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PROPERTY LEVEL FLOOD ADAPTATION MEASURES: A NOVEL APPROACH

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ABSTRACT

Despite increased investment in flood defences, it is not economically viable to protect all at risk properties from the threat of flooding. This has led to a move towards encouraging property owners to take their own steps in making their homes or businesses less vulnerable to flooding. For example, the UK Government has introduced a grant aid scheme to encourage property level flood protection and has called for the development of new innovative flood approaches and products. Examining the effectiveness of current flood protection products including both resistance and resilience measures, with regard to water ingress, installation cost and acceptance by homeowners, reveals shortcomings with the existing measures. To address this issue, a novel solution is proposed that combines resistance and resilience adapted basement waterproofing, using an internal hollow skirting system (patent protected GB-2449777 and GB-2452423) to address the ingress of floodwaters into properties with solid floors. The method does not attempt to resist floodwaters but manages the water using ways that homeowners can appreciate. It is easy to install and is affordable in line with current grant aid. Furthermore, the new system can be installed in both existing and new build properties and, in doing so, offers complete property flood level protection. It is concluded that the new system may provide a practical solution towards the uptake of property level flood adaptation measures.
Keywords: flooded homes, flooding, resilience, resistance.

1 INTRODUCTION

Flooding is a major problem for many homes and businesses, particularly as the risk of flooding escalates [1]. In the UK, the total estimate of homes currently at significant risk is 400,000 [2], and latest government figures predict this figure will double over the next 25 years [3]. According to Loucks *et al.* [4], climate change, coupled with increased societal pressure to further develop on floodplains, will result in a greater overload of infrastructure. In turn, this promises an ever increasing likelihood of further flooding events. The UK government has realised that centrally funded large-scale community level flood resistance is unsustainable [5]. Local flood protection, comprising a series of local measures available to property owners and small communities, is being promoted by the Environment Agency (EA) and its partner organisations as the most beneficial future path [6].

In 2004, the UK government launched the 'Making Space for Water' consultation exercise to seek views on flood management issues to further the development of a new flood strategy [7, 8]. This encouraged: (i) the promotion of flood resistance and resilience measures in both new and existing buildings, (ii) the introduction of flood resilience in the Code for Sustainable Buildings, (iii) the promotion of the use of flood resilience in existing properties with financial incentives, and (iv) advice on flood resistance and resilience to property owners by trained builders and surveyors to meet this objective. This strategy acknowledges that flood risk can no longer be removed and promotes resistance and resilience measures at property level, requiring homeowners to shoulder responsibility and install appropriate measures. According to the UK government, the benefits for the homeowner are substantial: (i) lower repair costs following a flood event, (ii) fewer health implications, and (iii) continued

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insurance [9]. However, it is recognised that the majority of homeowners who live in high-risk flood areas have not adopted any property level protection, despite the high profile attention given to flood events by the media [10]. Even those whose homes have been flooded several times before have taken only minimal action, often installing measures that are ineffective. A survey conducted for the Department for Environment Food and Rural Affairs (Defra) by Entec and Greenstreet Berman found that in areas of significant flood risk only 16% of households had taken any practical steps to limit potential flood damage [2].

In 2007, as a further development of the government policy 'Making Space for Water', Defra funded a UK pilot scheme, where Central Government funds (£500,000) were spent at six locations to examine whether grants provided an effective means of increasing the take-up of flood protection [2]. The results indicated the best way to encourage take-up of measures is to subsidise the cost for households and that grants (£4500 to cover basic protection) should be offered to all 'at risk' households [2]. Soon after, the Secretary of State, Hilary Benn, announced the launch of a £5 million property level flood protection grant scheme for residential properties at high risk of flooding and where they do not benefit from community level defences [11].

The measures necessary to protect a home are complex and it must be remembered that each house is different. To decide on appropriate measures many issues must be considered, e.g. flood risk, flood depth, frequency of floods, source of floodwater, construction and condition of the building. Therefore, as part of the grant aid, a free home survey is provided to the homeowner. Local authorities manage the survey tender process and allocate suitable funding. Broadbent [12] recommends that the homeowner should use a specialist surveyor who in consultation with the insurers can specify the best measures.

With regard to the much needed development of new products, the position of the government was clarified by the EA Chairman's speech at a recent National Flood Forum annual conference: '*I would like to see industry develop new, innovative products that can be installed in homes and businesses to reduce the risk of flooding. Climate change is likely to increase the frequency and severity of flooding, and the UK could be the global market leader on technologies to counter the impacts that it brings*'. Hence, in line with policy, the EA launched [13] the UK's largest flood test centre (at HR Wallingford) to test flood products against a new industry standard PAS 1188 for BSI kite-marked status. This facility and the kite-mark scheme offer manufacturers the benefit of demonstrating their products meeting the highest standards and display the kite-mark symbol.

Insurance companies have historically provided a 'comfort blanket' with their automatic cover policies and have not helped matters with their 'no betterment' approach to reinstatement. It is perhaps not surprising that many victims want their property to be put back as before, as they typically do not have the knowledge to make any other choice, so normality has been their sole safe option. However, the EA has recently completed more detailed flood mapping; such that it is now possible for insurance companies to access individual house data and set individual household premiums, instead of current street level data. This will match the property insurance premium to the individual risk, probably leading to much higher premiums, which may be a driver for the homeowner to install flood protection to reduce premiums and excesses. The trade body for insurers, the Association of British Insurers (ABI), commissioned research into public attitudes to flooding 1 year after the summer floods of 2007, when 48,000 homes had been flooded and the insurers had to deal with 180,000 claims for homes, businesses and vehicles. This revealed 66% of those in flood risk areas (who are likely to have seen the highest of any premium rises) recognise it is wholly acceptable that the cost of flood insurance will rise as floods get worse [14, 15].

