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To upgrade or not to upgrade:
Issues for consideration upgrading old apartment buildings

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Summary

This paper identifies the key indicators that owners need to take into account in order to choose the most affordable extent of upgrading of a typical post-1945 building. The exterior look of the building is not to be changed. Indicators include measures, risk assessment related to the changes in the building physics provided by upgrading measures as well as costs and savings needed to achieve different levels of energy savings. The extent of “Upgrade level 2”, and “Upgrade level 1” defined in the Danish Building Regulations from 2015 are addressed and seen to be reachable. However, it is recommended not to carry out upgrading of a building by adding thermal insulation to the internal side of the external wall. The upgrading measures are seen to result in constructions less robust to moisture than before upgrading and costs that cannot be paid back by energy savings. Analysing tools like Be15, HEAT2 and WUFI Light were used for the investigations. Finally, the owner is recommended to upgrade by adding thermal insulation on to the exterior side of the exterior walls, which will indeed change the look of the building.

Keywords: Upgrade, Upgrading level, Affordable, Extent, Apartment building, Post-1945, Measures, Savings, Risks

1. Introduction

Upgrading of old apartment buildings is necessary if they are to remain a part of the future attractive building stock. If not upgraded, they will deteriorate over time. Over the past decade, indoor climate and energy demand requirements for new buildings have gradually been tightened in many countries. They were initiated by a global priority to develop a climate change policy that develops measures to mitigate climate-change effects. This process has been going on for more than a decade. On a global scale, efforts to mitigate the impacts of climate change have focused on reducing greenhouse gas emissions within the framework of the Kyoto Protocol [1], which has been implemented partly on an international level and partly through individual national initiatives. Efforts to mitigate climate change focus on reducing greenhouse gas emissions with emphasis on reducing CO_2 emissions. In many countries, buildings using energy for heating and comfort are one of the principal energy consumers and therefore there is a great interest in reducing building energy consumption and in providing a CO_2-neutral energy supply.

Older buildings like post-1945 buildings are categorised as having a very high energy demand as well as a very poor indoor climate standard compared with modern requirements [2]. Upgrading of these old buildings is needed to ensure that they remain part of the attractive building stock. Otherwise, they will deteriorate as there is no financial incentive to maintain them [3]. However, upgrading of post-1945 apartment buildings to ensure that they remain part of the future attractive building stock is a complicated and costly process especially if the ambition is to comply with modern requirements.

This paper identifies the key indicators that an owner needs to take into account in order to choose the most affordable extent of upgrading of a typical post-1945 building. The key indicators include measures, costs and savings needed to achieve energy demand levels defined as the extent of “Upgrade level 2” and the extent of “Upgrade level 1” defined in the new Danish Building Regulations from 2015 [4].

It was considered to carry out measures to improve the thermal insulation of the building envelope on the internal side of the external wall as the owner considered that the architecture of the building contributed significantly to the uniqueness of the local urban environment. This paper also describes the challenges that an owner need to address with regard to redesigning the layout for attractive dwellings in a building meeting the effects of climate change, with an energy demand facing modern requirements, implemented within a budget that makes the decision to upgrade a wise decision that are with expenses covered by energy savings and a market driven request for attractive and better dwellings. The case study identified upgrading measures for the two levels of extent of upgrading as well as risk assessment related to the changes in the building physics provided by upgrading measures. PC programs like Be15, HEAT2 and WUFI Light were used for the analyses.

2. Requirements

In Denmark requirements to the thermal insulation of buildings have been significantly tightened over the last 30 years. Before the introduction of the first Danish Building Regulations [5], which came into force in 1961, no requirements to the thermal insulation of buildings existed. In fact, the first Danish Building Regulations did not focus on the energy demand of buildings. The average coefficient of heat transmission was given for primary building components such as exterior walls, ground slabs and for roof constructions that corresponded well with the existing building tradition. The average coefficient of heat transmission was tightened several times in the run-up to 2010. In 2006, individual requirements for the average coefficients of heat transmission and of building components were changed to requirements covering the aggregate energy demand of buildings [6]. The tightened energy provisions introduced in 2006 and 2010 were both estimated to result in an energy reduction of 25% for new buildings compared with buildings constructed according to the former editions of the Danish Building Regulations [7, 8 and 9].

