ZEB Project report 26 – 2015

Birgit Risholt, Silje Asphaug, Jan Ove Busklein, Sivert Uvsløkk,
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Window with integrated solar collector. Climate resistance evaluation report

The Research Centre on
Zero Emission Buildings

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Window with integrated solar collector. Climate resistance evaluation report

Keywords:
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The research has also been a part of the EU 7th framework project Retrokit[1]. The final aim of RetroKit is to develop a retrofit toolbox integrating flexible prefabricated solutions with integrated heat/vent/renewable energy technology to upgrade the building and its envelope. The Italian consultancy company D'Appolonia is coordinator of the Retrokit project, and SINTEF is one of the 19 partners. Husbanken is a member of the advisory group for the project.

[1] http://www.retrokitproject.eu

Abstract

The NorDan solar collector is a window/solar collector combination which can be mounted as a traditional window in the façade of a new building. The component is originally designed for new buildings, but the research and experiments carried out in Retrokit[2] focus on developing solutions for retrofitting.

Air- and rain tightness tests have been carried out at SINTEF Byggforsk`s Laboratory facilities in Høgskoleringen 7B in Trondheim. The U-value of a wall element with a solar collector for retrofitting has been calculated. A laboratory experiment of the moisture performance was carried out to investigate constructional details of the building integration and how the building integration can be solved without the risk of moisture condensation and mould growth behind the solar collector.

Laboratory experiments and U-value calculations verify that the NorDan solar collector function as designed. The NorDan solar collector is air- and rain tight and can replace the exterior cladding of new and existing buildings as a fully building integrated element for solar thermal energy production.

[2] RetroKit - Toolboxes for systemic retrofitting. (http://www.retrokitproject.eu/)

Content

1. Introduction

1.1 Background

The window/solar collector component (further referred to as NorDan solar collector) is a result of a cooperation between the two Norwegian companies NorDan (window manufacturer) and Aventa (solar collector manufacturer). The idea of combining a window and a solar collector appeared during work with ZEB while identifying the need for active façade elements for renewable energy production. The component is originally designed for new buildings, but the research and experiments carried out in Retrokit[3] focus on developing solutions for retrofitting of buildings.

1.2 Building integration and climate resistance verification

When integrated in both new and existing buildings, the NorDan solar collector replaces the cladding. This is both favorable for the architectural expression and for limited use of materials compared to traditional façade mounted solar collectors.

Because the NorDan solar collector replaces the cladding the component needs to be both air and rain tight. The collector also replaces the wind barrier and it is therefore important that the component allows built-in moisture to dry out in order to reduce the risk of moisture condensation and mould growth inside the wall. The U-value of a wall with NorDan solar collector should be calculated to verify the thermal properties of a wall element with a solar collector.

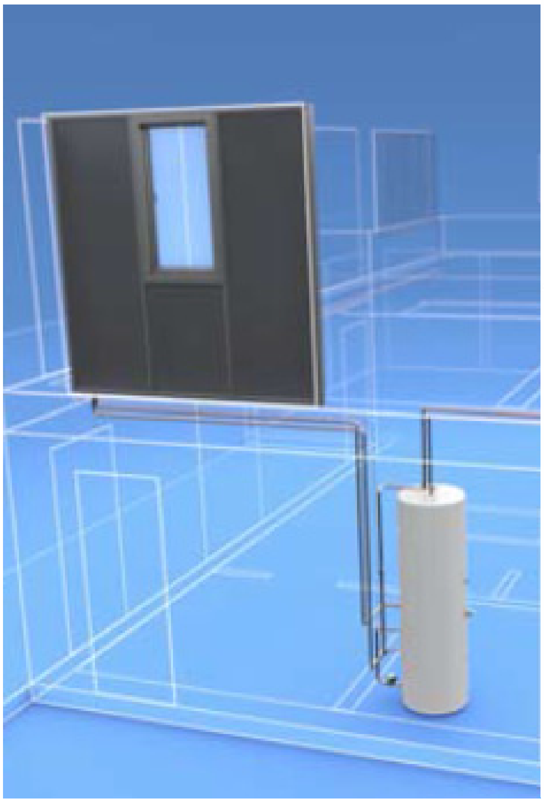
Air- and rain tightness tests have been carried out at SINTEF Byggforsk`s Laboratory facilities in Høgskoleringen 7B in Trondheim. Calculation of the U-value for a wall element with an integrated solar collector designed for retrofitting is carried out. To ensure good moisture performance, a laboratory experiment has been performed on a NorDan solar collector prefabricated element suitable for retrofitting. The purpose of the experiment was to investigate constructional details of the building integration and how the building integration can be solved without the risk of moisture condensation and mould growth inside the wall.

