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Examination of Water Damage Statistics in the Nordic Countries to Identify and Suggest Preventive Cost-effective and Sustainable Measures during the Maintenance and Operation Phase

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ABSTRACT

Water damage in the indoor environment is a rising issue within Nordic countries with about 90 000 cases in appx. 6.5 million insurance is reported annually in Sweden, and corresponding numbers are in Denmark and Norway. The question then becomes what type of measures residents, building managers, and insurance companies can take in the maintenance and operation phase to decrease the impact of the water damage. Another question is how the effects, cost, and extent of the water damage are affected if the measures were executed in this phase as preventive measures. This was done by selecting actions and measures that could reduce the impact and cost of water damage, examining the action and measures, and finally analyzing the payback time of the investment of the actions and measures. The study shows average payback times for the actions and measures studied, for passive investments between 10 months and 8 years, and longer for investments that actively shutting off the water in case of a leakage, between 18 years and 30 years on average. The study demonstrates the potential benefit of implementing cost-effective measures, such as waterproof underlays beneath the fridge and the dishwasher. This suggests that introducing effective measures in the maintenance and operation phase will reduce the effect of water damage and also reduce the effect of water damage in a large portion of the existing buildings and therefore also reduce the immense amount of resources annually spent on water damage (approximately 1 billion USD each year in Sweden).

INTRODUCTION

Water damage occurring from leaking pipes or connections, and inadequate membranes from building services, installations, or appliances are annually causing vast costs for building owners, managers, and insurance companies. In Sweden, the reported costs of 90 000 cases amounted to 4.4 billion SEK (0.39 billion USD) in 2021, which in terms of value is the largest damage that occurred in buildings covered by home insurance (Svensk Försäkring, 2022a, 2022b). In other Nordic countries, similar reports could be found (Finans Norge, 2022; Forsikring & Pension, 2022). Actions that are effective,

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sustainable, inexpensive, and applicable actions are desirable in all building industry fields and if the actions are proven to be easy to install and be able to prevent future costs, they are even more desirable.

Water damage tends to occur in specific rooms, of which kitchens have become a more common candidate in recent years. In 2019, it surpassed bathrooms with the most damage in Swedish resident buildings (Vattenskadecentrum, 2020, 2021, 2022). An explanation for this tendency could be the decrease in the expected time for kitchen appliances before they cause a leakage. A majority of the water damage in Swedish kitchens comes from dishwashers, fridges, and freezers, of which 65-70% of the damage comes from appliances installed during the last 10-year period (Vattenskadecentrum, 2022).

The positive outcome of the actions and measures could contribute to increasing sustainable solutions in terms of economic, technological, and health factors. Factors such as indoor air quality, moisture damage, and reducing the climate impact due to fewer damage repairs could be improved upon. Regarding indoor climate and moisture damage, earlier detection of leaking water and less water damage can be a means to reduce moisture in homes, which has been related to respiratory diseases and discomfort (Becher, Høie, Bakke, Holøs, & Øvrevik, 2017; Institute of Medicine, 2004). Further, regarding climate impact, the estimated carbon emission of water damage repair in Swedish buildings is estimated at approximately 250 – 700kgCO_2e, which could be reduced if the water damage is noticed and repaired earlier (Petrovic, Lindkvist, Pettersson, & Apel, 2022). This emphasizes the importance of research on actions to reduce the effect, cost, and amount of damage.

This paper presents actions and measures for reducing water damage that could be implemented, or advocated for, in the maintenance and operation phase of the building by the building owner, manager, or insurance company. The study presents a potential solution to minimize the effects of water damage. By using technology that indicates when water is flowing in undesired places or membranes that direct the leakage to a visible area. Further, the study evaluates the potential economic benefit of installing said actions and measures based on the potential and statistical risk of water damage derived from water damage statistics in Nordic countries. It is proposed that if awareness of the potential cost-reducing actions and measures are increased, the effect and costs of water damage could be reduced; however, it should also be pointed out that solutions merely indicating the water leakage or damage are not the whole solution, but that they could be a vital part of a strategy to reduce the currently vast costs of water damage.