Table 1 shows the required energy demand to be met in order to upgrade to level 2, and level 1 as defined in the Danish Building Regulations from 2015 [4].

Table 1. Energy demand for buildings defined in the Danish Building Regulations.

Name on energy class	Allowed energy demand
Requirements to new buildings 2015	30.9 kWh/m^2 per year
Building class 2020 (expected requirements to new buildings 2020)	20 kWh/m^2 per year
Upgrade level 1	53.9 kWh/m^2 per Year
Upgrade level 2	112.8 kWh/m^2 per year

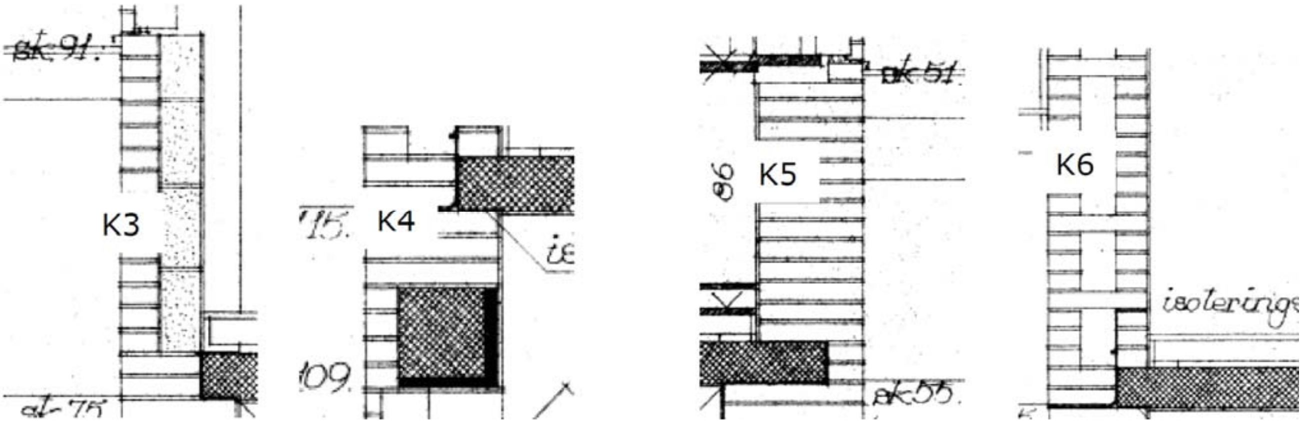
3. Building Description

3.1 The original construction

The building was constructed between 1945 and 1955 and is one of three similar buildings situated next to each other and separated by green spaces; it is located in the suburbs and in an area of single family houses. The building is orientated north south, rotated 15 degrees north. The built-up area of the building is 8 m x 35.36 m with balconies on both facades, two for each apartment. The building includes 3 floors and a basement, 2 stairwells with one lift each; the floor height is 2.6 m in the basement, 2.8 m at the ground floor and 1st floor and 2.75 m at the 2nd floor. There are 34 windows, each 1.45 m wide and 1.21 m high; 24 windows, each 1.65 m wide and 1.35 m high and 24 windows, each 0.88 m wide and 2.14 m high. The basement has 12 windows, each 0.65 m wide and 0.65 m high, 12 windows, each 1.45 m wide and 0.65 m high, 2 doors with double doors with windows, each 2.7 m wide and 2.14 m high, 2 lift doors, each 1.45 m wide and 2.14 m high and 2 basement doors, each 1.01 m wide and 2.14 m high, see Fig. 1.

Figure 1. Multi-storey building with apartments constructed between 1945 and 1955.

