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Façade system for existing office buildings in Copenhagen

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Abstract

This study investigates solutions for facade renovation of general office buildings built between 1960 and 1980 in the Copenhagen Municipality. 44 buildings are used for the study. They share common structural and construction principles like the use of beams and columns and prefabricated elements. The problems that face these buildings are a high number of overheating hours and high heating consumption. Four strategies are tested for the renovation: external re-insulation, double-skin facade (existing inner facade), double-skin facade (new inner facade) and curtain wall. External re-insulation and curtain wall provide the best results for reducing the energy consumption for heating.

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Keywords: Facade renovation; Sustainable solutions; Energy efficiency; Indoor climate.

1. Introduction

A large number of office buildings in Copenhagen Municipality need renovation to reduce energy consumption and improve the indoor climate. This paper will focus on evaluating different scenarios for the facade renovation of office buildings. According to different parameters such as facade materials and structure, 44 office buildings in Copenhagen Municipality have been analysed. Different strategies were tested for the renovation taking into consideration the reduction of heat loss, the increase of heat gain and optimizing the use of daylight through the facade.

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2. Background

Buildings are some of the largest energy consumers in society. Between 30 and 40 percent of Denmark's total energy consumption is used for heating, ventilation and lighting of buildings [1]. The Danish government has announced a strategy for energy renovation of buildings in Denmark and energy consumption of buildings in 2050 should depend only on renewable energy. To implement this goal there is a need to achieve energy savings in the building sector. The strategy is to reduce the energy consumption in the building sector by about 35% up to 2050.

Multi-storey office buildings in Denmark face different problems regarding indoor climate [2]or the envelope is with a high U-value leading to large heat loss in winter. The reason can be high thermal conductivity of construction materials and lack of the necessary amount of insulation materials in the facade.

3. Method

The method will start with a qualitative and quantitative research that will result in a classification and sorting of the office buildings in Copenhagen. This classification depends on parameters like construction year, building type, size and the structural components of the facade. Simulation research will be achieved by using software programs to investigate the indoor climate and energy consumption. The program IDA ICE [3] is used to provide these data and to e verify whether it fulfils the recommended criteria. Other software were used for daylight simulations like VELUX Visualizer [4] and Google Sketch up [5] to draw models that will be imported to VELUX Visualizer.

4. Building Classification

A building classification is made on buildings built 1960- 1980 according to information obtained from a master study that investigated office buildings in Copenhagen [6]. The classification of the buildings depends on the materials of the facade (or the parapet) and the distance between the columns in the facade. 44 office buildings in Copenhagen built 1960-1980 were analysed and classified as follows:

1. Medium heavy construction/ Concrete columns in the facade/ Light parapet of fibre cement panel, metal or wood, see Fig. 1 (a). Min and max U- value of the external wall are 1.40/2.20 (W/m^2K). Min and max combined U-value (wall and window) are 2.27/2.67 (W/m^2K). Number of buildings in this group is 9.
2. Medium heavy construction/ closely spaced columns in the facade/ mixed parapet materials see Fig. 1 (b). In this group the columns are closely spaced which will affect the window area and the daylight inside the rooms. Min and max U- value of the external wall are 1.76/2.20 (W/m^2K). Min and max combined U-value (wall and window) are 2.31/2.67 (W/m^2K). Number of buildings in this group is 5.
3. Medium heavy construction/ Concrete columns in the facade/ concrete parapet. Potentials for renovation can be good but more complicated. Min and max U- value of the external wall are 0.89/2.17 (W/m^2K). Min and max combined U-value (wall and window) are 2.02/2.66 (W/m^2K). Number of buildings is 7.
4. Medium heavy construction/ Concrete columns in the facade or detached/ concrete with facing brick. Min and max U- value of the external wall are 1.34/1.76 (W/m^2K). Min and max combined U-value (wall and window) are 2.24/2.45 (W/m^2K). Number of buildings in this group is 11.
5. Light construction/ columns detached from the facade/ fiber cement panel, metal or wood, see Fig. 1(c). The renovation is easier, since they are lighter than the facades on the buildings (compared to the other groups). Min and max U- value of the external wall are 0.61/0.62 (W/m^2K). Min and max combined U-value (wall and window) are 1.88/2.13 (W/m^2K). Number of buildings in this group is 4.

a **b** **c**

Figure 1 Building types: (a) building type 1, (b) building type 2, (c) building type 5.