PREVIOUS FINDINGS

In Sweden, Vattenskadecentrum (2022) reports that approximately 33% of water damage in 2021 occurred in the kitchen, and approximately half occurred because of leaking or faulty appliances. In other words, 17% of the water damage in Swedish residential buildings can be derived from faulty appliances or the installation of them. The prominent causes are fridges/freezers and dishwashers which account for 30% and 24% of appliance damage, respectively (Vattenskadecentrum, 2022). Even though there is a demand stated in the industry rules that waterproof underlays should be installed beneath a fridge/freezer and a dishwasher, it´s reported that 15% and 7%, respectively, of the damage occurring due to a fridge/freezer and a dishwasher, lacks a waterproof underlay (Vattenskadecentrum, 2022). However, the majority of damage (57%) occurs due to corrosion, freezing, age/wear, or faulty pipe system installation. Where approximately 53% of the damage occurs in the tap water system (Vattenskadecentrum, 2022). The Swedish insurance industry organization reported that insurance reimbursement in residential buildings from water damage is in terms of value the largest category, approximately 4.4 billion SEK (0.39 billion USD) annually (Svensk Försäkring, 2022a, 2022b).

In other Nordic countries, comparable trends in water damage statistics could be found. In Norway, appliances account for 16% of the total number of damage and 11% of the total reported costs. Where appliances connected to the water distribution system account for 7% of all reported damage (Finans Norge, 2022). In Denmark, approximately 67% of the reported water damage that occurred in 2021 was due to faulty pipes and connections.

The cost of water damage in residential buildings has been investigated and found to vary depending on the examined buildings and the matter of materials that are damaged. Björk, Lind, Kling, and Larsson (2018) studied the damage costs in wet rooms, kitchens, and multi-family residential buildings in Sweden. The study evaluated the cost of typical water damage in wet rooms with tiles or plastic mats as surface layers on the floor and walls, where water has entered the joist through the connection between the membrane and the drain. The studied repair consists of replacing the waterproof membrane and the surface layers, which also involves material costs, transport, taxes, and installation. In wet rooms with tiles of 8 -12 m^2 (86 – 130 sq ft), the total cost was estimated to be 85 000 – 101 000 SEK (7 500 – 9 000 USD). In a wet room with a plastic mat as a surface layer, with the size of 8 – 12 m^2 (86 – 130 sq ft) the total cost was estimated to 56 000 – 64 000 SEK (5 000 – 5 700 USD).

Furthermore, the study evaluated the costs of water damage in kitchens, where the damage studied was a leakage beneath the sink that arose from the tap water faucet. The repair consisted of replacing parts of the floor surface layer and parts of the supporting structure. The cost of water damage in the studied kitchen of 14 m^2 (150sq ft) was estimated to be 30 500 SEK (2 700 USD) (Björk et al., 2018). Other estimations of costs found for this study are not specified depending on in which specific room the damage occurred but are derived from the overall water damage statistics. For multi-family buildings, the cost has been estimated to 80 000 – 133 000 SEK (7 100 – 12 000 USD) per damage in a multi-family building (Björk et al., 2018; Mattsson, Nordquist, Johansson, Bagge, & Wallentén, 2022). The Nordic country's insurance companies cover statistics on water damage and total reimbursement paid out for the damage. The method for gathering and presenting statistics is different between the countries but the average reimbursement for damage is 49 000 SEK (4 400 USD) in Sweden, in Norway 76 500 NOK (7 300 USD), and in Denmark 19 600 DDK (2 550 USD) (Finans Norge, 2022; Svensk Försäkring, 2022a).