The building was originally designed to hold 18 one-room apartments and 6 two-room apartments. In 1990 the layout of the building was changed, so that the building today contains 12 two-room apartments four on each floor and a basement with shared facilities, rooms for the service staff and rooms for storage. The building is in a well-kept condition. The building has an exterior solid brick wall at the ground floor, the 1st and 2nd floors have an exterior cavity brick wall with brick joints and a cavity of 144 mm. Horizontal partition consists of reinforced concrete that is 150 mm thick. The brickwork of the exterior wall is three bricks in thickness. At the base of the building, the exterior solid brick wall is 480 mm thick starting 220 mm above the ground level and of 480 mm concrete under the ground level. The reinforced concrete deck reaches into the brick wall. The wall below the windows is one brick in front of 125 mm siporex and the wall above windows consists of 80 mm brick on 240 mm concrete with 30 mm wooden concrete on the interior side of the exterior wall, see Fig. 2.



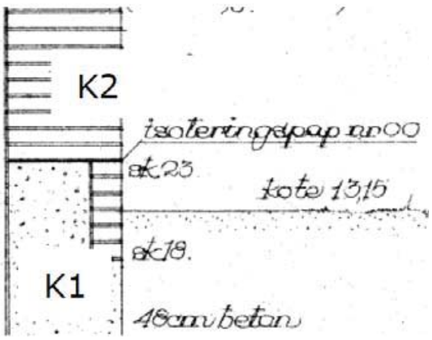


Figure 2. At the base of the building the exterior solid brick wall is 480 mm thick starting 220 mm above the ground level and of 480 mm concrete under the ground level (K1, K2). Exterior solid brick wall at the ground floor (K5), the 1st and 2nd floor exterior cavity brick wall with brick joints (K6). The wall below windows is brick in front of siporex (K3) and above windows it is brick on concrete with wooden concrete on the interior side of the exterior wall (K4). Horizontal partition is reinforced concrete.

Horizontal partition includes reinforced concrete. From the top: floor board with 50 mm sound insulation, reinforced concrete and a layer of plaster. The building has a cold attic room. The roof is a double-pitched roof with a 35 degree angle. The vertical section of the junction between the bases of the roof at the load-bearing exterior wall at the facade is shown in Fig. 3. Horizontal partition towards the attic room includes reinforced concrete. From the top: Thermal insulation consisted of 70 mm Leca concrete, 100 mm reinforced concrete and a layer of plaster.

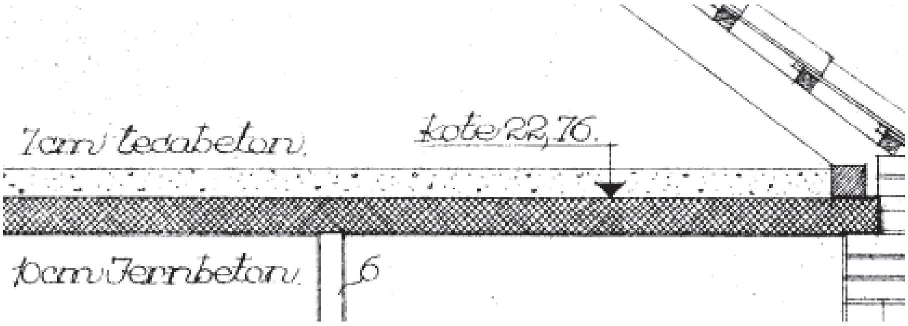


Figure 3. Horizontal partition towards the attic room. From the top: Thermal insulation consisting of Leca concrete, reinforced concrete and a layer of plaster.

The basement is warm as it is heated by uninsulated and poorly insulated installations for heating. The basement floor is 100 mm concrete with 25 mm cement-based plaster. U-values are shown in Table 2. The linear thermal transmittances for thermal bridges are shown in Table 3.

Table 2. U-values of building components and sections.

Component/Section type	U-value [W/m^{2}K]	Total area [m^2]
K1	0.96	131
K2	1.22	66
K3	0.86	47
K4	1.25	33
K5	1.49	179
K6	1.62	340
Horizontal partition towards the attic room	1.62	325
Basement floor	0.57	283
Windows and doors	1.8	199

Table 3. Linear thermal transmittances for joints between components.

