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Climate adaptation of school buildings through MOM – a case study

Steinar Grynning[a] *, Jørn Emil Gaarder[a], Jardar Lohne[b]

[a]*SINTEF Building and Infrastructure, Trondheim Norway*
[b]*Norwegian University of Science and Technology, Trondheim Norway*

Abstract

The aim of the study was to map routines and planning tools concerning climate adaptation measures in buildings based on an analysis of a case building. The case was used to assess the strategy and main challenges of Maintenance and Operations Management (MOM) and upgrades at a large public building owner. An additional aim was to identify building components that are critical in ensuring a well functioning and climate adapted building.

Following a comprehensive literature review, the study was carried out using document studies, three semi-structured interviews with representatives from the municipality and an on-site inspection in a case building in Trondheim, Norway. The documentation study included drawings, operations plans and state/conditions.

It was found that the MOM-system is structured. A Condition Analysis (CA) was conducted according to the governing standard every five years, making long-term planning feasible. In addition, the operations officer on site is required to yearly carry out and report a comprehensive maintenance routine according to a set plan. However, discrepancies between the prescriptions and practice were found, mainly concerning larger required maintenance and upgrades. The case building was also found to have challenges regarding dissipation of rainwater from the roofs.

Well-functioning MOM- and upgrade strategies and tools are key in ensuring that existing buildings can meet future climatic conditions with increased amounts of precipitation, high temperatures and more extreme weather. Measures for routine improvements are suggested. This study is a contribution to a development of such strategies and tools

Keywords: building upgrade; climate adaptation; maintenance operations management; professional owner; public buildings

* Corresponding author. Tel.: +47 975 66 103
E-mail address: steinar.grynning@sintef.no

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1. Introduction

Moisture related damages pose significant challenges to the Norwegian built environment. Indoor moisture, damp building structures and precipitation stresses the building envelope and can provoke significant damages. Climate change has been proven to increase the amount and intensity of precipitation. On average, an increase of more than 20 % has been registered over the last 100 years, and an increase of an additional 20% is expected before the year 2100 according to the IPCC [1]. Scenarios for climate change in Norway [2] indicate a warmer climate, an increased occurrence of extreme weather and more intense precipitation over parts of Norway. This will have a large impact on the built environment of the future. Changes in temperature equally leads to an increase in conditions where the temperature oscillates around the freezing point, and that more of the winter precipitation falls in the form of rain. All these changes leads to higher demands to the climate screen of the building. Correspondingly, improved technical solutions are required, as well as a thorough follow-up. Increased precipitation leads to challenges concerning floodwater. Thus, elements such as drainage, water retention and slope of the adjacent terrain becomes equally important to take into consideration.

Adaptation of the built environment to climate change has received significant attention in Norway over the last two decades [3, 4]. About 80 percent of todays' buildings in Norway will be standing in the year 2050 [5]. Not all existing buildings are designed for the challenges related to climate changes [6] and e.g. [7] underline the importance of balance mitigation with adaptation regarding new building design and when retrofitting old buildings. This emphasizes that proper Maintenance, Operations and Management (MOM) and upgrade strategies are vital tools in ensuring proper climate adaptation of the existing building mass.

During a prior study carried out within the framework of the Norwegian research program Klima 2050, a large need for research based knowledge concerning the maintenance of buildings was unearthed [8]. Through a comprehensive literature study, different thematic approaches were outlined, as well as a sorting according to the actors most predominantly concerned with the research. Several areas were identified where the lack of adequate research was evident. Climate related research is mainly related to how legal frameworks and overreaching maintenance strategies can be used to secure a proficient climate adaptation for the building mass. Furthermore, a large gap in the knowledge basis concerning maintenance and upgrading was identified, especially concerning technical solutions and components.

The principal goal of the research reported on in this paper has been to address what climate adaptation of buildings from a MOM perspective actually implies. To address this goal, a building – Charlottenlund elementary school, Trondheim Norway – was subjected to the attention of the authors. More concretely, the research was carried out in order to answer the following research questions

- What are the characteristics of present day MOM-system for climate adaptation?
- What are the challenges to these systems?
- How can these systems be improved?