METHOD

This section describes how the selection, examination, and analysis of different actions and measures were conducted to determine which and where in the buildings actions and measures are of the most efficiency. Firstly, the selection of which actions and measures to include in the study was done by searching the market for different actions and measures. The actions and measures included in this study were required to be installed by the homeowner, building manager, or contractor without any larger impact on the existing building. For example, adding extensions to existing pipes to indicate leaks, or temporarily moving appliances to add waterproof membranes beneath the appliance. The selection criteria did also include the demand that the actions and the measures should be implemented, used, and available. Secondly, an examination of actions and measures was made, where the selected actions and measures are examined in terms of cost, functionality, and what kind of damage they could prevent or minimize the effect of. The exchange rate used throughout this study was 1 SEK to 0.089 USD (InforEuro, 2022). Thirdly the analysis of the actions and measures was done by an estimation of the payback time in years that an investment in the actions and measures would have. By analyzing the actions/measures by a payback estimation the owners, residents, or building manager receives a reference to decide upon. Furthermore, the payback method is commonly used to assess investments (Yard, 2000). The actions and measures were analyzed in the matter of the potential economic savings due to the reduction of water damage and early prevention measures that could save resources, both in economical and sustainable terms. The selection of actions and measures was carried out by the problem areas where water damage could be prevented, and actions and measures selected to be included in the study were made based on the current market and what kinds of actions and measures were available (Vattenskadecentrum, 2022). The actions and measures that fulfilled the requirements of the study were waterproof underlays for appliances, water monitoring devices, water leak switches, and water leak alarms. These actions and measures have been implemented in projects, have been used, and are available on the market (Säker Vatten, 2020; Ömsen Försäkringar, 2022).

The waterproof underlays for appliances selected for the study are such underlays that if leakage from an appliance occurs the water flows out from beneath (usually hidden) the appliance to a visible area where the water leakage could be stopped. The measure is a passive way to indicate leakage from a dishwasher, fridge, freezer, or water-connected appliance and could also be used in a kitchen cabinet beneath the sink to indicate leakage. It is assumed to be installed by the resident or the building manager without any contractor costs. The waterproof underlay does not stop the flow of water in case of a leakage, but it limits the time that it takes to notice the leakage and therefore take action to stop it, which could reduce the effect of the damage. The damage costs categories that the device is assumed to prevent are kitchens, other spaces (average reimbursement for water damage in Sweden), and damage in multifamily buildings (Björk et al., 2018; Mattsson et al., 2022; Svensk Försäkring, 2022a). The waterproof underlay is used and available on the Nordic market and is a demand in the building regulations for new buildings and renovation in Sweden for example Säker Vatten (2020). The payback of the investment is calculated from the damage that occurred due to 15% of the faulty appliances that are reported missing water-proof underlays (Vattenskadecentrum, 2022). By comparing the reported damage where the water damage that the underlays could reduce or prevent the damage and the building stock, the probability that a building annually has water damage could be estimated to 1 out of 1225 dwellings in Sweden (SCB, 2022; Vattenskadecentrum, 2022).

The water monitoring device is a device that is installed at the inlet pipes of a building most commonly after the water meter. The device is constructed to, varies in performance and execution depending on the brand, monitoring the water flow and creating an overview of the system and the resident's water usage habits. It should be able to automatically shut off the water flow for the building if a leakage, small or large, is discovered. The damage that the water monitoring device could prevent are smaller leakages inside the structure that aren't visible and that could cause immense damage and even such damage that is the most common in the Nordics, such as leakages due to corrosion in the water tap-water system (Finans Norge, 2022; Forsikring & Pension, 2022; Vattenskadecentrum, 2022). Damage caused by sudden breakage of parts of the system is few but could also be prevented (Nordling & Månsson, 2020). In short, the device could prevent and make the resident or building manager aware of various kinds of unwanted leakages or unwanted flow both in visible and hidden pipes. Water monitoring devices are assumed for this study to be able to reduce and/or prevent the water damage that occurs due to faults in the tap-water system both for the pipes, connections, and appliances, which accounted for approximately 33% of the damage in 2021 in Sweden (Vattenskadecentrum, 2022). With this motivation, the damage costs categories that the device is assumed to prevent are wet rooms with tiles, wet rooms with plastic mats, kitchens, other spaces (average reimbursement for water damage in Sweden), and damage in multifamily buildings (Björk et al., 2018; Mattsson et al., 2022; Svensk Försäkring, 2022a). The devices are not a demand in the Nordic building codes but are available in the market and have been included in independent testing conducted by RISE (2022) (Nordling & Månsson, 2020). In estimation, the water damage that could be reduced or prevented occurs in approximately 1 out of 155 dwellings in Sweden (SCB, 2022; Vattenskadecentrum, 2022).