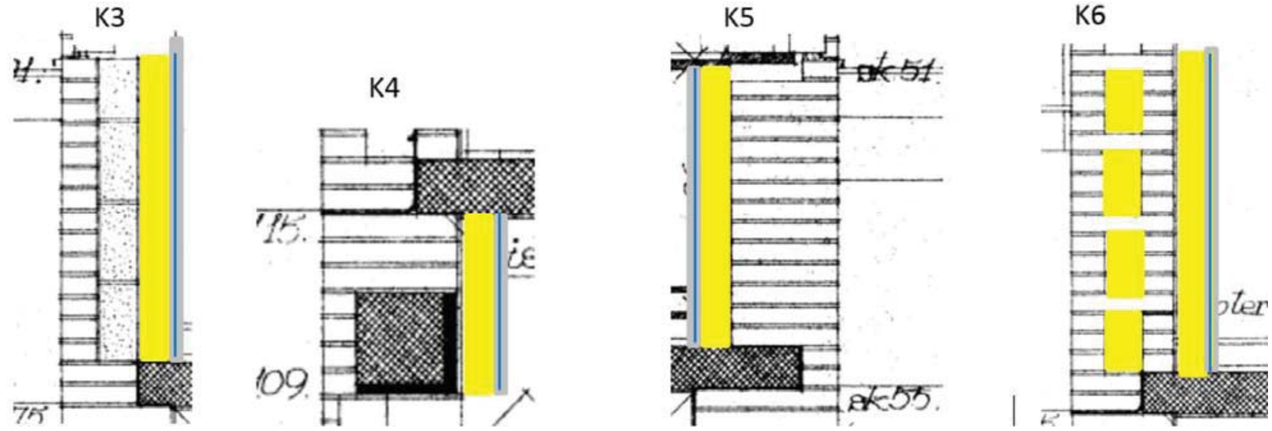
Connection between	Effective heat loss [W/mK]	Total length [m]
Window/door and exterior wall	0.13	608
Balcony and exterior wall	0.64	51
Basement perimeter of foundation	0.36	91
Horizontal partition basement – ground floor	0.05	77
Horizontal partition ground floor - 2nd floors	0.29	144

The building is assumed to be ventilated using outdoor air through windows/vents with a ventilation rate of 0.3 l/s per m^2 in winter. In summer the ventilation rate can be increased to 0.9 l/s per m^2 by opening doors and windows. The heat supply to the building is district heating with 70 degrees Celsius as supply temperature and a return temperature of 40 degrees Celsius. It is estimated that the water consumption is 250 l/year per m^2. The hot water is heated to 55 degrees Celsius and kept in a water tank insulated with 30 mm thermal insulation resulting in a heat loss of 4.7 W/K. The hot water tank is placed in the heated basement. The hot water is distributed using a circulation pump with an effect of 15 W. Hot water circulation tubes are 115 m long insulated with 25 mm thermal insulation resulting in a heat loss of 0.3 W/mK. The internal heat gain from occupants is 1.5 W/m^2 and 3.5 W/m^2 from equipment in both dwellings and basement.

3.2 Upgrading Case 1

The building is recognised as a building with architecture that contributes significantly to the uniqueness of the local urban environment. The owner would therefore like measures to improve the thermal insulation of the building envelope to be carried out on the internal side of the external wall.

Fig. 4 shows the improved thermal insulation system that was used for the facade, which consisted of a steel stud frame with 50 mm mineral fibre insulation. The thermal conductivity of the mineral fibre insulation was 0.030 W/mK. The thermal conductivity of the steel stud was 55 W/mK. The steel stud frame was attached to the exterior wall between the individual floors of the building with a distance of 450 mm. The cavity between the steel stud frame and the exterior wall was filled with mineral fibre insulation. To prevent air and moisture from penetrating into the insulated exterior wall from the inside, an airtight shell was established by a 0.2 mm polyethylene foil that also served as a vapour barrier. It was crucial that the foil was located on the warm side of the dew point and that the joints between the sheets of foil and joints were airtight and securely fixed [10].