There has been minimal research on the performance of buildings in floods but there has been extensive research to analyse householder experience [16]. The current choice of flood protection measures seems too large and complicated. Typically, the homeowner does not have the specialist knowledge to decide on a suitable package of measures to protect a home [12]. Property level solutions are either flood resistance or flood resilience based measures or a combination of these, and the task of recommending a suitable solution is complex and needs the input of qualified and experienced surveyors. Terraced and semi-detached houses can be particularly problematic as adjacent properties will need to treated in the same way. Even in a detached home, some resistance products require attendance and deployment before a flood event, and resistance measures will not protect against groundwater rising to flood ground floor rooms. Resilience in the form of 'tanking' can protect against party wall ingress and groundwater floods but is generally expensive. Moreover, a telephone survey of 1131 at risk households and businesses revealed 25% of homeowners are deterred from installing measures as they fear that such measures are unattractive and 17% do not want any measures installed that will be a continuous reminder of the flood risk they have to live with [2].

This study reports the development of a novel flood product that combines resistance and resilience adapted basement waterproofing, using an internal hollow skirting system (patent protected GB-2449777 and GB-2452423) to address the ingress of floodwaters into properties with solid floors.

2 CURRENT PROPERTY LEVEL MEASURES AVAILABLE TO THE HOMEOWNER

2.1 Permanent flood resistance

Flood resistance involves the construction of a building, or the adaption of an existing building, in such a way as to prevent floodwater entering the building and damaging its fabric [17]. That said, flood resistance must always be installed as a complete package [18]. Every water entry point must be blocked because one small entry point will render a whole suite of resistance measures ineffective. Furthermore, there is a limit to the height of floodwater that a conventional house wall can resist (current recommended limit: 600 mm [18, 19]), because of the hydrostatic pressure exerted by the water onto the outside structure of the building [20, 21].

It is noteworthy that many permanent resistance measures, such as bunds, boundary walls, fences, raised thresholds and porches (Table 1) can require planning approval. Furthermore, the EA will also require a flood risk assessment to be carried out and if, as a result, there is a possibility the measures will deflect floodwater onto neighbours then consent will be blocked [22]. Table 1 also details example costs for work needed to external walls, down to the foundations. Any external doors that are not essential should be either completely bricked-up or altered to provide a window. Table 1 also provides example costs for replacement of external doors. Retained doors and frames should be UPVC, fibreglass, or metal external grade preferably opening outwards with rubber gaskets to seal. Inward opening doors will require an extra locking system (£300) needed for a waterproof seal. Severn Trent (one of the national water companies) have successfully fitted such doors for >10 years to properties with flood depths up to 600 mm. The installation of permanent anti-backflow valves on sewers (Table 2) offers complete protection for every property against backflow.

Table 1: Permanent resistance measures.

Measure	Description	Cost
Earth bund walls	An earth bund may provide flood defence for a single property or a community. Expert engineering design is needed with extensive groundworks. There can be problems with seepage under/through walls and via garden wells. Auxiliary pumps usually required	£400/m run[a] £150/day auxiliary pumps
Boundary walls and fences	Concrete walls or part concrete part wooden fencing can be installed to provide flood barriers for individual properties or communities. Walls/fences can have sealed gates installed. There may be problems again with seepage, footings on to clay and deflection of water to neighbouring properties	£600/m run[a] concrete wall. Not included is any extra work involved sealing below ground
Raising building thresholds	If allowed by the existing external door lintols, the door and threshold may be raised by say two courses of brickwork. Generally only for short duration floods between 150 and 300 mm deep	£800 per door[a]
Storm porch to external doorway	If is not possible to raise the external doorway a raised porch may be constructed in front of the door to again resist up to 300 mm. External porch doors will need to have extra locking system (£300)	£4500 per porch[a]
Cementitious renders	Two coat work, e.g. renderstop. Not breathable	£50/m run[a]
Bituminous coatings	Brush applied. Two coat works, e.g. technoseal, susceptible to UV light but can be used below ground level. Not breathable	£50/m run[a]
Brick veneer	Extra skin of brickwork to external wall, must go down to foundation	£100/m run[a]
Water resistant external walls	Walls need careful attention to make them flood resistant down to the foundations. This involves excavation for attention to service/entry points and cracks with repointing using a 1:3 mortar below damp proof course (DPC) and 1:2:9 above DPC	£30/m^2 [b]
Mastic sealants	Applied with a sealant gun around door and window frames to seal joints with brickwork	£5 per door or window[b]
Airbrick heights	Periscope airbricks are tried and tested. The external height of the brick is raised. Work involves the removal of the old units and replacement with brickwork patching	£100 per airbrick (there may be one every metre of wall)[b]

Continued

Table 1: *Continued*

Automatic airbricks	Innovative new airbrick that automatically closes and opens with floodwater. BBA accredited, more expensive than the periscope but easier to install	£110 per airbrick (there may be one every metre of wall)[b]
External doors	New single flood resistant door and frame inc. fitting	£4700.00 + VAT[b]
	Standard single external door opening modified to brickwork and windows	£400[a] £500[a]
	French doors	£900[a]
	Patio doors	£300[a]
	Retain existing UPVC, fibreglass or metal external grade door and fit extra locking system	
Automatic activating external door guards	Must be combined with water resistant brickwork to external walls. A self-actuating barrier that is concealed underground and rises with the floodwater to protect doorways. There is no need for owner involvement but the system is very expensive and for it to be effective the external walls must be fully resistant down to the foundations. There still may be groundwater problems	£8500 per door[b] Standard single exterior door in. installation. Does not include wall waterproofing

[a]Rates compiled from Metric Handbook.
[b]Flood product price list.

Table 2: Sewer work for permanent resistance.