[3] RetroKit - Toolboxes for systemic retrofitting. (http://www.retrokitproject.eu/)

2. Product information

2.1 NorDan solar collector

The NorDan solar collector is a window/solar collector combination which can be mounted as a traditional window in the façade of a new building. In a retrofitting project, the preferred solution would be to integrate the element in an add-on construction allowing the pipes to be mounted on the outside of the existing wall. The window frame is a standard NorDan NTech window frame manufactured by NorDan[4]. The solar collector is manufactured by the company Aventa Solar[5] and is integrated in a fixed frame part of the window. This chapter gives a detailed description of the different components of the system as well as descriptions of the window/solar collector as a retrofit system.



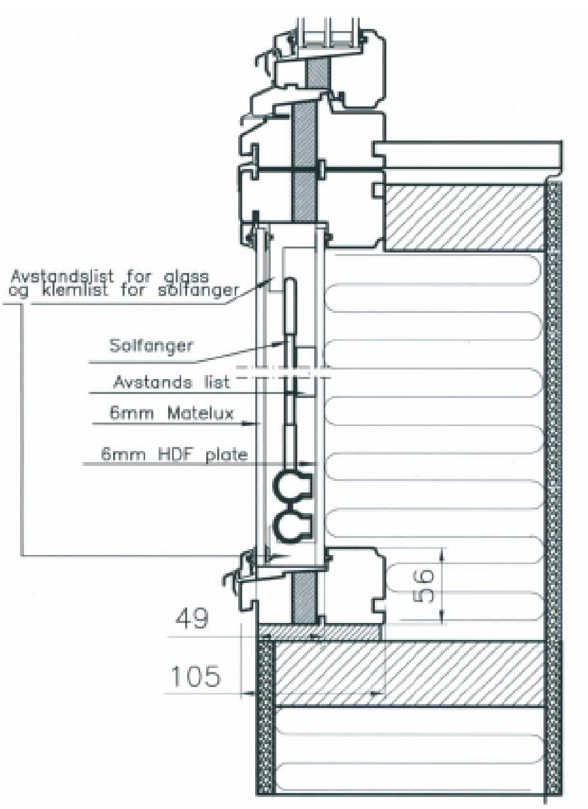


Figure 1 NorDan solar collector mounted as a traditional window in the façade of a new building (left). The window makes the frame for the component and the solar collector is integrated in the fixed frame part of the window (right).

2.2 NorDan NTech window

The frame is made of laminated wood (pine) where one of the lamellas is replaced with polyurethane (PUR) foam. The window and the frame are shown in figure 2. The PUR is a thermal barrier and the window has a U-value fit for passive house construction. The window is designed to meet the tough climatic loads of a wet, windy and cold Norwegian climate. Further documentation on technical properties of the window, including mounting instructions, maintenance instructions, detailed drawings and documentation of environmental properties, can be found on www.nordan.no.

[4] (www.nordan.no)

[5] (www.aventa.no)

Figure 2 Standard Nordan NTech window. The frame is made of laminated wood (pine) and insulated with polyurethane (PUR) foam (www.nordan.no).

2.3 AventaSolar solar collector

The solar collector is a flat collector for vertical mounting. The solar collector is shown in figure 3. The collector is constructed using polymer materials in all components. Water is used as the circulation liquid to absorb and distribute heat. The absorber is made of a polyphenylene sulphide extruded twin wall sheet. The absorber pipes are made of polytetrafluoroethylene and have a diameter of 8 mm.

The solar collector manufacturer Aventa declares that the systems absorptance is 0.94 and the emittance is 0.76 for a 2.9 m^2 solar collector (brutto area) with a heat carrier volume of 3.3 l/m^2.