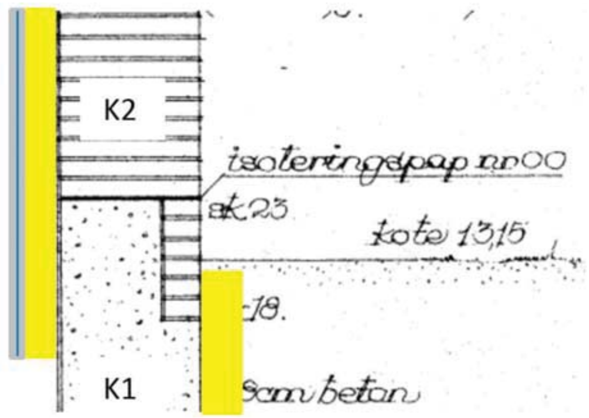


Figure 4. The improved thermal insulation system used for the facade and the basement. Mineral fibre insulation behind two layers of gypsum boards added at the interior side of the exterior wall (K3, K4 and K5). The exterior cavity brick wall was in addition filled with loose-fill mineral fibre insulation (K6). At the base of the building exterior insulation was added to the exterior wall from the ground level and down.

Towards the bottom and the top of the steel stud frame wall, the foil was extended to the exterior brick wall and fixed airtight. Two layers of gypsum boards 12.5 mm thick were added as the new interior side of the exterior wall (K3, K4 and K5). The plaster at the ceiling was intact and without cracks. The exterior cavity brick wall was filled with loose-fill mineral fibre insulation (K6). The thermal conductivity of the loose-fill mineral fibre insulation was 0.038 W/mK. At the base of the building, 150 mm thermal insulation was added at the exterior side of the exterior wall from ground level and down. The thermal conductivity of the insulation material used under the ground was 0.041 W/mK (K1, K2). Improvement of the thermal insulation towards the cold attic room was carried out by adding 500 mm mineral fibre insulation on top of the leca-concrete. The thermal conductivity of the insulation was 0.030 W/mK. To prevent air and moisture from penetrating into the insulated attic room from the inside, an airtight shell was established using a 0.2 mm polyethylene foil that also served as the vapour barrier at the sealing. It was crucial that the foil was located at the warm side of the dew point and that the joints between the sheets of foil and joints were airtight and securely fixed [10]. One layer of gypsum boards 12.5 mm thick was mounted as the new ceiling on the 2nd floor. Existing windows were replaced by new windows with a U-value equal to U = 0.78 W/m^{2}K and g-value = 0.52. The glazing/frame ratio was not changed.

3.3 Upgrading Case 2

With the objective of achieving further energy savings, the thermal insulation thickness used in Case 1 was increased. The extension was carried out on the interior side of the exterior walls above the ground. The extension was carried out by adding another layer of steel stud frames with 50 mm mineral fibre insulation. The thermal conductivity of the mineral fibre insulation was 0.030 W/mK. The thermal conductivity of the steel stud was 55 W/mK. The second layer of steel stud frames were attached to the frames already installed with a distance of 450 mm. The cavity between the steel stud frames were filled with mineral fibre insulation. The airtight shell was established behind the two layers of gypsum boards added as the new interior side of the exterior wall (K2, K3, K4, K5 and K6).

In order to reduce the energy demand further, the building was fitted with solar cells and solar panels on the roof.

3.3.1 Solar cells

6 kW mono-crystal solar cells covering 40 m^2 were installed. The system had a Peak Power of 0.15. The system was expected to have a power or impact of 0.75 and was mounted at the west side of the roof having a 35 degree angle [11].

The solar cells can reduce the energy demand by 8.9 kWh/m^2 per year, corresponding to 12 MWh/year.

3.3.2 Solar panels

An area of 1.5 m^2 panel per person is required to cover the hot water supply of a family of three-four persons in the summer period. Assuming that there are 1.5 persons per apartment, as the apartments are retirement homes, the building includes 18 persons which gives the demand of 27 m^2 solar panels.

