Use of EPS formwork blocks in 4-storey apartment buildings

Risk- and vulnerability analysis

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Abstract

The purpose of this paper is to present a risk- and vulnerability analysis for the use of EPS formwork blocks in 4-storey apartment buildings.

EPS is defined as combustible insulation by the Norwegian building regulations [1], which limits the pre-accepted use to low-rise buildings of maximum 2-3 floors (fire class 1). Use of EPS in 4-storey buildings (fire class 2) is thus a deviation from the regulations.

Thermomur is formwork blocks of *Jackopor*, which is made of expanded polystyrene (EPS), together with binders of high density polyethylene (HDPE) and polypropylene (PP). The *Thermomur*-elements are piled on top of each other and filled with a core of concrete which is reinforced. The building system is used for outer- and inner walls.

Figure 1. Thermomur Building System.

The specification of fire safety requirements for a 4-storey case building have been identified as a first step of this study. An important requirement is that internal and external cladding/plaster needs to protect combustible insulation (EPS) in the required time for evacuation and rescue. This is because EPS can melt and produce toxic gases during fire, making poor conditions for evacuation and rescue.

To examine the problem of using EPS in 4-storey apartment buildings, different types of analytical models and methods are used, including calculations of required safe egress time and specific fire energy, and fire testing. This is then used as input to a risk- and vulnerability analysis based on the method in NS 3901 [2].

The risk evaluation shows that when the measures in the analysis are taken, the risk is considered to be at an acceptable level, and the use of EPS formwork blocks in 4-storey apartment buildings is considered fire safe for people and the fire brigade.

Introduction

Thermomur is formwork blocks of *Jackopor*, which is made of expanded polystyrene (EPS), together with binders of high density polyethylene (HDPE) and polypropylene (PP). The *Thermomur*-elements are piled on top of each other and filled with a core of concrete which is reinforced. The building system is used for outer- and inner walls.

The EPS is always covered, and abrupted by the concrete for each floor and each wall. Figure 2 shows an example of a transition between the outer wall and concrete floor.

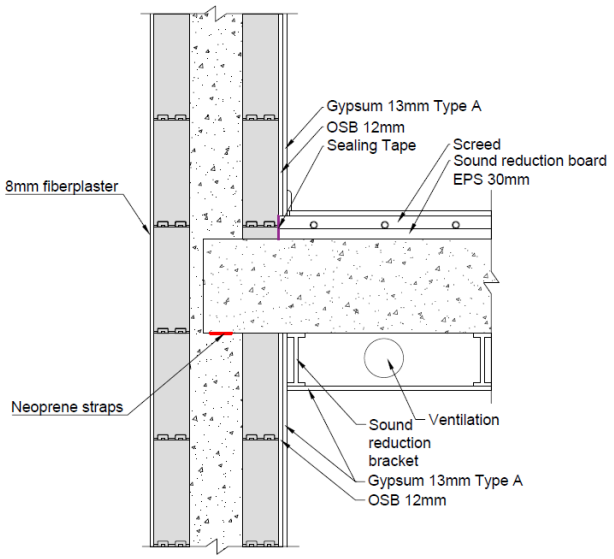

Figure 2. Transition outer wall - floor

This research seeks to find solutions for using Thermomur in 4-storey apartment buildings. EPS is defined as combustible insulation by the Norwegian building regulations [1], which limits the pre-accepted use to low-rise buildings of maximum 2-3 floors (fire class 1). Use of EPS in 4-storey buildings (fire class 2) is thus a deviation from the regulations. A risk- and vulnerability analysis after NS 3901 [2] is performed to verify the solutions.

A 4-storey apartment building in Losjevegen 3A-3B in Melhus, Norway is used as a case building for the project, see Figure 3 and 4. The case building has 5 apartments per floor, and parking/storage in the basement. The case building is used to find relevant fire safety requirements for 4-storey apartment buildings in VTEK, to calculate the specific fire energy and to determine the available safe egress time.

Figure 3 Facade, Losjevegen 3A-3B

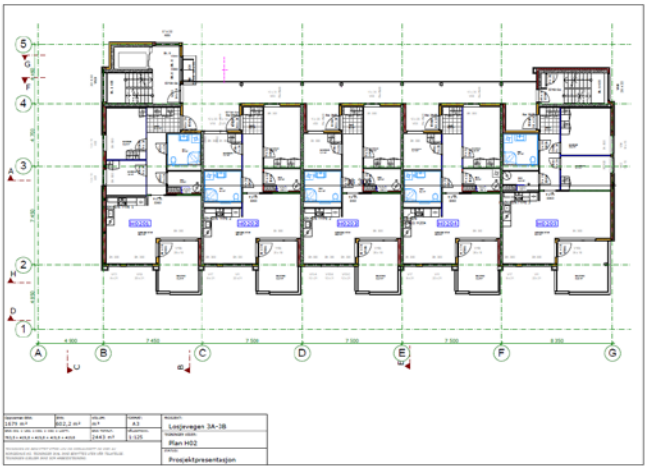

Figure 4 Layout 1st to 4th floor, Losjevegen 3A-3B

Case study methods

The objective of this study has been to carry out a risk- and vulnerability analysis according to NS 3901. The risk- and vulnerability analysis has included focused discussions on fire safety issues with participants from Jackon (manufacturer of Thermomur), SINTEF (researchers with experience in fire safety and building design) and Norgeshus and Solid Entreprenør (contractors with experience from using both Thermomur and other building systems).