Measure	Description	Cost
Anti-backflow	Ball valves/gate valves/flapvalves need to be fitted to sewers 100 mm for foul drains. An inspection chamber is needed for installation	£500–£900 per valve[a] 100 mm drain installed
	32/40 mm for sink/dishwashers and washing machines	£2.50 per nylon sealing plug 30/40 mm[a]

[a]Flood product price list.

2.2 Temporary flood resistance

At property level, aperture flood guards fitted by the homeowner offer the most cost effective temporary resistance (Table 3). The National Flood Forum (NFF) quotes £1500 for installation of these products to an average semi-detached house [23]. Typically, homeowners prefer resistance products because they offer the cheapest and most cost-beneficial package with

Table 3: Temporary flood resistance.

Measure	Description	Cost
Aperture guards	These are property level measures that protect the apertures through which floodwater can enter the dwelling. The smallest apertures are airbricks. Airbrick covers range from single use adhesive covers to those with cover frames which are permanently attached to the airbrick surround. Larger apertures are the doorways into the dwelling. A range of door guards is available from a DIY kit to a BSI accredited bespoke guard with cover frames permanently attached to the dwelling. These guards need the homeowner to deploy them which requires advanced warning of any flood event. Some plank assembly models take time to deploy and homeowners dislike the permanent frames fixed to the property. However they are an essential line of defence for resistance	£10–100 airbricks[b] £60–1600 doorguards[b]
Flood skirts	A complex and expensive method for protection. The dwelling must be sealed from the foundation upwards to the external ground level. All service entry points and drainage entry points must be effectively sealed. Non-return valves must be fitted to drains and sewers. From ground level upwards the dwelling is then protected by a flexible skirt that is deployed by the homeowner. The skirt is housed in a below ground duct running all around the property. The flexible skirt is anchored to the walls of the property when deployed. The system has several disadvantages. It has to be deployed by the owner and require a level of skill. It also needs advanced warning, is very expensive and cannot be used on a single semi-detached house. All the attached properties must be done at the same time. Groundwater may still enter the property from below the floor	£25,000–£35,000[a]

Continued

Table 3: *Continued*

Commercial mains units flood alarm	Commercial mains units operated by floodwater or water rising in foul sewer with alarm inside house. Some alarms are able to telephone several numbers when activated and continue calling until answered so that resistance products can be deployed before the floodwater reaches the house. Community based alarms also available	From £300.00[b]
Individual property unit	Individual property unit triggered by floodwater in garden can be battery operated/inexpensive but unreliable	From £30.00[b]

[a]Rates compiled from Metric Handbook.
[b]Flood product price list.

minimum disruption [2]. However, resistance alone does not provide complete protection (Table 4), as it will not protect from ingress of groundwater or floodwater from the adjacent house, where the house is a semi-detached or terraced property, i.e. Routes D and E of Table 4 [20]. Previously, many flood victims have been sold expensive door guards and air-brick covers (BSI approved) and these have functioned perfectly well, but their homes have still been flooded [19]. In general, resistance products and the building fabric can offer adequate initial protection against floodwater; however, the protection is not complete and supplementary resilience measures are needed to manage floodwaters lasting several hours, as water will gradually seep into the home [20, 24].

2.3 Flood resilience

Flood resilience involves constructing a building, or adapting an existing building, in such a way that although floodwater may enter the building its impact is minimised (i.e. no permanent damage is caused, structural integrity is maintained and drying and cleaning are facilitated) [2]. Flood resilience measures focus on reducing the damage caused and decreasing the recovery time. Resilience measures are permanent and require high standards of workmanship to be effective but, unlike resistance, they can provide complete protection for all entry routes (Table 4).

Resilience measures (Table 5) for a typical 55-m^2 property with complete internal tanking are ~£30,000 and will keep the interior of the property safe. Internal tanking can be as shown in British Standards Type-A using a waterproof layer bonded to substrate which tries to hold water back, or a Type-C cavity membrane that drains water for disposal [25]. Another option is the use of resilient construction/materials; whereby, floodwater is allowed to enter a property and rapid cleaning and reoccupation is facilitated (usually within 24 h). The costs associated with this latter protection can be seen from evidence provided in Lowestoft, (Norfolk, UK) where the Norwich Union Insurance Company and the local authority applied resilience measures to a single house, investing in excess of £24,000 [14].

Table 4: Details of floodwater ingress.

Route	Details of floodwater ingress
Route A	Through toilet pan ground floor, sinks/shower/washing machine/dishwasher
Route B	Through brickwork/blockwork, cracks in external walls, flaws in construction, gaps between door frames and brickwork, below door thresholds, gaps around service/drain entry and exit holes, movement joints where drains pass through loadbearing walls as required in B.Regs., expansion joints, inadequate mortar to frogs and perps, line cracking due to thermal expansion of brickwork
Route C	Through open airbricks, open vents, joints between doors/windows and their frames where seal inadequate. Note: doors to open outwards so water pressure increases seal
Route D	Through joint between floor and wall, gap between DPC and floor membrane where floor membrane not sealed into DPC around perimeter of external wall, cracks in floor, joints in different floor slabs at doorways, underground seepage rising directly under floor, gaps and non-welted joints in floor membrane, holes where services or drains pass through the slab and membrane
Route E	Through party walls of semi-detached and terraced properties where the house next door is flooded

Table 5: Resilience measures.