27 m^2 solar panels can reduce the energy demand by 8.4 kWh/m^2 per year, corresponding to 11 MWh/year.

4. Results

Results from Be15 [11] calculations are summarised in Table 4. Table 5 shows temperature calculations from HEAT2 [12]. HEAT2 simulations were carried out for critical locations in the construction. The temperature was 20 degrees Celsius indoor and -0.6 degrees Celsius outdoors, which is the mean temperature in January, the coldest month of the year. WUFI Light [13] was used for moisture simulations in the exterior wall including the effects of driving rain load. Fig. 5 shows an example of such a calculation.

Table 4. Energy demand and energy savings from energy upgrade incl. renewable energy.

	Case 1		Case 2	
	kWh/m^2 per year	MWh per year	kWh/m^2 per year	MWh per Year
Original building's energy demand	196.6	256	196.6	256
Savings by upgrading the roof construction	42.2	55	42.2	55
Savings by upgrading doors and windows	11.6	15	11.6	15
Savings by upgrading exterior walls	62.8	82	71.7	92
New energy demand	80.0	104	71.1	94
Savings using solar cells	8.9	12	8.9	12
Savings using solar panels	8.4	11	8.4	11
Energy demand incl. renewable energy	62.7	77	53.8	71

Table 5. Calculated temperature in degrees Celsius at critical locations in the construction.

Location in the exterior wall, type of wall section	Original building	Case 1	Case 2
Surface indoors at a plain wall partition, K5	16.0	18.7	19.3
Surface indoors where wall meets window frame, K5	13.6	17.7	17.5
Surface indoors where plaster meets floor panel, K6	14.5	16.3	16.9
Surface indoors 50 mm under the ceiling under a balcony, K4	16.8	18.0	18.3
Surface indoors 50 mm under horizontal partition, K5	16.7	18.4	18.6
Surface indoors where plaster meets floor panel, K5	13.6	17.3	18.3
Surface indoors 200 mm over horizontal partition, K5	15.4	18.8	19.3
Surface indoors 50 m under horizontal partition, K6	17.0	18.6	18.8
Surface indoors where plaster meets floor panel, K6	16.8	18.5	18.8

WUFI Light was used to determine the moisture content in the exterior walls. Figure 5 shows the result of calculations over a 3-year period on the original exterior wall denoted K3. Simulations included load from driving rain. Simulations were carried out for the southern facade.

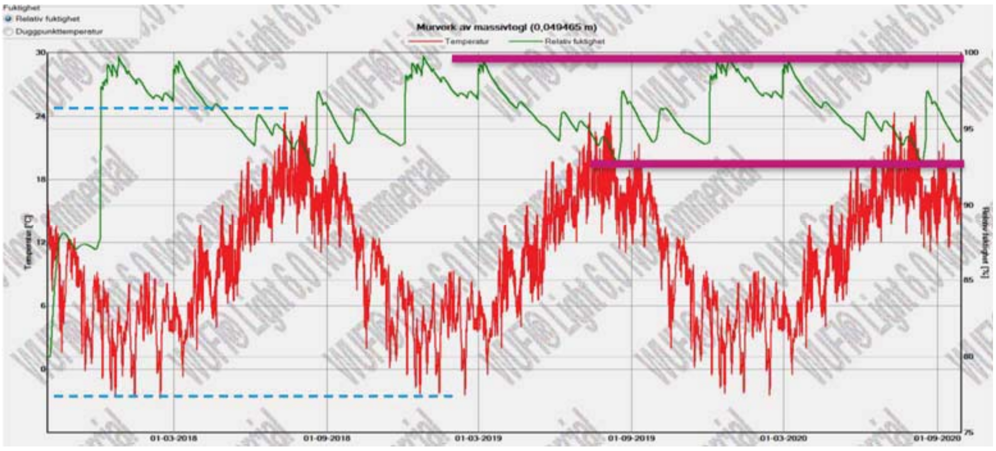


Figure 5. A WUFI Light calculation of the moisture content in the original exterior wall denoted, K3.