In order to address these questions properly, the theoretical framework section will outline the state-of-the-art internationally, concerning the understanding of terms such as floodwater, water retention and building envelope adaptation to climate changes. The analysis will be based on the condition of the case studied. The findings section therefore first outline the nature of the case, subsequently the state of the case and thereafter the MOM system.

2. Theoretical framework and definitions

2.1. Climate changes

Climate change refers to; *a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer* [9]. In addition, the climate is changing, of that there is little doubt and it has been investigated by a vast amount of researchers. Climate change has been proven to increase the amount and intensity of precipitation. On average, an increase of more than 20 % has been registered over the last 100 years, and an increase of an additional 20% is expected before the year 2100 according to the IPCC [1]. Depending on which scenario described by the IPCC that will actually occur, one can expect a global temperature increase of from 1.5 to more than 6°C before 2100. In the Norwegian context, temperature increase is estimated to 2.3 – 4.6°C in the same period [2]. The impending climate changes will have a large impact on the built environment of the future. Estimations carried out on behalf of the Norwegian government show that the impact on the building and infrastructure sectors are high both in terms of monetary costs, and as societal costs [10].

The most critical aspects of climate changes relevant for building adaptation challenges evolves around; an increase of annual mean temperature. Increased annual precipitation levels, increasing amounts of winter precipitation will fall in the form of rain, increase of wind-driven rain. An increase in the number of freeze-thaw cycles (temperature oscillating around 0°C) is also expected to occur [6]. Other factors like increase in avalanches floods and surges as well as a rising sea level are not considered to be of relevancy for this study and is, thus, not addresses.

2.2. Climate adaptation

Climate changes must be taken seriously and met by the proper responses. In the existing literature, two fundamental approaches are acknowledged; climate mitigation and climate adaptation. Climate mitigation is defined by the IPCC [9] as: t*he notion of limiting or controlling emissions of greenhouse gases so that the total accumulation is limited*. This approach falls outside the scope of this paper and is not addressed here. Climate adaptation as a general topic has been widely researched. The IPCC defines **adaptation as;** being; *the notion of making changes in the way we do things to respond to changes in climate*. **Adaptation** in the context of climate adaptation is by the United Nations defined as; *Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities* [11]. **Climate adaptation costs** is not within the scope of this paper.

2.3. Climate adaptation of buildings

The impending climate changes will afflict buildings in several ways. Four aspects, with the corresponding main building physical challenges, have been identified as crucial:

1.Increased temperatures
- Increased mould growth potential
- Increased rot decay risk
- Changes in frost-cycles
- Reduced heating demand
- Increased cooling demands

2.More precipitation (rain)
- Increased mould growth potential
- Increased rot decay risk
- Longer periods w/ free water on roofs
- Robustness of roof membrane
- Freeze-thaw cycles
- Membrane joints
- Gaskets and protrusions
- Drain/gutter capacities
- Blocking of drains
- Overflow in drains
- Standing water due to limited capacity of drains

3.Wet winter precipitation
- Increased structural loads
- Robustness of roofing
- Increased water pressure on ground constructions
- Ice formation on surfaces and in pore structures of materials

4. Driving-rain
- Increased mould growth potential
- Increased rot decay risk
- Surface treatment of facades
- Drying out of walls
- Flashing details
- Window/door mounting solutions

One can see from the listed challenges that the design of the weather skin is a key component in climate adaptation of the buildings. The weather skin is, in the context presented in this paper, defined as the b**uilding envelope**. **Adaptation** in a general term, relates to the buildings physical properties and its flexibility to handle change in use, function and volume [12]. Temperature increase will also influence and increase mould-growth potential in the building envelopes. A study carried out by Almås et.al. shows that an estimated total of 615 000 buildings in Norway are situated in areas with a potentially high risk for rot-decay. In 2100, this number is estimated to be 2.4 million buildings [13]. In addition to rot-decay risks, increased temperatures will generally lead to lowered heating demands, but cooling demands will increase.