Measure	Description	Cost
Tanking	Waterproof membranes are fitted on floors and walls to prevent water from entering the property. The membranes are under the floor and behind walls or the plaster on walls. The water may sometimes drain under the membrane to a sump and is then pumped out of the property. The installation is done by specialists as the area must be completely sealed. Attention is also needed to electrics as the installation of wall tanking cannot be compromised due to holes caused by electrical installation. This method is used successfully for long duration flooding and continuous ground water ingress to a property. This method has proved to be a very effective but expensive method of protection and was omitted from a recent DEFRA report on the basis of being simply too expensive	£30,000 + [b]

Continued

Table 5: *Continued*

Ground floor construction	100 mm deep concrete floors are resistant to floodwater [23] under 1 m head of water there is no uplift and no seepage. Water ingress is usually through gaps around the edge or joints. Concrete floors may be finished with ceramic floor tiles in preference to carpets Suspended timber floors can be replaced with treated timber or more durable hardwood but access will be needed to the sub-floor void for the drying out of the floor members and the void. Chipboard floors should not be used. Better is to replace wooden floors with concrete as this also removes the necessity for airbrick treatment. Under floor voids can be filled with concrete wall blocks before laying a membrane and a new concrete floor	Wood treated and sleeper £62 m^2 [a] New concrete £74 m^2 [a]
Pump and sump system	A sump is installed at a low point and floodwater entering is pumped out of the property. With a suspended floor, a sump may be installed in the sub-floor void. A concrete floor may have a sump at a low point. It is important that the electrical supply is on a circuit that will not trip out due to flooding. Alternatively a small generator could be kept on standby	£100–£900[b]
Internal doors	Doors to rooms can be fitted with rising butt hinges that allow them to be lifted off and stored in a safe area. Doors can also be made of plastics or acrylics that are resilient to water. Kitchen unit doors can be dealt with by the same method	£100 per door internal doors[b] £50 per door kitchen doors[b]
Internal wall finish	The bottom 900 mm of wall can have existing plaster removed and replaced with a waterproof render finished with ceramic tiles or lime based plaster finish that is more resilient than gypsum products. Alternatively the bottom 900 mm could be replaced with a sacrificial horizontal plasterboard using a dado rail to disguise the joint	£120 m^2 [a]
Skirting boards	Plastic skirting boards or painting all sides of wooden skirting are both resilient measures	£10/m plastic skirting including installation[a] £10/m painting all sides of existing skirting[a]

Continued

Table 5: *Continued*

Flood resilient kitchen	Dependent on the flood depth the kitchen units can be raised on plinths or extendable plastic or stainless steel legs allowing access for cleaning. There is a limit of 250 mm for the legs after which the worktop heights to standard kitchen units become too high. For heights in excess of 250 mm resilient kitchen units are available in plastic and stainless steel. All white goods must be located above flood level in the kitchen	Legs 250 mm including installation £12 each[c] Plastic kitchen unit 1000 mm base £180[c] Stainless steel unit 1000 mm base £400[c] including legs Standard kitchen unit 1000 mm base £120[c]
Replacement bath	Better quality baths do not have external chipboard bases. The baths have internally moulded support with a frame	£500 per bath installed[a]
Move service meters	Move service meters to 1 m above floor level	£600/m[a]
Move boilers	Mount boilers at least 1 m above floor level	£600 per boiler[a]
Move electrics	At least 1 m above floor level. TV coax to at least 1 m above floor level. All ring mains to drop from chamber joists and not rise from under the floor	£900 per dwelling[a]
Flood bag	Flood bags are very large (2 cu.m.) capacity waterproof bags into which items can be placed for dry storage. Place bag on floor put furniture, valuables, etc. inside. Zip up bag and leave intact on floor	£38 for 2 cu. m. £275 for 6.5 cu.m.[b]
Toilet bung	See details in the resistant list of products. Anti-backflow valves are essential for resilient protection to prevent contaminated floodwater entering through the drainage system	£60[b]

[a]Rates compiled from Metric Handbook.
[b]Flood product price list.
[c]Mitch Lawrence – mitch@rkb-furniture.com.

Previous research has shown that flood resilience can be more cost effective when carried out as reinstatement after a flood event [27]. Insurers are now being more flexible in this regard and there are signs that many will now discuss resilient repair with the insured. Unfortunately, the homeowner must take responsibility for the quality of the work and they must also shoulder the extra costs [28, 29]. This places the burden on the homeowner at their worst possible time, when they are at the peak of anxiety and stress due to the immediate aftermath of the flood event, particularly as the scale of the disruption becomes clear and initial coping strategies dwindle [30].

Homeowners, in general, find resilient measures too expensive and disruptive due to the lengthy time required for their installation [2]. There is a desire to avoid the serious effects of disruption and keep the home as normal, so the use of resilient measures and permitting floodwater ingress is not favoured [31, 32]. Unfortunately, this is the only option when differential flood depths in excess of 600 mm are present as they can cause structural damage [20, 21].

3 THE NEED FOR INNOVATIVE FLOOD PROTECTION

There can be no doubt that the climate is changing in a way that will increase flood risk [33]. The government acknowledges that flood defences cannot be provided for all homes at risk so property level flood protection is essential for these homes. There is an urgent need for new and innovative property level products that must: (i) be affordable in line with available grant aid, (ii) be quick and easy to install, (iii) involve the minimum of disruption to the homeowner during installation, (iv) involve methods/measures that the homeowner can easily understand, (v) address all points of water entry and building types (not just simply the more obvious routes), (vi) provide a complete and effective solution, (vii) be practical, and (viii) remain of use even if the flood overwhelms the measures installed.

3.1 Introducing a new property level flood product

The Flexible Skirting System (FSS) (patent protected GB-2449777 and GB-2452423) has been specifically designed to satisfy the above requirements, including an installation cost in line with current grant aid (Table 6). The FSS is designed for installation into properties with solid floors that are subject to short duration flood events of >600 mm differential depth (f_{diff}). The system is a combination of resistance and resilient measures that provide full protection against floodwater ingress (Table 4). Figure 1 illustrates the new product design, where a simple extruded plastic skirting is fixed to all internal walls and the lower front horizontal face of the skirting is sealed to a 20-mm studded floor membrane, e.g. Oldroyd Xv20 high profile cavity membrane that has a high flow capacity [34].