Due to simplification, 8 of the 44 buildings are not included in the above mentioned groups. The U-value of the external walls is calculated according to DS 418 [7]. The properties of the materials and the window are according to building regulation 1961, 1966 and 1972 [8]. The U-value of windows in all the groups is 3.14 W/m^{2}K (two layers glazing with air in cavity). The insulation thickness of the outer wall is between 50-100 mm. Lambda value is 0.045, 0.042 and 0.039 W/mK [9].

5. The simulation of existing buildings

Three facade compositions were chosen to be simulated in the program IDA ICE. The facade type 1, the columns represents 20% of the facade area, windows 60% and parapet 20% of the facade area; see Fig. 2 (a). This facade has the highest weighted heat loss. This facade refers to buildings belong to type 1; see Fig 1(a). The facade type 2, the columns represents 30% of the facade area, window 30% and parapet 40% of the facade area; see Fig. 2 (b). This facade refers to buildings belong to type 2, see Fig 1 (b). The facade type 5 has no columns but only parapet and window, each is 50% of the facade area; see Fig. 2 (c). This facade refer to buildings belong to type 5; see Fig 1(c). U-value for columns is 1.71 W/m^{2}K, windows 3.14 W/m^{2}K and parapets 0.62 W/m^{2}K [10].

5.1. The simulation input data

According to the analyses made for different buildings in Copenhagen, a room with inner dimensions 5 x 4.5 x 3 m (L x W x H) is chosen for the simulation in IDA ICE program. The room has one external facade and adjacent rooms surrounding it. 4 occupants are in the room (activity level 1.2 met, occupancy 80%) [11], with 4 computers (40 W/pc). Total lighting power is 85 W with Luminous efficacy 80 lm/W. The mechanical ventilation system is CAV in the working hours with air flow 1.511 l/s m^2 and heat recovery 60% [10]. Heating set point is 20°C in the working hours and 16°C outside working hours. Natural ventilation is through 10% of the window area opened at 22°C and it is fully opened at 23°C (only between 1.April and 31.October). The infiltration is 0.45 l/s m^2 [10]. External shading devices, shading coefficient 0.09, solar gain factor 0.14. Window U-value is 3.14 W/m^2 K, LT_g 0.76 (light transmittance), g_g 0.75, U-value for frame 3.1 W/m^{2}K [10]. For heating is used district heating. Daylight factor (in the centre of the floor at a height of 0.85 m) for facade type (1, 2, 5) is (7%, 3.4 %, 7.4 %). The result of the simulation in IDA ICE for energy consumption for heating for the three facades can be seen in table 1.

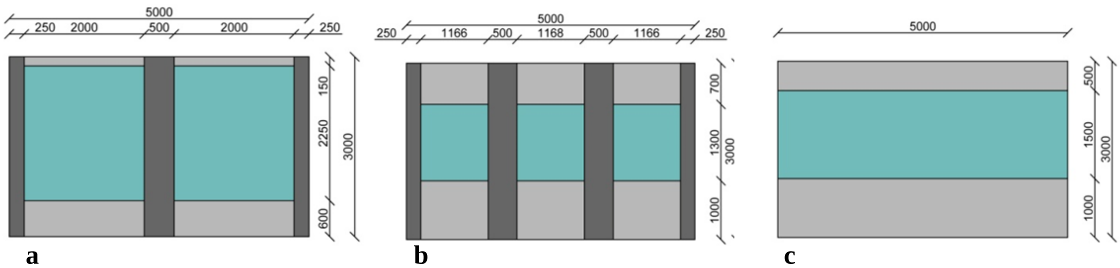

Figure 2 Facade types: (a) facade type 1, (b) facade type 2, (c) facade type 5.