The need for development of well-functioning technical solutions of the building envelope and other parts with respect to both strategies and solutions was demonstrated in [14, 15], who, by examining the SINTEF Building and Infrastructure building defects archive, found that damages and defects in the Norwegian building stock could be explained in the following ways:

- 3/4 of the investigated defects are caused by moisture;
- 2/3 of the investigated defects are related to the buildings envelope;
- 1/4 of the investigated defects are caused by precipitation;
- 1/3 of the investigated defects linked to outer walls above terrain are caused by moisture;
- 1/2 of the investigated defects linked to roofs and terraces are caused by moisture.

The total annual costs related to repairs of buildings in Norway amount to roughly 1.65 billion Euros [13].

2.4. Climate adaptation of buildings using MOM

This paper presents work related to maintenance and operations management (MOM). The terminology is based on standardized definitions in NS 3424:2012 [16] and NS 3456:2010 [17], where; **Maintenance** is a combination of technical, administrative and managerial actions with the intention of maintaining or re-allocating the condition to a level that fulfils the functional requirements throughout the life-cycle of an item [16]. **Operation** is a *combination of all technical, administrative and managerial actions, other than maintenance actions, that result in the item being used* [16]. **Upgrade** is related to *work that is to be carried out on a building or its technical installations in such a manner that the building fulfil new, stricter demands and/or that the buildings area or capacity of installations are increased* [17].

The development of MOM-strategies as well as technical solutions suitable for the implementation of MOM strategies is crucial to ensure a proper climate adaptation of existing buildings meeting future functional requirements. **Functional** in this context, refers to *the expression of how the physical building works according to its purpose and fits the need of the user organization* [12].

The presented causes for climate adaptation and building defects should be related to findings from Flyen et. al. [18] where it is concluded that there was a significant lag in maintenance of public buildings in 2014 and that this lag increases the vulnerability to the predicted increase of climatic strains. Furthermore, to put things into perspective, a report by RIF [5], presenting the state-of-the-nation for Norway indicates that the value of the entire built environment in Norway constitutes 5800 billion NOK and that the cost for upgrading the entire Norwegian building mass to a good level of standard is estimated to 2800 billion NOK. Correspondingly, the Norwegian gross national product (GNP) was 3100 billion NOK in 2016 [19].

3. Method

An initial literature study was based on queries among experts and representatives from major research projects within the field in order to arrive at a premier comprehension of the state of the art of contemporary research. This premier research revealed articles and large research initiatives of high relevance to the field. A more traditional literature search following the prescriptions of Blumberg [20], using mainly the Google Scholar search engine, was subsequently carried out. In addition, the database Science Direct was used for searching, resulting in relatively few relevant hits. Main search words were; climate adaptation, climate change, facility management, maintenance and operation management, school buildings and climate adaptation of buildings. An additional 15 articles, reports and other literature considered of high relevance to the field were thus identified.

A mapping of Norwegian research projects within the field of maintenance and operations management was carried out by the authors in a previous study [8, 21]. There, 28 projects of which 10 addressed climate adaptation issues were identified. Documentation from these ten projects was scrutinized in order to identify main knowledge gaps within the Norwegian context.

The main methodological approach guiding the study being reported on in this paper consisted in a case study concerning specific elements of maintenance and operations management, based on a documentation study, on-site inspection and interviews. The case scrutinized was the Charlottenlund elementary School in Trondheim, Norway. The case study was carried out according to the guidelines presented by Yin [22].

The documentation study included drawings, operations plans and state/conditions analyses according to the guidelines in Weber [23]. A total of 21 case specific documents were scrutinized.

One on-site inspection was carried out by two of the authors of this paper, accompanied by the maintenance officer who commented on maintenance needs and to what extent different solutions were working or not during the inspection. The main object of analysis was the building envelope (facades and roofs) and adjacent terrain, with the specific intention of identifying climate related damages and weak spots.