Once the product is installed, since hydrostatic pressure will be greatest at the base of the wall, water will pass through holes on the rear face of the skirting and, hence, under the floor membrane. Similarly, water entering at the vulnerable floor/wall join will also pass under the floor membrane. The floor membrane will also collect water ingress entering through construction joints or cracks in the solid floor. To enable water movement below the membrane it is essential that there are no undulating surfaces or depressions in the floor slab to allow ponding. To enable water movement both new and existing concrete floor slabs can incorporate perimeter floor drains and/or floor drains to direct water towards a collection point. Alternatively, for existing floor slabs a series of perimeter surface channels 30 mm wide and 25 mm deep can be cut into the floor slab to prevent water ingress from migrating across the slab. Also, such channels cut in a chevron or fan pattern can prevent ponding across low areas of the slab and move water towards the collection point. In new build, or when ceiling heights are not a concern, the perimeter and floor drainage channels can be formed in a layer of rigid foam board floor insulation installed between floor slab and floor membrane. However, when water flows through concrete there is a tendency for precipitate of dissolved lime within a

Table 6: Price for flexible skirting based on a standard UK 55 m^2 semi-detached house.

Description	Cost
Survey	£600[a]
Install sewer back-flow valve (£150)	£498[b]
Nylon blanking/testing plugs for sink/wash mc/etc. 32/40 mm	£9[b]
Ground floor toilet pan seal	£65[b]
Remove existing floor carpet/tiles	£390[c]
External walls excavate, repair holes, coat with brush on technoseal waterproofing solution below DPC	£980[c]
Necessary repairs to floor slab, cracks, falls, grind fan channels, and floor drains	£490[c]
Sump/pump installation to include 40 mm exit pipe	£900[c]
'Oldroyd' semi-rigid waterproof floor membrane to inc. sealing tapes and laminated floor finish installed on top of membrane	£1730[c]
Flexible skirting to internal walls	£600[c]
External door guard	£840[b]
Total protection from all routes of water ingress	£7102

[a]Peter Brent Associates.
[b]Flood product price list.
[c]Rates compiled from Metric Handbook.

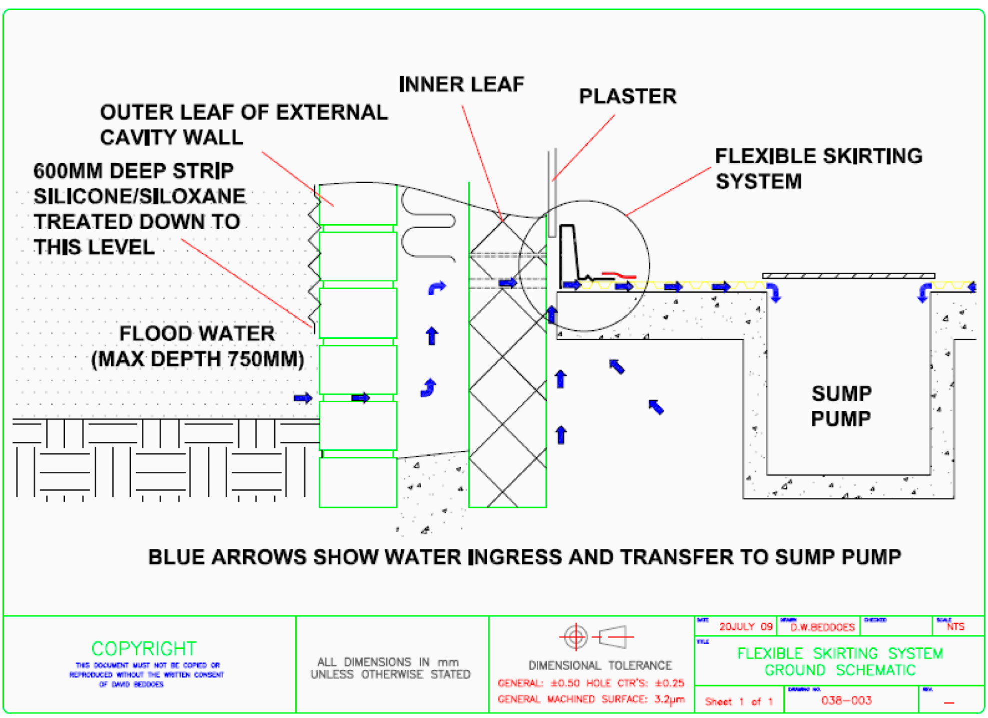

Figure 1: Flexible skirting system ground schematic.

cavity [35]. To avoid the lime blocking cavities/water passages, it maybe necessary to treat all concrete surfaces with a combined hardener, sealer and anti-lime treatment prior to laying the floor membrane, e.g. Vandex Super/Super White [36]. The membrane is used to drain and control water ingress that passes the initial structural resistance of the property. The membrane cannot accept any hydrostatic water pressure. It is essential, therefore, as required by British Standards, to have a drainage facility at a collection point within the floor [25]. The recommended facility is a sump/pump unit. Specifically designed kits are available with an automatic float switch, non-return valves, high-level alarms, dual pumps and battery backup, e.g. Sentysumpsystem™ [37].

The FSS extruded skirting is affixed to internal walls in place of existing skirting. Holes can be drilled at floor level through the inner skin of a cavity wall to prevent water build-up inside the wall cavity. Water in a cavity damages insulation, wall ties and the structure of timber frame houses. When the whole room perimeter is fixed the membrane is laid and the horizontal face of the skirting is sealed to the membrane. The membrane can then be covered with 2 mm foam insulation and boarding or a simple laminate floor to prevent damage by subsequent trades. Any corners/joints in the skirting can be sealed with mastic or clip-on trims as the system is not subject to hydrostatic pressure. Reveals and door casings are protected with a plain DPC attached to the flexible skirting and the membrane as used in existing tanking applications, e.g. Oldroyd guidance notes for internal fixing above and below ground [38]. Installation is an easy and fast process involving a minimum of disruption for the homeowner.