The water leak switches with switches are devices that are installed locally to detect and stop water leakages from e.g., appliances. In contrast to water monitoring devices, the water leak switches stop the water from a single or pair of pipes that feeds a single unit. That, most commonly, consists of a switch and a water-sensitive sensor. The switch is connected between the appliance's main pipe and the distribution pipe. For example, the water-sensitive sensor is placed where the water would flow if leakage appears, which could be wired and wireless to the switch. These devices are most common in kitchens and rooms without a drain, it is also in these rooms the device could stop the leakages with the most damage, due to that these rooms usually don't have a waterproof membrane, as a wet room usually has, whereas a small but continuous unnoticed leakage could cause large damage to water sensitive material. With this motivation, the damage costs categories that the device is assumed to prevent are kitchens, other spaces (average reimbursement for water damage in Sweden), and damage in multifamily buildings (Björk et al., 2018; Mattsson et al., 2022; Svensk Försäkring, 2022a). These devices are a demand in some installations in Swedish regulations and the product could be widely found in the Nordic market (Säker Vatten, 2020). Water leak switches are assumed for this study to reduce and/or prevent the water damage that occurs due to appliances, accounting for approximately 28% of the damage in 2021 (Vattenskadecentrum, 2022). In estimation, the water damage that could be reduced or prevented occurred in approximately 1 out of every 185 dwellings in Sweden (SCB, 2022; Vattenskadecentrum, 2022).

The water leak alarms are devices that are placed, usually by the resident, in areas where water could leak, the alarm is designed to indicate this, usually with a loud sound, light, or a message to the resident's phone or a combination of the three. These devices are available on the Nordic market but are not demanded by the regulations (Säker Vatten, 2020). The alarms have a similar area of application as the water leak switches, except that the alarms don't shut off the water flow in case of a leakage. The damage costs categories that the device is assumed to prevent and therefore studied are kitchens, other spaces (average reimbursement for water damage in Sweden), and damage in multifamily buildings (Björk et al., 2018; Mattsson et al., 2022; Svensk Försäkring, 2022a). Water leak alarms have a similar area of application as the water leak switches therefore, the estimation of water damage that could be reduced or prevented is the same as earlier, 1 out of 185 (SCB, 2022; Vattenskadecentrum, 2022).

These actions and measures were then examined in terms of cost, functionality, and what kind of damage they could prevent or minimize the effect of. The retail price of the different actions and measures was obtained from a search of different distributors within the Nordic market. Together with the retail price the installation cost and the vat of the product needed to be added. The vat was added according to regulations in Sweden and the installation was added by half a day's work (4h) or a whole day's work (8h) conducted by a contractor with 500 SEK per hour (44.5 USD/h) estimated to 2 000 SEK (178 USD) and 4 000 SEK (356 USD). The measure that required a full day of a contractor that conducted the installation was water monitoring devices since that measure requires encroachment of the pipes and could even demand rebuilding the piping which could take more time but 8 hours for a contractor was deemed sufficient. Water leak switches with switches were considered to require a contractor for 4 hours since is action requires smaller if any, encroachment of the existing pipes. The water-proof underlays and the water leak alarms were not allocated any cost for installation since it was considered, for this study, not to require any contractor for installing such equipment, the installations require no encroachment of the existing pipes and are only to place the device or underlay where water could leak. This is most often written in the installation instructions.