The analysis was followed up by three semi-structured interviews with representatives from the municipality (operations officer, project manager maintenance and sustainability advisor) carried out according to Yin [22].

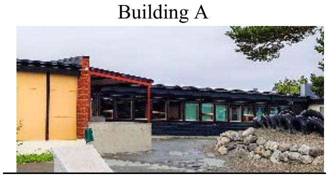
4. Findings

The findings section outline the nature of the case, the state of the case and thereafter the MOM system used.

4.1. The case project – presentation

Charlottenlund elementary school consist of several buildings, and has been developed over several stages. It has approximately 700 pupils from first to seventh grade, and a staff of about 100 employees.

Table 1. Building overview and main characteristics Charlottenlund elementary school.

Building	Type of building and function	Year of construction	Main building characteristics
Building A 	Main building with several extensions	1964, 1997 and 2000	Flat compact wooden roof w/exterior drainpipes ('64). Interior drainpipes from '97 and '00 Mix of brick masonry walls and aired wooden cladding on walls Basement in approx. ½ of building
Building B 	Swimming pool and gym	1964	Flat compact wooden roof w/exterior drainpipes Brick masonry on 3 walls, the 4th has ½ aired wooden cladding Basement w/technical installations under entire build.
Building C 	Teaching areas	1964	Same as Building A
Pavilion 	Temporary modules. Used as teaching areas	2007	2 stories of 10 joined modules Compact aired wooden roof Aired wooden cladding on walls Cellar crawl-space only (vents. every 5 meters)

4.2. Condition Analysis (CA)

Table NR. Main findings from the Condition analysis (CA) from 2011 and 2016.

Building	CA 2011	CA 2016
A	• General observation: facades has varying need of maintenance • Parts of the building with ETICS solution suggested replaced due to bad workmanship; especially around foundation flashings • Bad workmanship of cornice flashings • Windows, roof drains and solar shading should be considered replaced • Wall cladding should be painted (surface treatment)	• ETICS replaced with aired sheet-covering solution • No comments regarding cornice and foundation flashings • Solar shading replaced, windows not replaced
B	• A comprehensive CA of the brick masonry was recommended due to frost-damages and cracking and water leakages in joint of masonry and wood constructions. Possible weakened headers between interior and exterior flanges. Replacement of entire wall recommended • Bad conditions of windows • Exterior roof drains taken into the warm part of walls is risky • Poor drainage of basement • Interior damages caused by water • Major upgrade of technical installations are needed • Total rehabilitation or demolition of entire building recommended	• Nothing has been done with the defects revealed in the 2011 CA report. This is explained by the fact that the building only has a remaining lifetime of 5-7 years when a new municipal swimming pool is planned to be finished.
C	• Need for surface treatment (paint) of wooden wall cladding • Bad conditions of roof drains; should be replaced • Windows (from 1984) should be replaced due to old age	• All issues from 2011 have been addressed
Pavilion	• Leakages from roof. This was handled as a claim issue.	• Roof leakages have been resolved

4.3. General findings during the on-site inspections

Several of the points mentioned in the 2011 CA was included in the MOM-plans in the following years. Roof drains were changed, wooden cladding was treated (painted) and the above-mentioned flashings were replaced and/or repaired. The external thermally insulated composite system (ETICS) facade in building A has been replaced with an aired sheet-covered solution. Building C has not been repaired due to estimated remaining service lifetime.

The maintenance officer reports that pine- and fir-needles from roof-drains is a frequent problem. The roofs above the entry-doors have limited drainage due to low sloping. This has been partially solved by installing additional water overflows and by frequent cleaning of roofs. In addition, heating coils have been mounted in drainpipes to avoid icing and icicle formation, which may constitute an environment, health and safety (EHS) risk.