Figure 2 shows a further important feature of the system where optional waterproof vent holes in the skirting can be unplugged and used to service, examine and descale the system.

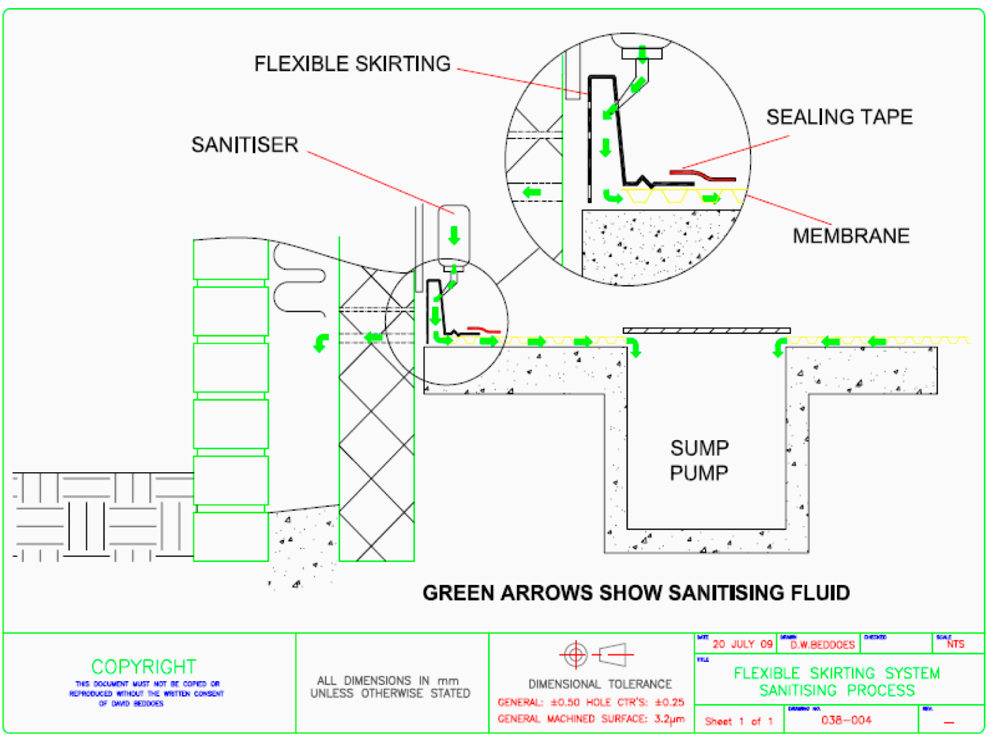

Figure 2: Flexible skirting sanitising process.

Injected descaling fluid is evacuated via the sump/pump. Similarly sanitizing fluid can be utilised after a flood event. Figure 3 shows the introduction of blown air into the sump re-circulates via the system to dry floors and walls. The air exhausts via the unplugged holes in the skirting face for party walls and can also exit to external atmosphere on external walls.

The FSS also addresses residual risk. For instance, if the flood should overwhelm the external resistance, or water has to be permitted entry for structural reasons, the installation has the sump/pump that can be used to quickly evacuate the water and, thereby, reduce the cause of the greatest damage (i.e. that caused by the exposure of the internal structure of the dwelling to water) [27]. The structure of the building can then be dried out by removal of the boarded or laminate floor, detaching the horizontal skirting face from the floor membrane and propping open the FSS to allow air circulation into the walls behind the FSS. During a flood event, with the FSS installed, there is a possibility of capillary action within the inner skin of the cavity wall, this can be reduced by chemical injection during installation. Any plaster damage can be addressed room by room at a later date via a minor insurance claim. Most importantly, because any repairs are minor, the flood victim can still remain in their home. Subsequently, as part of this work after the flood event, a wall membrane could also be included for minimal extra cost; thereby, offering a complete future solution even down to the wall decoration.

There is also the issue of using cavity membranes to move groundwater because certain salts found in groundwater which can adversely affect the performance of a Type-C cavity membrane system, e.g. chlorides, nitrates and sulphates. Many Type-C basement systems can fail after an initial period of use (12 months), when the inaccessible cavity membranes become