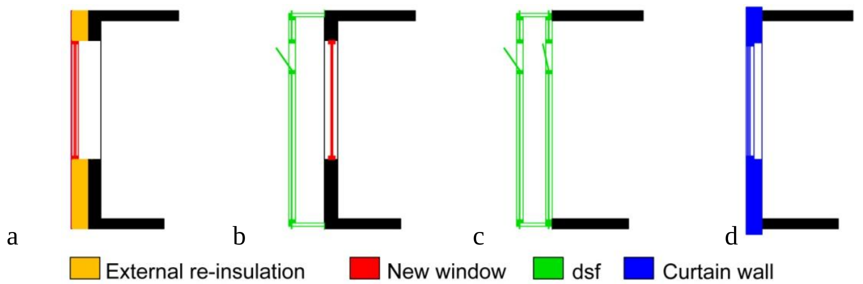

Figure 3The renovation strategies: (a) External re-insulation (b) Double-skin façade (the external part) (c) Double-skin façade (d) Curtain wall.

6. The renovation of existing buildings

6.1. The renovation strategies

Four strategies were chosen for renovating the three facade types See Fig 3. The chosen strategy depends on the construction of the facade and all the strategies include window replacement.

a. External re-insulation: Adding insulation on the external side of the wall to reduce the U value and thermal bridges. It has also less impact on users, different cladding possibilities, but possible space limitation
b. Double-skin façade (the external part only): This strategy can be used when it is necessary to preserve the original facade of the building.
c. Double-skin façade: This strategy can be used to a whole facade window to reduce the U value of the facade in the heating season and improve the indoor climate in the hot season. It is preferred not to have columns in the facade, which can cause some complexity when adding the components between the columns.
d. Curtain wall: This strategy can be used when both the window and the parapet are not energy efficient. It is easier to apply it when there are no columns in the facade (less joints and thermal bridges), which make the renovation faster and less disturbing for the occupant through the renovation process.

6.2. The simulations results for the renovation

Facade type 1

It is easier to apply strategies a and b on facade type 1, where there is no total replacement of the parapet. In case of applying strategies c and d, the placement of the columns will affect on the complexity of the renovation (more joints) and they are thermal bridges. The strategies c and d might cause disturbances for the occupants that need to vacate the room through the renovation. Of course there are exceptions when the parapet is damaged (leaning over, bowing, has extensive cracks, or is deteriorated on both sides). In this case the parapet might need to be replaced. By applying strategy a (External re-insulation), the following parameters are specified: The chosen window for the renovation is a three layers glass with argon ((U_g (W/m^2 K), g_g (%), U_f (W/m^2 K), LT_g (%)) (0,53 0,5 1,56 0,72)) [12]. A 0.245 m external insulation layer (λ= 0.036W/mK) [13], is added to the parapet and the columns to give an accepted and low U-value. The daylight factor is 5.9%. The U-value of the external wall is 0.125 W/m^2 K, which is lower than the max value 0.2 W/m^2 K [14]. An air change through leaks in the building envelope does not exceed 0.5 l / s per. m² heated floor area by pressure test with 50 Pa [15]. The rest of the parameters are the same as before the renovation.