The first step of the analysis was to define the relevant fire safety requirements in the Norwegian building code for the case building.

The second step was to investigate necessary parameters as safe egress time and to compare the fire energy in an apartment in the case building. Fire energy calculations was carried out also for traditional wooden construction systems. Values calculated for Thermomur solutions were compared with similar values for wooden constructions.

A third step was fire testing of Thermomur elements with covering to protect the EPS during fire. The testing including testing of internal board cladding for fire protection and also testing of claddings with holes and imperfect joints to simulate damages during use and non-professional execution of construction work.

The fourth and final step was to do the risk- and vulnerability analysis based on the findings from step one to three.

Fire Safety Requirements

A specification of the fire safety requirements for the case building have been identified as a first step of this study. The load bearing structure shall fulfill class R 60 in general and R 90 for parking areas (in basement). Separation walls between apartments shall have a fire resistance of EI 60. Floors shall also fulfill EI 60 except for floor between parking areas and dwellings that shall fulfill EI 90. Parking areas requires incombustible constructions with fire resistance EI 60 A2-s1,d0 or EI 90 A2-s1,d0, and Thermomur can therefore not be used here. Internal cladding needs to protect combustible insulation (EPS) in the required time for evacuation and rescue. External boards or plaster shall prevent fire spread between apartments/stories.

Available Safe Egress Time

Because EPS can melt and produce toxic gases during fire, it can make poor conditions for evacuation and rescue. It must therefore be covered to avoid it from being involved in fire during evacuation and rescue. Required safe egress time in the case building has been calculated after SINTEF Building Research Design Guide *520.385 [3]* to 6 minutes and 40 seconds. Including a safety margin of 50 %, the available safe egress time is 10 minutes. EPS must therefore be covered for at least 10 minutes in the case building.

The calculations presume simultaneous escape from the 3rd and 4th floor, which will have the longest escape route down to terrain / safe place. 25 people escape from the 3rd floor, and 25 people escape from the 4th floor. The calculations also presume that 4 out of 50 persons has reduced functional ability which makes it hard to walk or register the fire alarm and needs assistance from neighbours, and that people will not wait still to be rescued by the fire brigade.

Available safe egress time in other buildings may be longer than 10 minutes. It is therefore desired that the fire testing results in a coverage that protects the EPS for 15 minutes.

Fire testing – Vulnerability

Small scale fire testing has been done in the project, using a pilot furnace measuring 1,5 x 1,5 m. Results are not described here except for a test where the test specimen was made with inlaid mistakes and damages. The objective of the test was to investigate the vulnerability of the building system. What would happen to the EPS when the internal cladding was damaged? The test included the following conditions:

- Thermomur covered with 12,5 mm gypsum board type A, fastened with 30 mm screws
- Test duration 10 minutes
- Poor execution, where the tape was left out from the joint and no filler was used
- Inserted gypsum plug
- Inserted gypsum anchor
- Hole after a gypsum plug is removed
- A larger hole with diameter 28 mm, simulating a damage after e.g. a bookshelf has been torn down and a larger bit of the gypsum has been removed

The visual results are shown in Figure 5.

Figure 5 Result after small-scale test with inlaid mistakes and damages (12, 5 mm gypsum plate type A, 10 minutes)

- Melting from poor execution in joint is hardly visible
- Melting from inserted gypsum plug or anchor is hardly visible
- Hole after gypsum plug causes local melting and shrinking with a diameter of 30 mm
- Larger hole with diameter 28 mm causes local melting and shrinking with a diameter of 90 mm and a depth of 70 mm

The results showed that the building system is not vulnerable to damages in the cladding and poor execution, it only leads to local melting and shrinking. But the screws fastening the gypsum board easily loosened from the binders after the test, because of the heat. The minimum screw length of 30 mm is thus critical.

Fire testing – Coverage

Based on the test results from the small scale pilot furnace, a large scale fire test was carried out according to NS-EN 14135 [5]. The substrate was a 50 mm plastic stud reinforced EPS, Jackon Thermomur 250x. The covering consisted of 12 mm OSB and 12,5 mm gypsum board type A. The fire resistance of the covering was classified as K_1* according to EN 13501-2 [6]. There was no failure in any criteria after 15 minutes testing time.