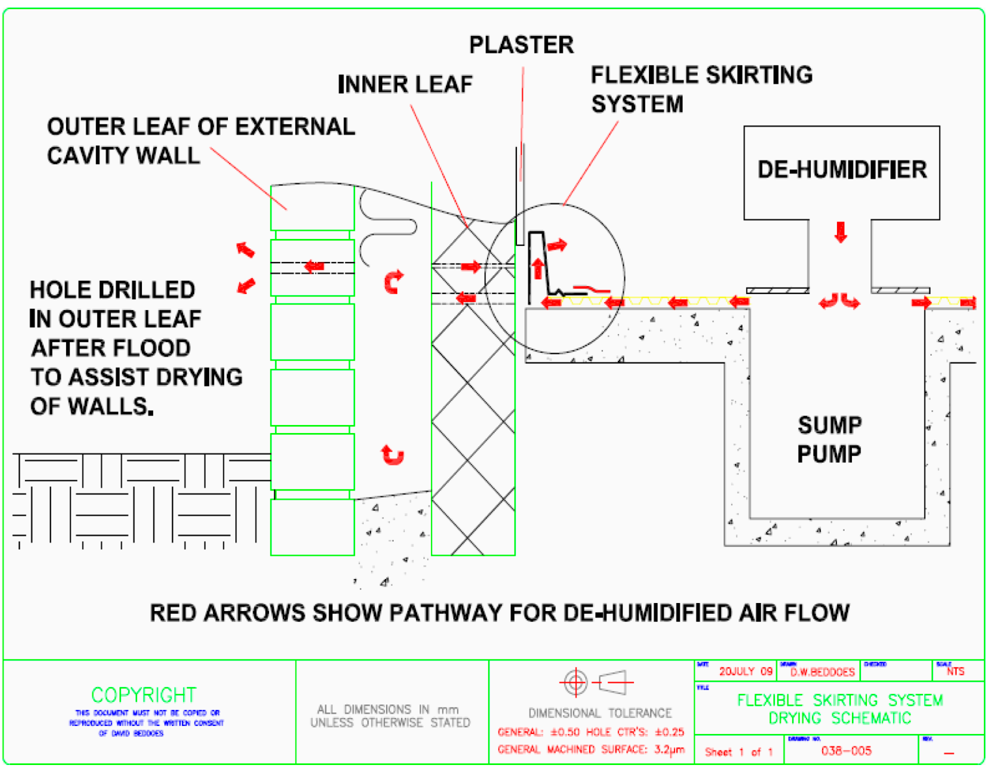

Figure 3: Flexible skirting drying schematic.

blocked. The groundwater ingress can bring silt in suspension and salts in solution, and dead level floors produce areas of standing water ideal for evaporation and recrystallization. The silt and salts can build-up over time and block membranes [35]. However, this continuous process and the eventual build up to a level sufficient to block a membrane are not applicable to the use of membranes in flood measures where floodwater ingress is only very occasional. Perimeter floor channels prevent water ingress from migrating under the floor membrane and new high capacity membranes are used that can be readily accessed via the FSS.

3.2 Performance rationale for the uptake of FSS

Since the FSS is reliant on managing the ingress of floodwaters through the building fabric, it is necessary to appraise its theoretical performance before pilot testing is initiated and any future installation commences. Unfortunately, there is minimal information available on floodwater ingress rates into buildings. Most detailed UK studies on damage for residences in floods have almost exclusively considered depth–damage curves, where the flood depth is assumed to rise slowly [20]. DTLR [18] comments that 'modern solid concrete floors with damp-proof membranes are generally regarded as the most flood resistant floor type … concrete floor slabs are unlikely to be significantly damaged by flooding'. Therefore, knowing the water infiltration rate from outside to inside a building is a necessity for determining the drainage capacity of the floor membrane. Kelman [20] states that past studies on the water infiltration rate into buildings were not found; therefore, infiltration studies of a different fluid (i.e. air) are adapted for applicability to water infiltration. These studies emerge mainly from literature on natural ventilation and air leakage rates. They focus on airflow under external wind pressure through small openings (i.e. the cracks between a window frame and the wall, the gap underneath a door, and the porosity of brickwork and render).

The flood infiltration rate is termed FIR (m^3/s) (eqn (1)) and the flood rise rate inside a residence is termed FRR (m/s) (eqn (2)).

$$\mathrm{FRR} = \mathrm{FIR}/A \tag{1}$$

$$\mathrm{FIR} = \mathrm{FRR} \times A \tag{2}$$

Considering a typical UK dwelling, floor area (A) 55 m^2, at $t = 0$ with maximum flow velocity of 5 m/s and $f_{diff} = 600$ mm. From Table 7 the upper bound for FRR can be interpolated as 0.0034 m/s. Such that: FIR = 0.0034 × 55 = 0.187 m^3/s = 187 l/s. And if the perimeter is 30 m, the $\mathrm{FIR}_{perimeter}$ = 187/30 = 6.24 l/s/m.

This value is for a 'leaky' property, designed for a large FRR. The design features a suspended timber floor, no draught exclusion on doors/windows openings, a postal flap and openings for pipes/vents that all allow water ingress. This value of 6.24 l/s/m is considered to be too large and unrealistic, as at this FRR the f_{diff} of 600 mm would be achieved in 150 s. However, the drainage capacity of a 20-mm stud membrane is 10 l/s/m, which is adequate even for this upper bound ingress rate (e.g. Delta Membranes MS20 Technical Specification [39]). Moreover, perhaps a more realistic ingress rate is the statement by Victoria Heywood: 'We were woken … by our next-door neighbour who, fortunately for us all, had popped down to the kitchen for a glass of water and noticed the first trickle under his door … Within an hour the whole ground floor was flooded to a depth of about six or seven cm' [20]. However, this statement is anecdotal and cannot be used further.

Laboratory investigations carried out for DCLG [40] discuss leakage through cavity walls for f_{diff} of 1 m. Water was collected as it leaked through the wall so that f_{diff} did not decrease

Table 7: FRR (m/s) for a typical residence (designed for a larger FRR) [20].

	f_{diff} (m)					
v (m/s)	0.0	0.5	1.0	1.5	2.0	2.5
0.0	0.000	0.001	0.002	0.004	0.007	0.011
0.5	0.000	0.001	0.002	0.004	0.007	0.011
1.0	0.000	0.001	0.002	0.004	0.007	0.011
1.5	0.000	0.001	0.002	0.004	0.008	0.011
2.0	0.000	0.001	0.003	0.005	0.008	0.012
2.5	0.000	0.001	0.003	0.005	0.009	0.013
3.0	0.000	0.002	0.003	0.005	0.010	0.013
3.5	0.000	0.002	0.003	0.006	0.011	0.014
4.0	0.000	0.002	0.004	0.006	0.012	0.015
4.5	0.000	0.003	0.004	0.007	0.012	0.016
5.0	0.000	0.003	0.005	0.007	0.013	0.017

with time. The average leakage rate was 0.15 m^3/h for a typical brick wall. For these calculations, we use the maximum measured leakage rate with the most porous wire cut brick, which was 0.400 m^3/h over a 1-m wall length. This rate is equivalent to 0.11 l/s/m. For a dwelling of area 55 m^2 and perimeter of 30 m f_{diff} of 600 mm would require $0.6 \times 55 = 33$ m^3 of water. Water ingress at 0.11 l/s/m over 30 m is 3.3 l/s, and take 33/0.0033 = 10,000 s = 2.78 h at f_{diff} 1 m. This value is perceived as more realistic and accords with anecdotal statements provided by flood victims. As previously stated the drainage capacity of a 20-mm membrane is 10 l/s/m or nearly 100 times the experimental values [40]. This work also measured the average ingress rate for an externally rendered brick wall as 0.002 m^3/h (i.e. <2% of the value for the typical brick wall), which supports the use of a waterproof breathable exterior treatment to external walls as part of the designed system.