The investment costs of the studied actions and measures were examined at the time of the study. This was done in the Swedish market. In case of any variation of the retail price of the actions/measures, an average price was calculated, as in the case of water monitoring devices, where 7 different devices were studied, and water leak alarms, where 8 different devices were studied. The retail price was one factor that could affect the payback time but since the differences in the found actions and measures within the category were not the function of stopping or reducing water damage but rather other features and additional functions that didn´t affect the inclusion or exclusion of the action/measure in this study. The differences in retail price were therefore reduced to the average price of the included actions/measures. The investment cost included the retail price, the cost of the installation of those actions/measures that were considered to require an installation by a contractor, and the vat. The investment cost for the different actions and measures, whether the action/measure is passive or active the prevention of leakage, the percentage of dwellings estimated to have damage per year, and the estimated damage costs that the action/measure prevents, chosen for the study, are presented in table 1. The estimated damage cost categories are presented in the table for each action/measure, where kitchens, wet rooms with tiles, wet rooms with plastic mats, and multifamily buildings are derived from the study conducted by Björk et al. (2018). Other spaces have an estimated damage cost calculated by the average reimbursement costs in Sweden in 2021 (Svensk Försäkring, 2022a). The rooms, kitchens, other spaces, and wet rooms or buildings allocated to the cost of the water damage were used in this study to describe the difference between water damage occurring in the different spaces and buildings.

Table 1. Average investment cost of studied action/measures (includes retail price, an installation by a contractor, and VAT), if the action/measure has an active or passive way of indicating a leakage, the percentage of dwellings estimated to have damage per year, and the estimated damage cost that the actions/measures could prevent.

Underlays (3 units) *	**Water monitoring devices (7 units) ***	**Water leak switch (2 units) ***	**Water leak alarms (8 units) ***
300 SEK (27 USD)	10 500 SEK (930 USD)	4 700 SEK (420 USD)	460 SEK (41 USD)
Passive**	Active**	Active**	Passive**
0.03%	0.58%	0.54%	0.54%
Kitchens 30 500 SEK (2 700 USD) Other Spaces 49 000 SEK (4 400 USD) Multifamily buildings 106 500 SEK (9 500 USD)	Kitchens 30 500 SEK (2 700 USD) Other Spaces 49 000 SEK (4 400 USD) Multifamily buildings 106 500 SEK (9 500 USD) Wet room with tiles 93 000 SEK (8 300 USD) Wet room with a plastic mat 60 000 SEK (5 300 USD)	Kitchens 30 500 SEK (2 700 USD) Other Spaces 49 000 SEK (4 400 USD) Multifamily buildings 106 500 SEK (9 500 USD)	Kitchens 30 500 SEK (2 700 USD) Other Spaces 49 000 SEK (4 400 USD) Multifamily buildings 106 500 SEK (9 500 USD)

* Number of units studied for the different actions and measures.
** Passive and active prevention describe whether the action/measure stops the flow of water or not when leakage is noticed.

The analysis of whether the actions and measures are considered to be cost-effective is conducted with a payback calculation of the investment of the action/measure, which describes, within the limitations of the study, how many years the initial investment of the action/measure is expected to be earned back. The calculation doesn't take inflation and economic speculation into consideration. The payback calculation was done by an estimation, based on the statistics provided by Vattenskadecentrum (2022), on the risk of water damage by the number of occurring damage within the specific water damage that the action/measure is assumed to prevent (room of the building, water damage statistics describing the problem that the actions/measures are assumed to prevent). Furthermore, the probable damage cost was calculated by multiplying the percentage of dwellings with damage per year and the estimated damage costs, and finally, the payback calculation is estimated by dividing the investment cost by the probable damage cost per year. For example, the water leak switch where damage due to appliances is investigated. 11 386 damage were reported in 2021 which approximately corresponds to 0.54% of the dwellings in Sweden reported damage. This corresponds to 1 out of 185 dwellings in Sweden, calculated by comparing the reported damage where a water leak switch could reduce or prevent water damage and the building stock. This estimation of buildings corresponds to the probability that a building annually has water damage. The cost of the damage could, for this study, be in kitchens, other spaces, and multi-family buildings. These costs are divided by the corresponding amount of dwellings with damage per year