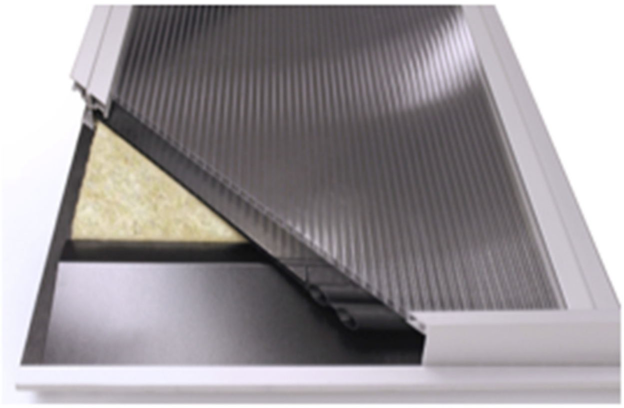


Figure 3 AventaSolar solar collector (www.aventa.no).

2.4 Window/solar collector system

The system consist of a wooden window, an integrated solar collector and boiler, plumbing connecting devices (pipes) and a water storage tank, as illustrated in figure 4. NorDan offers this complete system delivery with components adapted for flexible mounting.

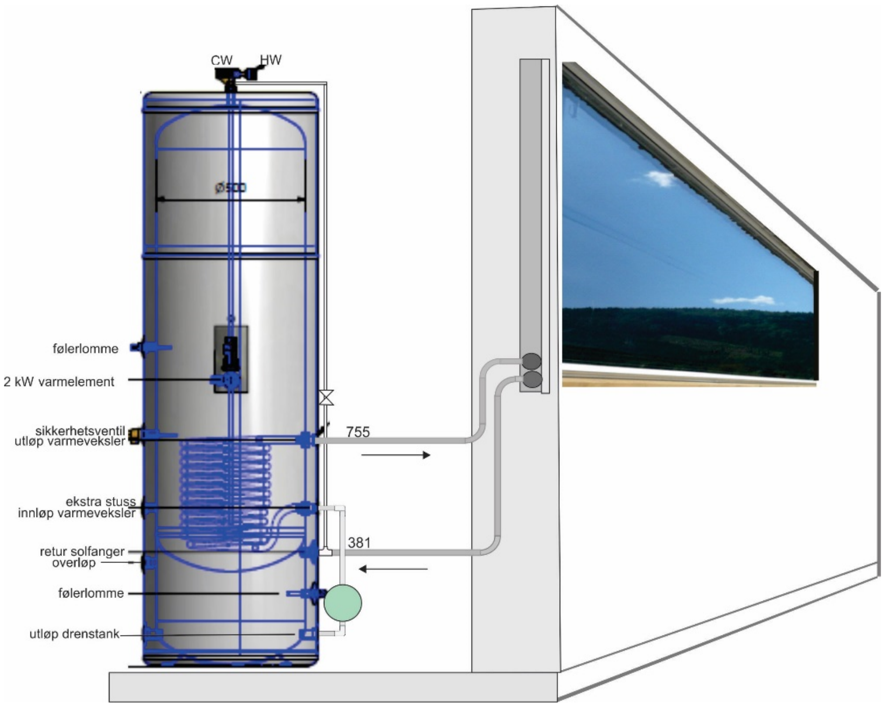


Figure 4 Schematic overview of the window solar collector system consisting of the window with solar collector (grey), pipes, circulation pump and storage tank.

2.5 Building integration in the facade

The NorDan solar collector can be mounted as a traditional window in the façade of a new building. In a retrofitting project, the preferred solution would be to integrate the element in an add-on construction allowing the pipes to be mounted on the outside of the existing wall. When integrated in both new and existing buildings, the NorDan solar collector component replaces the cladding. It is therefore important that the component is both air and rain tight.

When mounting the NorDan solar collector on existing building envelopes in multi-family buildings, it will be a necessity to have an effective way of implementing the façade solution. By having a good way to mount the façade solution, the families living in the buildings get minimum exposure to the effects off living on a construction site (noise levels, dust exposure, etc.).