By applying the strategy b, if it is necessary to preserve the original facade of the building, the following parameters are specified: The external leaf consists of one layer glazing ((U_g, g_g, U_f, LT_g) (5.6, 0.86, 1.56, 0.89)). The distance between this and the old facade is 0.5 m. The daylight factor is 6%. The cavity is naturally ventilated (depending on intensity of solar radiations in the facade) between April 1st and October 31st, (façade toward south and east), May 1st to September 31st (façade toward north) and sealed in the rest of the year (no air change). The windows of the old facade are renovated to a 3 layer glazing energy window ((U_g, g_g, U_f, LT_g)(0,53 0,5 1,56 0,72)) [12]. The delivered energy for the room after renovation with strategies a and b is shown in Table 1 and the number of overheating hours is shown in Table 2. Strategy (a) fulfil BR10 [14], but it doesn't with strategy (b).

Facade type 2

It is easier to apply strategies a and b on facade type 2, where there is no total replacement of the parapet. In case of applying the strategies c and d, the placement of the columns will affect the complexity of the renovation (more joints) and they are thermal bridges. This might also cause disturbances for the occupants that need to vacate the room during the renovation. By applying strategy a (External re-insulation), the following parameters are specified: The window properties, the insulation and the infiltration are the same as in facade type 1. The rest of the parameters are the same as before the renovation. A daylight simulation is made and the daylight factor is 2.4%.

By applying the strategy b (DSF, external part only) to preserve the original façade, the same technical data is used as in facade type 1. The daylight factor is 2.8 %. The delivered energy with strategies a and b is shown in Table 1, the number of overheating hours is shown in Table 2. Strategy a fulfil BR10 [14], but it doesn't with strategy b.

Facade type 5

It is easier to apply the strategies c and d when there are no bearing columns in the facade. This makes it easier and faster to remove the old facade especially when it is of light construction and add a new facade. The two strategies can be applied when both window and parapet`s energy efficiency is poor.

By applying strategy c (Double-skin facade), the following parameters are specified: The window area is 100% of the façade area in the internal and external leaf. The external leaf consists of one layer glazing ((U_g, g_g, U_f, LT_g) (5.6, 0.86, 1.56, 0.89)). The distance between this and the internal leaf is 0.5 m. The daylight factor is 9%. The cavity is naturally ventilated between March 1st and October 31st (façade toward south and east), June 1st and August 31st (façade toward north) and sealed in the rest of the year (no air change). The window of the inner leaf is 3 layer glazing energy window ((U_g, g_g, U_f, LT_g)(0,53 0,5 1,56 0,72)) [12]. The daylight factor is 9%.

By applying strategy d, a curtain wall is added to the facade. The chosen window for the renovation is a three layers glass with argon ((Ug, gg, U_f, LT_g)(0,53 0,5 1,56 0,72)) [12]. A 0.245 m insulation layer (0.036W/mK) [13] is used in the parapet. The U-value of the external wall is 0.142 W/m^2 K, which is lower than the max value 0.2 W/m^2 K [14]. The daylight factor is 7.2%. Regarding occupancy, internal heat load, electrical lighting, mechanical ventilation, heating and venting are as described in section 5.1. The delivered energy for the room with the facade type 5 after renovation with the strategies c and d is shown in Table 1 and the number of overheating hours is shown in Table 2. Strategy c doesn't fulfil BR10 [14], but it does with strategy d.

Table 1. The delivered energy for the room with the facade 1, 2 and 5. It is assumed that the energy consumption for lighting and HVAC Aux. in existing are the same as in after the renovation