Results are shown for calculations at a point located 50 mm into the brick wall, measured from the outside. Markings of the highest and the lowest relative air humidity, RH are shown as thick red lines and the highest and the lowest temperature are marked with dotted blue lines. The relative air humidity is seen to stabilise between 92% RH and 99% RH; the temperature ranges between -3 degrees Celsius and 24 degrees Celsius. Further into the wall, 180 mm, the relative air humidity stabilises between 92% RH and 95% RH with a temperature ranging between 4 and 22 degrees Celsius. Even further into the wall, 50 mm from the inside, the relative air humidity stabilises between 88% and 92% RH with a temperature ranging between 11 and 22 degrees Celsius.

5. Discussion

Older apartment buildings dating from the 1940s and 1950s are categorised as having a very high energy demand as well as a very poor indoor climate standard compared with modern requirements [2]. Upgrading these old buildings is needed in order to ensure that they remain part of the attractive building stock. Otherwise, they will deteriorate as there is no financial incentive to maintain them [3]. However, it can be a complicated and costly process which might not comply with building physics, especially if the ambition is to comply with modern requirements. This raises the question whether upgrading is the right decision?

The investigations carried out here have shown results regarding measures and their impact on the building and amount on savings and maintenance work that needs to be considered prior to upgrading of the building. In 1990, the layout of the building was updated to contain larger apartments, lifts were installed and the basement updated to contain shared facilities, rooms for service staff and rooms for storage. Now modern demands regarding indoor climate calls for another upgrading of the building.

The building has a basic energy demand of 196.6 kW/m^2. By carrying out measures described as Case 1 without use of renewable energy, the energy demand can be reduced to 80 kW/m^2 and in Case 2 reduced to an energy demand of 71.1 kW/m^2 without use of renewable energy. This means that “Upgrade level 2” in the Danish Building Regulations, [4] can be reached without using renewable energy either in Case 1 or in Case 2. By carrying out measures described as Case 2 in combination with the use of renewable energy like solar cells and solar panels the “Upgrade level 2” in the Danish Building Regulations [4] can be reached. However, It is also required that the number of hours in a year that the indoor temperature is above 27 degrees Celsius may not exceed 100 hours and temperatures above 28 degrees Celsius should not occur for more than 25 hours. Paralel calculations on Case 2 using BE15 show 917 hours over 27 degrees Celsius and 503 hours over 28 degrees Celsius. Meaning that approx. 10% of the time the temperature is too high according to “Upgrade level 2” in the Danish Building Regulations [4].

Upgrading as described in Case 1 will reduce the living space by 2 m^2 for each apartment and upgrading as described in Case 2 will reduce the living space by 3 m^2 for each apartment.

Calculations of the indoor surface temperatures were carried out using the PC program HEAT2 [12]. Improving the thermal insulation by mounting thermal insulation at the interior side of the exterior wall caused a drop in the temperature in the existing exterior wall. That will reduce the drying potential of the wall. Improving the thermal insulation increased the overall temperature at the surface at the interior side of the exterior wall. The risk of mould growth is related to the relative air humidity. Assuming that at temperatures above 5 degrees Celsius and 75% RH can cause mould growth [14], the critical surface temperature indoors is 15.9 degrees Celsius, which is seen not to be reached in the original construction. Upgrading of the building will decrease the risk of mould growth and improve the indoor environment by providing higher surface temperatures.

Surprisingly, the improvement of the indoor climate by upgrading the building is seen to cause concerns for the original construction shown by the WUFI Light [13] calculations. The moisture content and temperature was calculated with the PC program WUFI Light. The driving rain was taken into account for the calculations and they were carried out for the southern facade. Calculations show that for all the types of walls K3, K4, K5 and K6 used in the building, the moisture content increases in the masonry with the upgrading initiatives. The moisture level was seen to increase and reach a level over 90% RH, even reaching 100% RH. Combined with the decreases in drying potential and a colder exterior wall the risk of frost damage will increase. Upgrading will increase the risk of degradation of the exterior side of the exterior wall.