2.6 Energy harvesting performance

The Nordan solar collector system generates approximately 300 kWh/m^2 per year when installed in a building in Norway[6]. A solar collector of 6-8 m^2 can generate 50-70 % of the energy required to heat domestic hot water for a family.

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[6] E-mail from Nordan 18.05.15, John Olav Rasmussen

3. Tests and calculation methods

3.1 Air tightness

An air permeability test was performed on a NorDan solar collector with frame dimensions 0.76x2.088 m. The air permeability test was performed in SINTEF Byggforsk`s air permeability chamber in accordance with NS-EN 1026:2000, applying external static positive and negative pressure differences across the test section, the pressure differences over the two sides of the test specimen are up to 600 Pascal, for both positive and negative pressure. Results from the air permeability test are calculated and adjusted with the air leakage of the test chamber. Air leakage is reported in m^3/m^2h for the overall window area and in m^3/mh for the length of the opening joints. The window area is calculated based on the outer dimensions of the window frame; joint length is calculated from the outer dimensions of the window sash.

3.2 Rain tightness

A water tightness test was performed on a NorDan solar collector with frame dimensions 0.76x2.088 m. The water tightness test was performed in SINTEF Byggforsk`s water tightness chamber in accordance with EN 1027:2000. During the testing, water is sprayed on the test specimen by a row of nozzles horizontally spaced at 400 mm. Each nozzle delivers 2.0 l/min. The nozzle angle is set at 24° so that the top joint is exposed to the water spray. After an initial period of 15 minutes of applied water, the air pressure difference is increased in 8 steps up to a maximum positive static pressure of 600 Pascal on the external side of the test specimen. Each pressure step lasts 5 minutes. Leakages are detected by observation of the internal side of the specimen during testing.

3.3 Thermal insulation, U-values

U-values have been calculated for the NorDan solar collector. U-values (U_f) and linear edge heat loss coefficients (ψ_g) for the frames have been calculated alongside the U-value for the whole solar collector (U_{sc}). The calculations were carried out for a solar collector with dimensions 0.76 m x 2.088 m (width x height) according to NS-EN ISO 10077-2:2007, using the two-dimensional finite element program THERM[7]. The numerical models, as drawn in THERM, are shown in Figure 5. The total depth of the unit, including the underlying insulation layer, is 149 mm. Input values and material parameters used for the calculation are given in tables 1 and 2. The calculated U-value of the solar collector (U_{sc}) is also compared to an uninterrupted layer of insulation with the same total thickness (d = 149 mm) to show how the U-value relates to a wall without a solar collector.

[7] THERM version 7.2.9.0. Available at: http://windows.lbl.gov/software/therm/therm.html

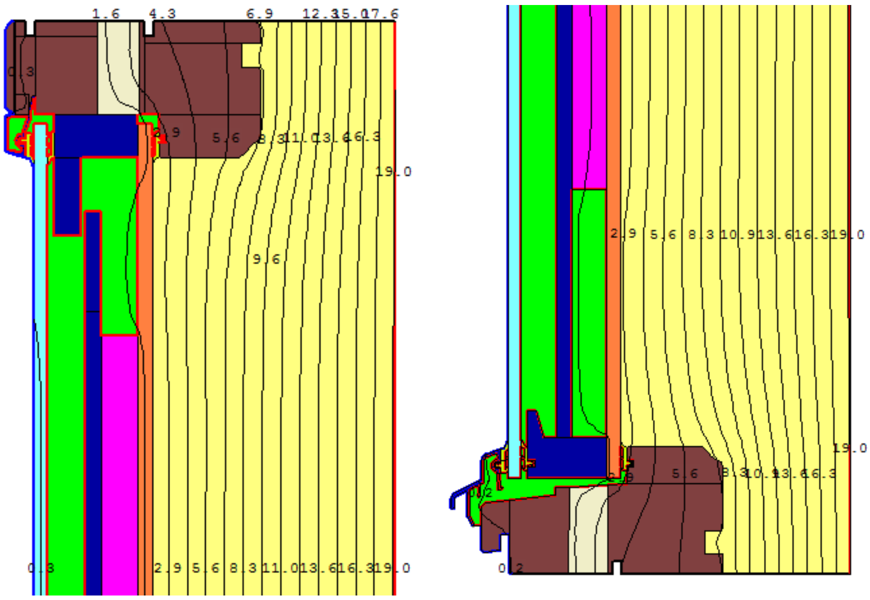

Figure 5 Top- and side frames of the solar collector façade (left) and bottom frame (right) modelled in Therm for U-value calculations.