(0.54 multiplied by the cost of the damage in this example). This cost corresponds to the annual cost that the resident would have if the investment wasn´t made, these costs are presented in table 2. If the investment was made the payback time is calculated by dividing the investment cost by the probable damage cost if the investment wasn´t made. Then the result is calculated which describes the number of years needed for the investment before it starts paying off in relation to the estimated cost that water damage would cause.

Table 2. Estimated probable water damage cost per year without any measure taken varying due to different expected costs of water damage and what the water damage the action/measures act to reduce/prevent

The expected cost of water damage	Underlays (3 units)	Water monitoring devices (7 units)	Water leak switch (2 units)	Water alarms (8 units)
Kitchens **30 500 SEK (2 700 USD)**	10 SEK/year (1 USD/year)	200 SEK/year (18 USD/year)	165 SEK/year (15 USD/year)	166 SEK/year (15 USD/year)
Other spaces **49 000 SEK (4 400 USD)**	16 SEK/year (1.5 USD/year)	320 SEK/year (28 USD/year)	266 SEK/year (24 USD/year)	267 SEK/year (24 USD/year)
Multifamily buildings **106 500 SEK (9 500 USD)**	36 SEK/year (3 USD/year)	690 SEK/year (61 USD/year)	576 SEK/year (51 USD/year)	577 SEK/year (51 USD/year)
Wet room with tiles **93 000 SEK (8 300 USD)**	-	600 SEK/year (54 USD/year)	-	-
Wet room with plastic mat **60 000 SEK (5 300 USD)**	-	390 SEK/year (34 USD/year)	-	-

LIMITATIONS

Specific manufacturers and companies of studied actions and measures are not presented, the action and measures are only presented within the 4 chosen groups presented in the previous section. The cost is presented as an average value of the found actions/measures that is chosen to represent the cost of the product if it was bought on the market in Sweden at the time of the study. The function of the different actions and measures within the specific cost categories is considered to fill the same basic functions. The water damage costs are assumed to reflect the different damage types that are occurring in buildings in Sweden but could also reflect buildings in countries with the same cold climate. The expected costs studied are complex and could vary in extent and therefore also size but they reflect common and documented water damage in buildings constructed in cold climates, e.g., with the demands of insulation and structures built in moisture-sensitive material. Another assumption made for the study was that the water damage statistics by Vattenskadecentrum (2022) corresponded to the entire building stock of homes in Sweden.

RESULTS

The examination of actions and measures included the assumptions of what kind of damage they are designed to reduce and/or prevent, and the estimated cost that the water damage would cause which resulted in an estimation of the payback time in years of the investment. Figure 1 presents the estimated payback times for the action measures investigated, calculated with the investment costs provided in table 1. For water alarms, the payback was estimated to be an average of 10 months. For waterproof underlays, the payback was estimated to be an average of 8 years. For the water leak switch, the payback was estimated to be 18 years on average, but with a 10 year-variation in each direction (Figure 1). For water monitoring devices the expected payback time is an average of 30 years.

