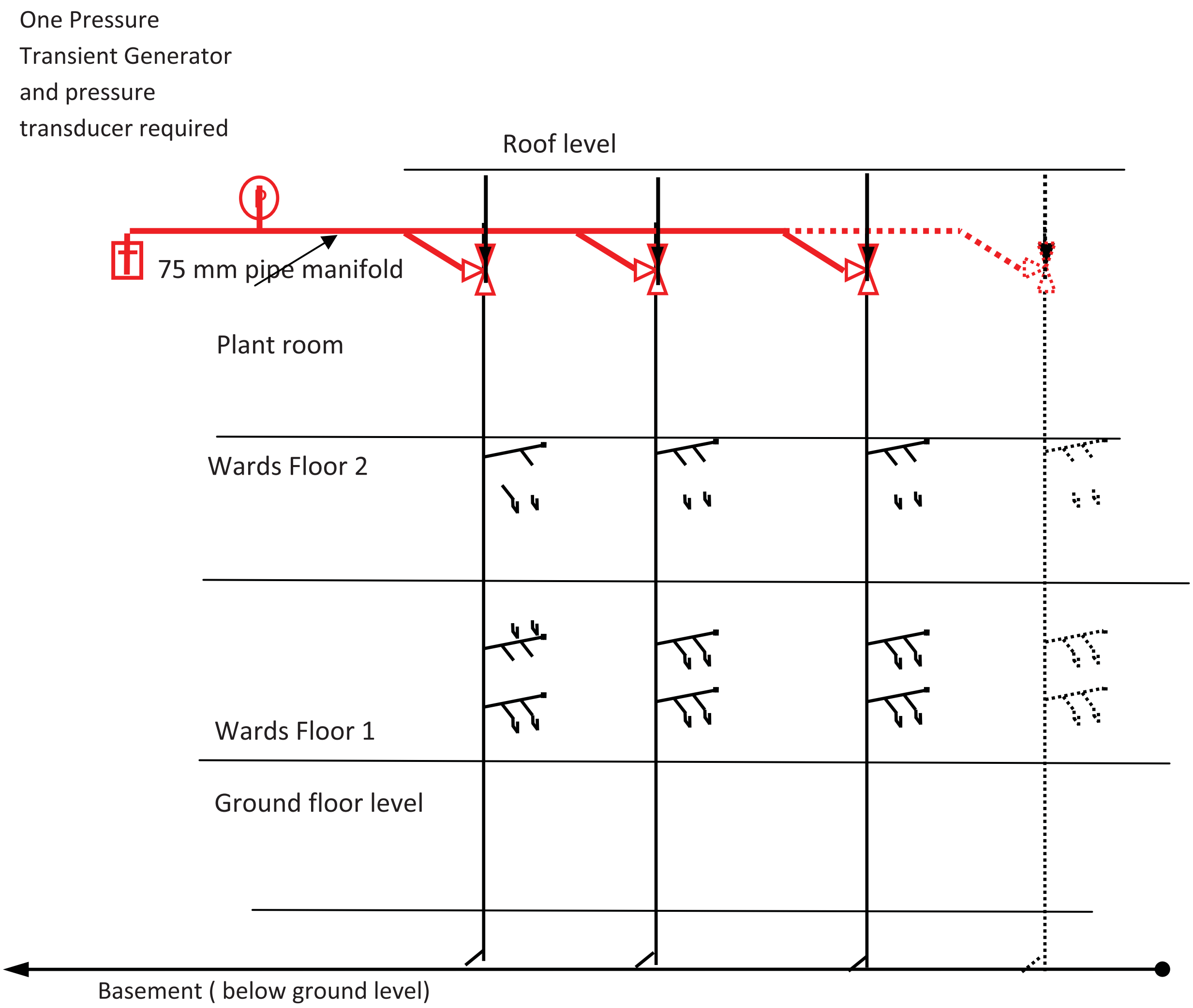

Figure 8 Proposed layout of installation for RIE showing innovative manifold system.

4. Conclusions

The derivation of solutions to complex problems is the main function of the engineer, and the engineering academic is no exception. A collegiate approach, through interactive research group to wider academic community and industrial collaboration is vital to producing solution to real issues in the real world. The approach to the development of the DETIS has included all these elements and is success is due to the commitment of all involved to work together to produce a technology with far reaching benefits for all.

On a practical level the use of the iterative and incremental conceptual framework outlined in this paper has been a powerful tool in producing a robust methodology for assessing the state of the seal in a building drainage system. The water trap seal, for all its vulnerabilities, is still the main protection against ingress of foul odours, gases and potentially harmful infectious material. The technology produced by this research has gone a considerable way in highlighting this significant fact and has raised the issues with those in healthcare for whom protection against vulnerabilities is more important than for most.

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6. Presentation of Authors

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