	South			**North**			**East**		
	Façade type			**Façade type**			**Façade type**		
	1	**2**	**5**	**1**	**2**	**5**	**1**	**2**	**5**
Lighting (kWh/(m^2·year))/ strategy	1.6/a 1.3/b	3.6/a 1.8/b	0.9/c 1.8/d	1.9/a 5.5/b	3.8/a 8.2/b	3.5/c 2.2/d	1.8/a 2.2/b	3.6/a 2.8/b	1.8/c 2.1/d
HVAC Aux (fans & pumps). (kWh/(m^2·year))/ strategy	12.4/a 12.4/b	12.4/a 12.4/b	12.4/c 12.4/d	12.4/a 12.4/b	12.4/a 12.4/b	12.4/c 12.4/d	12.4/a 12.4/b	12.4/a 12.4/b	12.4/c 12.4/d
Heating (kWh/(m^2·year))/ strategy	22.6/a 35.5/b	20.6/a 41.7/b	27.9/c 21.6/d	30.1/a 50.5/b	23.2/a 57.5/b	44.4/c 28.0/d	28.1/a 47.4/b	24.1/a 53.8/b	39.2/c 26.3/d
Heating (kWh/(m^2·year))/ existing	136.0	108.0	125.0	149.0	119.0	137.0	146.0	116.0	134.0
Total (kWh/(m^2·year))/ strategy (According to BR10) [14]	57.6/a 69.7/b	60.6/a 77.2/b	69.7/c 57.1/d	65.8/a 95.2/b	63.7/a 109/b	84.1/c 64.5/d	63.6/a 83.9/b	64.1/a 91.8/b	74.7/c 62.5/d
Total (kWh/(m^2·year))/ Existing	171.9	149.5	162.1	184.5	158.2	173.7	182.0	156.8	171.4

Table 2. The number of overheating hours that exceed 26°C and 27°C in the working period for the room with the facade 1, 2 and 5

	South			**North**			**East**		
	Façade type			**Façade type**			**Façade type**		
	1	**2**	**5**	**1**	**2**	**5**	**1**	**2**	**5**
Working hours above 26°C / strategy	103/a 74/b	70/a 65/b	91/c 103/d	34/a 9/b	40/a 18/b	3/c 43/d	47/a 47/b	43/a 50/b	47/c 59/d
Working hours above 27°C/ strategy	30/a 35/b	25/a 38/b	39/c 34/d	11/a 2/b	15/a 6/b	0/c 18/d	17/a 23/b	21/a 28/b	25/c 27/d

7. Conclusion and Discussion

The result of the research will lead to provide an overview to the building-owners and decision makers for the potentials in the facade renovation of the office buildings. This will contribute to the reduction of energy consumption and the reduction of CO_2 emission according to the government energy policy.

According to the simulations, the saved energy after the renovation for facade type 1 is 65-67% of the energy consumption before the renovation for strategy a and 48-59% for strategy b (depending on the orientation). For facade type 2, the saved energy is 59-60% of the energy consumption before the renovation for strategy a and 31-48% for strategy b. For facade type 5, the saved energy is 52-57% of the energy consumption before renovation for strategy c and 63-65% for strategy d. The four strategies fulfil the criteria regarding the number of overheating hours (max 100 h above 26 °C, and 25 h above 27 °C/year). The renovation is only in the facades, the heating system is not renovated (extra heat losses). The ventilation system is CAV, which consumes more energy than VAV.

For the building facades that are similar to facade type 1 and 2, using strategy a will help to reduce the energy consumption for heating and the occupants don’t need to vacate the room through the renovation. If the daylight factor is lower than the limit (2%), so it is possible to use a window where the side walls of it are splayed to allow more light to enter the room. There are also different cladding possibilities for this strategy. Using strategy b will preserve the expression of the facade but the energy consumption is still high especially when the facade is oriented to the north. Of course there are exceptions when the parapet is damaged (leaning over, bowing, has extensive cracks, or is deteriorated on both sides). In this case it might need to be replaced. For the building facades that are similar to facade type 5, curtain wall can be an energy efficient solution when both the old window and the parapet are not energy efficient. The renovation can be faster than if curtain wall is used in facade type 1 and 2 (only one facade component), which is less disturbing for the occupants. If there is a wish for an architectural or acoustic reason to have a whole facade window, a double skin facade can be a solution to improve indoor climate.

The aim of the paper was to improve the energy efficiency of the buildings. There are also architectural aspects that need to be investigated due to the importance of the facade for the total expression of the building. The result of the renovation should fulfil both the technical criteria and the aesthetic values of the buildings.

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