The roof of building A is in good condition. However, some ventilation ducts creates runoff problems. The ducts leads to clogging of the runoff, as shown in Figure 1 (left). The roof cladding shows signs of wear and should be replaced. Parts of the cladding was replaced in conjunction with the installing of the district heating.

The wooden cladding of building A facing the playground is a source of much manual maintenance work. Needles from surrounding trees together with gravel from the playground is clogging the ventilation aperture under the cladding as shown in Figure 1 (right). Thus, the airing of these parts of the facade is poor and may lead to moisture-damages in these parts. In addition to this, the terrain is sloping towards the facade causing heightened moisture strains due to poor rainwater runoff abilities. However, improvements of this is planned to be carried out.

Figure 1. (left) The casings for ventilation ducts and technical pipes. (right) The clogged ventilation aperture of the wooden cladding in parts of building A.

4.4. The MOM system

Trondheim Municipality have dedicated maintenance officers who are responsible for the daily maintenance and operations of their buildings. The maintenance officers are responsible for planning of the necessary MOM and upgrade tasks for their building(s) based on the systems described below. As a rule, a maintenance officer may have responsibility for one or several buildings depending on the size of the buildings in question. For Charlottenlund, there is one maintenance officer employed in a 100 % position who has responsibility for the daily MOM of the four buildings. If any larger MOM- or upgrade tasks are to be carried out, external contractors are hired.

Trondheim municipality structure their MOM- and upgrade plans based on two main activities. The first is a year-to-year MOM routine for the maintenance officers of the buildings. These routines are distributed yearly to the responsible maintenance officers and consists of a booklet describing all routines, checkpoints etc., which are to be carried out that year. The checkpoints- and lists are filled out continuously throughout the year. At the end of each year, it is resubmitted to the central property department of Trondheim municipality. The structure of the booklet is outlined here, showing the nine main chapters of the content of operations plan (example from 2013 version). 1 Description of tasks with checklists, 2.Checklist for ordered tasks, 3.Checklist for critical operations tasks, 4.Checklist for operations tasks, 5.Checklist for electrical system and equipment, 6.Checklist for outdoor areas (playground), 7.Internal control of building safety, 8.MOM-routines for bomb-shelters, 9.Internal control of operation tasks

Secondly, an external consultant carries out a condition analysis (CA) every five years. This forms the basis for more long-term MOM plans of both the building envelope, technical installations (heating, cooling, ventilation etc.) and interior MOM and upgrade needs. Such CA's were carried out in 2011 and 2016 as described in the previous part of this paper.

5. Discussion and conclusions

In this paper, we proposed to address the following research questions:

- What are the characteristics of present day systems for climate adaptation of existing building mass?
- What are the challenges to these systems?
- How can these systems be improved?

The present day system for climate adaptation of Trondheim Municipality's existing building mass and hence for Charlottenlund Elementary School, is orderly and systematic. There is a routine for yearly reporting using annual MOM-plans in addition to a more thorough conditional analysis every fifth year. This way of structuring the planning ensures good control of the running, day-to-day maintenance and upgrade-needs. In addition, it makes long-term planning easier.

However, it was found that challenges arises when estimations of remaining service-life time of buildings comes into play. There exist no rules regarding maintenance for buildings with limited time to demolishment. The swimming pool at Charlottenlund, which is estimated to be decommissioned within the coming 5 to 7 years, exemplifies this.

Some of the technical solutions that have been chosen to solve particular issues are not necessarily the most appropriate. The biggest challenges related to building physics that was unveiled during the on-site inspection were related to the roof and adjoining solutions. The use of heating-coils to keep water from freezing in the roof gutters and drains are not particularly sound. A solution with internal drains is in general assessed to be a much more robust solution. In addition, some flaws related to the cladding were found. The ventilation aperture behind the wooden cladding of building A, was clogged in one of the facades. This leads to continuous work with opening of this for the maintenance officer. With today's amounts of precipitation, the design seems to be functioning well. However, this should be improved and a solution/design, which accommodates for the anticipated increase of precipitation in the years to come without the need for active maintenance should be developed.

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