Table 1. Dimensions of the solar collector and the underlying insulation layer.

Solar collector exterior dimensions - Width - Height	 760 mm 2088 mm
Frame profile depth (including underlying insulation layer)	149 mm
Frame width (top, side and bottom)	56 mm

Table 2. Input values used in the U-value calculations.

Component	Material (thickness)	Thermal conductivity
Frame	Wood PUR-foam	λ = 0.12 W/(mK) λ = 0.024 W/(mK)
Glass flashings	Aluminum alloy	λ = 160 W/(mK)
Gaskets	EPDM	λ = 0.25 W/(mK)
Fiberboard behind the spacer	6 mm HDF	λ = 0.10 W/(mK)
Solar collector tubes	Aluminum alloy	λ = 160 W/(mK)
Solar collector spacer bar	Polymer	λ = 0.36 W/(mK)
Insulation behind collector tubes	Mineral wool	λ = 0.037 W/(mK)

3.4 Moisture performance

A climate exposure test was performed on a NorDan solar collector suitable for retrofitting. The test is performed to investigate the risk of moisture condensation and mould growth behind the solar collector. The tested element is an add-on retrofit, suitable for mounting on the outside of an existing wall, see figure 6. The test was performed in SINTEF Byggforsk`s climate simulator. Equipment information for the climate simulator is given in appendix 1.

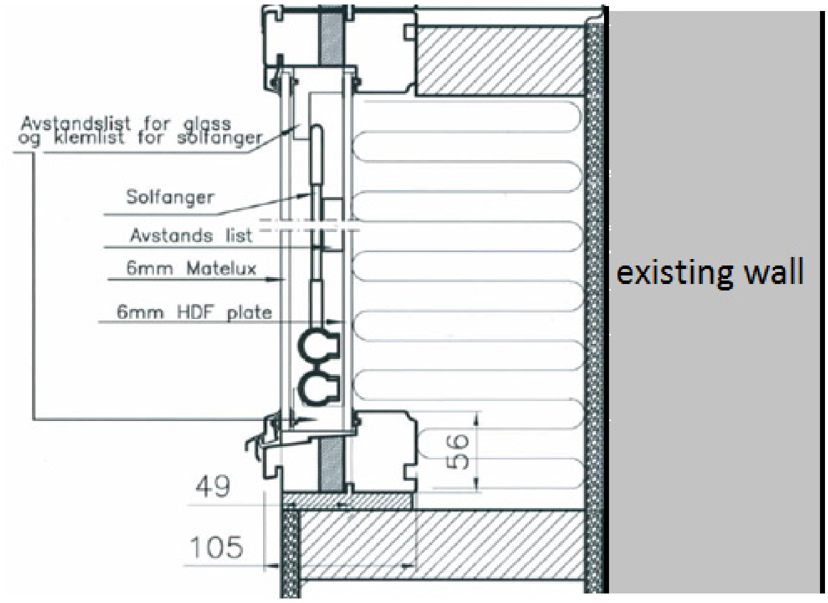

Figure 6 Add-on retrofit where a NorDan solar collector element is mounted on the outside of the existing wall.

Note that thermal insulation is mounted directly behind the collector and there is no air gap or ventilated cavity behind the solar collector element. This building integration of the window/solar thermal collector gives challenges related to building physics. Especially in cold climates there is a risk of condensation of moisture on the pipes supplying liquid to the solar collector as well as on the back of the solar collector element in the winter season. Such condensation can be critical regarding rot decay and mould growth for timber parts and thermal insulation in the wall. The experimental work has therefore focused on the building physics of the building integration with focus on risk for condensation of moisture on the pipes and the back of the element and also how moisture can dry out and be ventilated to prevent mould growth.