From a building physics point of view, upgrading by adding thermal insulation to the internal side of the external wall can increase the indoor thermal environment and decrease the risk of mould growth. On the other hand, the upgrading can increase the degradation of the load-bearing exterior masonry wall.

Return on investment depends on the price of energy and decisions must be made on specific offers from craftsmen to carry out the work. From day to day, the time of return on investment can be calculated on the basis of the energy price and opportunities of financial support and how much the building owner will allow the rent to increase, while still offering attractive and affordable accommodation.

It could be argued that the upgrading does not fully meet today’s requirements, which is why the building has served its purpose and has reached its end-of-life. Even though the building is constructed of long-lasting materials like brick, wood and concrete, the masonry has an estimated remaining service life of 13 years and the roof a lifetime that has been exceeded by 7 years. Both are types of materials that can be re-used and go into the circular economy.

If energy upgrading of the building is required, the increased indoor thermal environment and decreased risk of mould growth can be obtained by adding thermal insulation to the exterior side of the external wall. By adding thermal insulation to the exterior side of the external wall, the original masonry exterior wall will be protected and kept warm at a lower moisture level. As the roof of the building is soon to be renovated, it should be considered to carry out this renovation at the same time. In this way, the roof construction can be extended to cover the new facade of the building.

6. Conclusions

In the present case studies the owner of a building asked for professional assistance prior to a decision on whether or not he should carry out an energy upgrading of his building. As the owner recognises his building as a building with architecture that contributes significantly to the uniqueness of the local urban environment, he would like measures to improve the thermal insulation of the building envelope to be carried out on the internal side of the external wall.

By carrying out measures described as Case 1 without use of renewable energy, the energy demand of the building can be reduced by 116.6 kW/m^2 per year, and in the case of measures described as Case 2 it can be reduced by 125.5 kW/m^2 per year without use of renewable energy. This means that “Upgrade level 2” in the Danish Building Regulations, [4] can be reached without use of renewable energy in both Case 1 and Case 2. By carrying out measures described as Case 2 in combination with the use of renewable energy like solar cells and solar panels, the “Upgrade level 2” in the Danish Building Regulations, [4] can be reached. However, the number of hours per year that the indoor temperature may exceed 27 degrees Celsius was calculated to be 917 hours and above 28 degrees Celsius for 503 hours. Meaning that in approx. 10% of the time the temperature is too high according to “Upgrade level 2” in the Danish Building Regulations, [4].

Calculations of the indoor surface temperatures showed that upgrading of the building will decrease the risk of mould growth and improve the indoor environment by providing higher surface temperatures.

Surprisingly, the improvement of the indoor climate by upgrading the building was found to increase the moisture content in the masonry exterior walls. The moisture level is calculated to increase and reach a level above 90% RH, even reaching 100% RH. Upgrading will decrease the drying potential of the exterior wall and increases the risk of frost damage and degradation of the exterior masonry wall.

From a building physics point of view the upgrading by adding thermal insulation to the internal side of the external wall can increase the indoor thermal environment and decrease the risk of mould growth. On the other hand, the upgrading can increase the degradation of the load-bearing exterior masonry wall. Energy upgrading of the building by adding thermal insulation to the exterior side of the external wall can also increase the indoor thermal environment and decrease the risk of mould growth. Additionally, the thermal insulation will protected and keep the original exterior wall warm and with a low moisture content. As the roof of the building has exceeded its service life by 7 years, it might be considered to renovate it at the same time as an energy upgrade. In this way, the roof construction can be extended to cover the new facade of the building. However, upgrading of the building does not fully meet the requirements of today, which is why the building owner needs to consider whether the building has served its purpose and has reached its end-of-life. Even though the building is constructed of long-lasting materials like brick, wood and concrete, the masonry has an estimated remaining service life of 13 years, and fortunately these types of materials can be re-used and go into the circular economy.

Besides, there has to be a much clearer financial return on investment in upgrading buildings if they are to take part in an overall reduction of energy demand in the building sector.

7. Acknowledgements

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