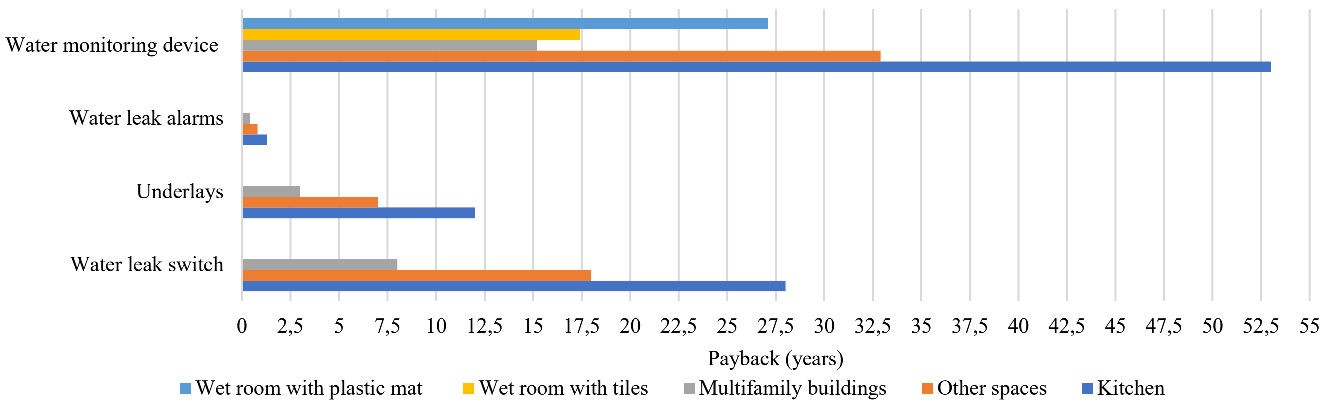

Figure 1 The estimated payback time of water monitoring devices, water leak alarms, underlays, and water leak switch investments divided by the different water damage cost categories (table 1).

DISCUSSION

Constructions built for cold climates pose a number of challenges related to water damage. For one, In the Nordic countries, these constructions are often built with wood or timber, which are vulnerable to moisture, and the constructions also contain considerable amounts of built-in materials, which if exposed to water likely causes expensive moisture damage. The building codes additionally demand that buildings should withstand the climate and the moisture that they must endure in construction and during the building's lifetime both from the indoor and outdoor climate. Furthermore, the Nordic countries have problems with the freezing of pipes and connections that causes leakages, which has increased in recent years (Mattsson, Nordquist, Johansson, Wallentén, & Bagge, 2021). Taken together, it is clear that measures must be taken to reduce the increasing trend of water damage, and actions have been taken regarding building regulations, industry rules, and insurance policies. However, few measures have been taken in the maintenance and operation phase. As a background to this study, then, it is assumed that actions and measures could have a large impact on the total amount and cost of damage since a large portion of the damage occurs in buildings with an age of 30 years or more (Vattenskadecentrum, 2022). This could be because the expected lifespan of the installed products is coming to an end but if products that monitor the water system or indicate that damage has occurred, are installed and if these investments have a payback time that is relatively short of the expected lifetime of the building a vast amount of the water damage and the cost of these could be reduced.

The study shows that water leak alarms have the shortest payback time, approximately 10 months after the installation even though the costs of these devices are for the most part higher than the waterproof underlays, for example, but since the action was estimated to reduce or prevent a higher number of cases the payback time was shorter. A further advantage is that the water leak alarms have a wide area of application and could be used in existing buildings with an underlay already installed, whilst the waterproof underlays are used in 85% of the reported damage cases (Vattenskadecentrum, 2022). However, the combination of actions and measures could be studied in more detail to evaluate how the different measures complement each other. With the method used in this study a higher investment cost, as a combination of multiple actions would imply, would lead to a longer payback time, but that is not certain to be accurate. If the start of the leakage and the time of the leakage detection, by the occupant, building manager, or the device, are reduced the cost could be significantly reduced. For example, the combination of a waterproof underlay and a water leak switch with a switch does limit the leaking water to reach places where moisture-sensitive construction material could be, and the water leak switch turns off the flow of water that would otherwise continue the flow and the actions would not be effective in reducing the water damage if the leaking water would not be stopped manually by a resident. The active actions and solutions are therefore preferable, even though they have a longer payback time because they stop the flow of water from the source without any physical action that needs to be taken by the occupant, building manager, or anyone else. But the passive actions/measures are still better than no action since they make the water damage visible and easier to notice and could also be a way of reducing the time between the leakage and the turning off of the water flow. Furthermore, it could be installed on more than one device and different devices in a building could have an effect, not only on the water damage security but on the payback time as well, due to more damage could be prevented/reduced. Not studied in this study but will be regarded in studies further on in the project. Additionally, when installing actions and measures the insurance companies could have incentives such as a reduction in the insurance premium due to the installation of the studied actions and measures, which could reduce the payback time as well.