4 DISCUSSION

Recent severe flood events in the UK have illustrated the need to offer improved flood protection to homes and businesses in flood risk areas. The summer floods in 2007 showed that not only are properties damaged but also people lose their possessions and suffer long lasting disruption and emotional distress [41]. As everywhere else in the world, the UK will probably suffer increased flooding as a direct result of climate change due to global warming [42]. The UK Government has realised that not all properties can be protected with large-scale community level flood defence schemes [5]. Therefore, the shift in government strategy transfers responsibility for flood protection from the government to the property owner, who is encouraged to install appropriate measures. Accordingly, government grant aid is now available for homeowners [43]. However, homeowners generally cannot accept the concept of allowing water into their property. It is therefore essential for professional advice to identify appropriate measures and inform homeowners how best to protect their properties [44]. Advising homeowners what actions to take requires specialist building surveyors, with knowledge of appropriate and up-to-date measures.

The insurance industry also finds itself in a difficult situation, as continuing to provide blanket home flood cover is no longer sustainable [45]. An insurer must be able to match the premium with the risk of flooding and the likely cost of damage that may ensue. To achieve this, insurers must work closely with specialist flood surveyors [12]. A home flood surveyor needs to be able to carryout a survey that covers all aspects such as risk, expected depth, duration and then tell the homeowner exactly what must be done for protection. The survey must address the fact that building elements are permeable and there will be some floodwater ingress. Similarly, based on the type of construction, the rates of ingress must be quantified and means must be specified to collect and manage the water ingress so that it can be evacuated from the building. Ideally, the survey and recommendations should be formulated in conjunction with the insurer so that both homeowner and insurer can benefit. The insurer will be able to quantify risk and match policy to current and reduced risks when appropriate measures are implemented. The homeowner can install measures, gain some peace of mind and in the process possibly reduce insurance costs.

The current choice of property level flood protection lies between resistance and resilience. The homeowners' first instinct is to keep water out and resistance products are more popular and are supported by kite-marked products and promoted by manufacturers. The homeowner seems to understand resistance; whereas, any form of resilience that makes the interior of the home unattractive and is still going to let water in may be difficult to accept [27].

Both resistance and resilience have their advantages and disadvantages, so a suggested solution is a combination of the two. Initial resistance is provided by the building fabric and external aperture guards and this is combined with an adaptation of Type-C basement waterproofing that uses high capacity cavity membranes [25]. The aperture guards are temporary resistance products (Table 3) that are inexpensive and acceptable to homeowners [2]. Temporary resistance products (Table 4) will not protect against all routes of water ingress and, with time, the floodwater will start to enter the permeable building fabric and groundwater rise under floors [20, 24]. To manage this ingress the building needs to include a form of resilience but these materials are sometimes perceived as unattractive [31]. Agreeing to allow floodwater inside the house is not favoured by homeowners [32]. The other alternative resilient option would be complete internal 'tanking' as British Standards Type-A or -C, but this is expensive (Table 5) and extremely disruptive to homeowners [31].

The FSS resilient solution is far less disruptive to install compared with installation of wall membranes and associated plastering needed with complete 'tanking'. The work can be carried out at any time, it is not necessary to install these measures as part of reinstatement work after a flood event when tradesmen are in great demand and quality of work maybe poor [29]. After a flood event, if the walls suffer any water damage above the skirting line then this can be addressed at a later date and tackled room by room; the important issue is that the homeowner will be able to remain in their home, during and after a flood event [2, 30]. With this system, there is also provision for residual risk. The system can be used to help rapid drying if the resistance measures are overtopped or floodwater has to be let into the property due to a differential depth >600 mm [18, 19]. The laminate floor becomes sacrificial and the joint tape between plastic skirting and floor membrane can be removed so that the skirting can be propped open around the room to facilitate drying of the wall construction. A skirting used in this way and fixed to a cement based wall board could be frequently flooded and dried.

5 CONCLUSIONS

The UK Government has realised many buildings cannot be protected from flooding by large-scale flood defence schemes and, therefore, property level flood protection is necessary.

To date, few homeowners have installed flood protection, so the government has recently introduced a grant scheme to provide free home flood surveys and, moreover, subsidise the cost of flood protection measures for homes at risk. However, the public has minimal knowledge, understanding and experience of flood measures and, when they do act, they tend to favour resistance products; not liking resilience measures due to the disruption, inconvenience, expense and stigma on the property. Furthermore, there are drawbacks associated with both resistance and resilience measures at property level and in the face of increasing frequency and severity of flooding the government are seeking solutions to reduce the impact. Addressing the issue, this work has reviewed the existing portfolio and presented a FSS as a new solution. This is a combination of resistance and resilience, using a simple adaptation of proven basement waterproofing technology; whereby, the system manages the ingress of water passing through the permeable building fabric to provide property level protection at a cost commensurate with current grant aid. The work has also highlighted the need for more information to be made available (or research conducted) on water ingress rates of buildings so that similar products can be appraised.

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