*The classification period for K1 is 10 minutes according to EN 13501-2, but the test lasted for 15 minutes.

Specific Fire Energy

It has been made calculations [7] of specific fire energy to see if Thermomur contributes more to the fire energy in the building than other building systems, and to see when the contribution comes. The calculations are used as basis for the risk- and vulnerability analysis. Calculations are made for four different construction types after NS-EN 1991-1-2, Annex E (Standard Norge, 2008). The calculations are

based on material contribution from inner and outer walls in a 74 m^2 large fire compartment from the case building. The statistical value for variable characteristic specific fire energy per m^2 floor after NS-EN 1991-1-2 is 948 MJ/m^2. The fire energy from the materials in the walls is then added.

The specific fire energy has been calculated for the following four construction types. Floor and ceiling are made of concrete, except for construction type 4 where the ceiling is made of wooden beams:

1. Thermomur, internal cladding one layer of 12,5 mm gypsum board type A
2. Thermomur, internal cladding 12 mm OSB + 12,5 mm gypsum board type A
3. Inner walls of concrete, outer walls of wooden studs and internal cladding 12,5 mm gypsum board type A
4. Inner and outer walls of wooden studs, ceiling of wooden beams and internal cladding 12 mm fibre board (walls and ceiling)

A summary of the specific fire energy for the four construction types is given in Table 1.

Table 1 Specific fire energy [7]

	Type 1	**Type 2**	**Type 3**	**Type 4**
Total fire energy	76 000 MJ	84 000 MJ	82 000 MJ	122 000 MJ
Fire energy from materials	7 800 MJ	16 100 MJ	12 600 MJ	52 400 MJ
Part of total fire energy from materials	10 %	19 %	15 %	43 %
Part of fire energy before 15 minutes	0 %	0 %	0 %	59 %

The specific fire energy from Thermomur building system (type 1 and type 2) is far lower than for a traditional building system with wooden structures and claddings of fibre boards (type 4). And the contribution to the fire from Thermomur comes after escape and rescue from the building is assumed finished (after 15 minutes).

Risk- and Vulnerability Analysis

A risk- and vulnerability analysis after NS 3901 is the chosen method for the analysis. The different risk aspects of the building system are systematically evaluated, and the probability and consequence for each risk is considered. The analysis will be presented in a risk matrix. Underlying analysis techniques are calculations of available safe egress time and specific fire energy and use of results from fire testing.

To map the risk, a methodology is to categorize the events according to a risk matrix. The matrix is divided by consequence if an incident occurs, as well as frequency / probability that one incident shall occur. Based on the assessment of the probability and risk that an incident will occur, the various incidents are placed into the matrix as shown in Figure 6. The incidents are then categorized by colour (green-yellow-red) and numbered with risk categories (R1-R9).

	1 Safe	2 Dange-rous	3 Critical	4 Highly critical	5 Very critical/ Unacc-eptable
5 Very likely	R5	R6	R7	R8	R9
4 Highly likely	R4	R5	R6	R7	R8
3 Likely	R3	R4	R5	R6	R7
2 Less likely	R2	R3	R4	R5	R6
1 Not likely	R1	R2	R3	R4	R5

Figure 6 Risk category (R1-R9) presented as a risk matrix

The need for necessary measures to be taken depends on the coloured area the incident is placed in. One shall always seek measures to reduce the frequency of an incident first, and then reduce the consequence. Green area is in principle acceptable, but necessary measures should be considered to further reduce the risk. Yellow area requires a critical evaluation of the need to take measures, or a more detailed analysis shall be considered. Red area requires that measures must be taken. Level of probability (LP) varies from 1 (not likely) to 5 (very likely). Level of consequence (LC) for people and/or reputation for Thermomur and the contractor ranges from 1 (safe) to 5 (very critical/unacceptable).

The different incidents, accompanied by cause, level of probability, consequence, level of consequence, risk level and measures are summarized in Table 2. The different values have been discussed in the project group, consisting of Jackon, SINTEF, Norgeshus and Solid Entreprenør. The values are based on experience, statistics, common knowledge and "best guessing". When in doubt, the more conservative value is chosen.