The study is subject to certain limitations, mainly to do with the dataset. First, the study was conducted based on actions and measures used and available in the Swedish market. The damage that the studied actions and measures could have an impact on did not include all the reported damage in that study. Certain water damage types were therefore not included in the study. Specifically, approximately 58% of the reported damage in Sweden has been studied, which implies that the studied actions and measures, even though they could have an impact on the number and cost of water damage, still needs other actions and measures to impact all the reported damage. For example, the results show that water damage occurs from sewage pipes, waterproof membranes in wet rooms, and water-based heating and cooling systems. The results presented in this study are based on statistics where the majority of the reported damage is from dwellings, due to the quality of the insurance coverage and the lack of reporting of damage in other building types in Sweden and the Nordics (not covered by the damage report) but since the statistics are based on a large selection of damage cases (approximate 40 000 cases) in Swedish dwellings it was deemed to represent the entire building stock in Sweden and it could also be applicable in other Nordic countries with similar construction techniques and climate.

Another assumption was the number of dwellings estimated to have damage per year, which the different actions and measures were assumed to be able to prevent. This was done by estimating, from the water damage statistics, the annual risk of one water damage occurring per household. This method accounts for the estimation of water damage to be able to conduct the payback calculation but does not account for multiple units leaking in the same home in the same year. The payback times presented in this study represent the time that the studied investments installed, with the statistics used, would pay back if the studied action/measure was conducted with no relation to other factors such as the size of the building, the number of appliances, usage, and the number of residents. Factors such as these are not included in the statistics and could therefore not be considered. A limitation not related to the dataset is, the total costs of water damage are not only reimbursements from the insurance companies. Costs such as deductible, age reduction of the damaged material that the homeowner needs to cover to get the reimbursement from the insurance company, and costs due to the effects of the water damage, such as sick leave due to moisture in the indoor environment, were not included in this study (Mattsson et al., 2022). The payback times can therefore be assumed to be overestimated in this study. Further research in payback time for a combination of the studied investments together with other measures to reduce or limit water damage would be beneficial to further develop the field and provide decision-makers with more information to reduce the effects of water damage.

CONCLUSION

The study demonstrated that passive actions and measures, such as waterproof underlays for fridges, freezers, and dishwashers and water leak alarms have an average payback time of 10 months (alarms) and 8 years (underlays) depending on the estimation of the damage repair cost. Active actions and measures, such as water leak switches and water monitoring devices have, as an investment an average payback time of 18 years (water leak switches) and 30 years (water monitor device) depending on the estimation of the damage repair cost. Further, the study concludes that the actions and measures investigated would have a substantially shorter payback time if the repair cost were higher. If the studied actions and measures are installed in buildings where the residents/owner are aware that water damage could be costly and if the building is built before 1990 the actions/measures investigated could be used with a shorter payback time to prevent and/or reduce the economic impact water damage but also improve sustainable aspects regarding material usage and indoor air quality and residents' well-being. Lastly, the study recommends a number of actions and measures that can be implemented in the maintenance and operation phase of the building to reduce water damage, without major renovation or encroachments to the specific building.

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