Table 2 Risk- and vulnerability analysis

#	Incident	Cause	LP	Consequence	LC	Level	Measure
1	Uncovered EPS on external wall	Damage from screw holes for outdoor lamps, accident with car bumps etc.	4	Local melting or shrinking of EPS	1	R4	Inform the apartment owners to be careful with taking holes in external wall. The information must be available in the buildings MOM-documentation (management, operation, maintenance).
1.1	Uncovered EPS on external wall	Poor execution, including uncovered edges, too little thickness on plaster, plaster close to the ground subjected to moisture can crackle and fall off	3	Local melting or shrinking of EPS where EPS is visible.	1	R3	Training of the contractors using the building system. Make the contractors aware of the instructions for each plaster system. The assembly instructions for Thermomur building system must be updated, with focus on details and transitions.
2	Uncovered EPS in internal cladding	Damage from screw holes etc.	4	Local melting or shrinking of EPS	1	R4	Inform the apartment owners to be careful with taking holes in internal cladding. The information must be available in the buildings MOM-documentation (management, operation, maintenance).
2.1	Uncovered EPS in internal cladding	Poor execution, including cracks around door and window openings, and around block-outs for electrical boxes and ventilation ducts.	3	Local melting or shrinking of EPS	1	R3	Training of the contractors using the building system. The assembly instructions for Thermomur building system must be updated, with focus on details and transitions.
3	Fire spread between fire compartments caused by melted EPS	Poor execution	1	Fire spread between fire cells.	4	R4	Shall not be possible, the EPS is abrupted by the concrete for each floor and each wall. And fire tests show low degree of melting as long as the cladding stays in place, only local shrinking. In addition, casted constructions are less vulnerable to gaps and displacement than wooden constructions.
4	EPS is involved in fire before available safe egress time is due (may be up to 15 minutes for buildings other than the analysis building)	Internal cladding has fallen down due to fire, because the screws has loosened	2	Fire spread to the escape route on the gallery. People can still escape because there is a closed staircase in each end of the gallery.	4	R5	Fire testing according to NS-EN 14135 show that internal cladding of 12 mm OSB + 12,5 mm gypsum board type A is classified with fire resistance K_1*. *The classification period for K1 is 10 minutes according to EN 13501-2, but the test lasted for 15 minutes. In addition, the sprinkler system will control or delay the fire, giving a longer available safe egress time. The minimum screw length of 30 mm is critical and must be specified in the assembly instructions for Thermomur building system.
5	The fire brigade has difficulties with extinguishing the fire because of (possibly) higher specific fire energy than for a similar building with wooden structures	Internal cladding has fallen down after 15 minutes or more	2	Difficulties with extinguishing the fire	2	R3	Calculations shows that the specific fire load is not higher than for a similar building with wooden structures. Materials used for internal and external claddings in the analysis building does not give more contribution to fire spread than materials used in the reference building. Fire testing shows that when the cladding is removed from burning EPS the fire spreads on the exposed area, but it can easily be extinguished with water.
6	The sprinkler system is not activated	Sprinkler bulb is covered or damaged	2[1)]	Faster fire growth. Evacuation starts as normal due to activated fire alarm.	1	R2	Coverage of EPS is tested without sprinkler, and EPS will not be involved in the fire before available time of escape is due (10/15 minutes). The

							condition is not relying on sprinkler activation.
7	The fire alarm is not activated	Detector is covered or damaged	4[2)]	Evacuation is delayed. People will still be alarmed when the sprinkler bulb is activated at 68 °C (normally).	2	R5	The extent of the delay depends on the fire growth. When activated, the sprinkler system will control or delay the fire, giving more available time for escape.

[1)] Sprinkler system for life safety have a reliability of 0,9 [4]
[2)] Domestic smoke detectors have a reliability of 0,75 [4]

Risk Evaluation

The risk- and vulnerability analysis shows that the risk level for the different incidents varies from level R2-R4 (green) to level R5 (yellow). When the measures in Table 2 are taken, the risk is considered to be at an acceptable level, and the use of EPS formwork blocks in 4-storey apartment buildings is considered fire safe for people and the fire brigade. The measures are summarized in the following:

- Incident # 1 and # 2: Apartment owners must be informed to be careful with taking holes in internal and external walls. The information must be available in the buildings MOM-documentation (management, operation, maintenance).
- Incident # 1.1 and # 2.1: The contractors using the building system must go through training. The contractors must be made aware of the instructions for each plaster system. The assembly instructions for Thermomur building system must be updated with focus on details and transitions.
- Incident # 3: Shall not be possible, no actions are needed.
- Incident # 4: Fire testing according to NS-EN 14135 show that internal cladding of 12 mm OSB + 12,5 mm gypsum board type A will protect the EPS for at least 15 minutes. If a longer available safe egress time than 15 minutes is required in a building, Thermomur building system cannot be used. If evacuation by chance should take longer, the sprinkler system will control or delay the fire, giving a longer available safe egress time. The minimum screw length of 30 mm is critical and must be specified in the assembly instructions for Thermomur building system.
- Incident # 5: No actions are needed.
- Incident # 6: No actions are needed.
- Incident # 7: The extent of the delay in alarm depends on the fire growth. When activated, the sprinkler system will control or delay the fire, giving more available time for escape. Fire alarm and sprinkler alarm gives a double safety barrier, and no actions are needed even if the risk level is yellow.

Acknowledgements

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