The NorDan solar collector is installed in a wood frame wall section (3.6x3.9 m) the same way as a traditional window. The back plate of the solar collector is instrumented so that it is possible to monitor the relative humidity (RH), temperature and condensation (figure 7). A schematic overview of the instrumentation is shown in figure 8. In addition, the moisture in the stanchions beside the solar collector is monitored at the top and bottom of the cold and warm side of the stanchions. The RH, temperature and condensation is logged while the wood moisture is measured manually. The casement is filled with mineral wool insulation before a vapor barrier and a wooden plate sealed the opening towards the indoor side.

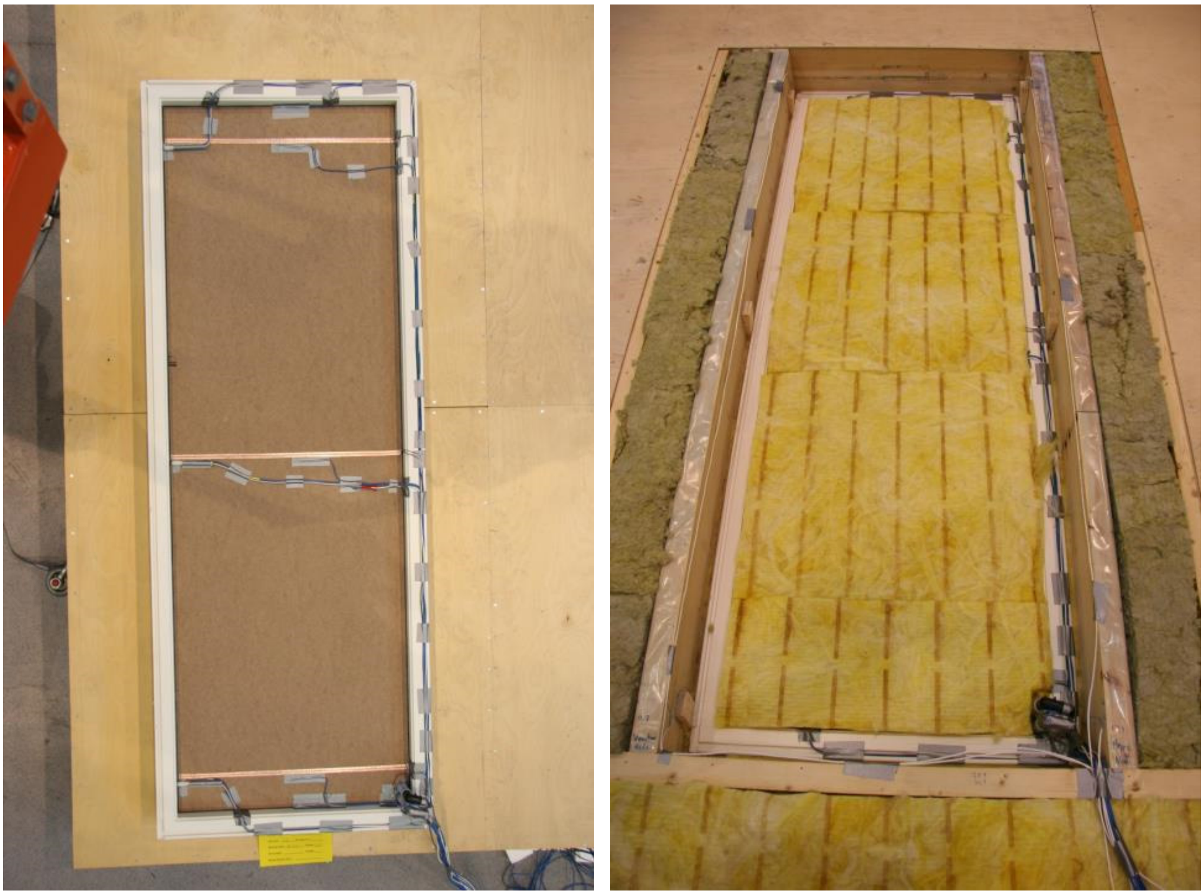

Figure 7 Instrumented interior side of the solar collector (left) and frame filled with mineral wool (right).

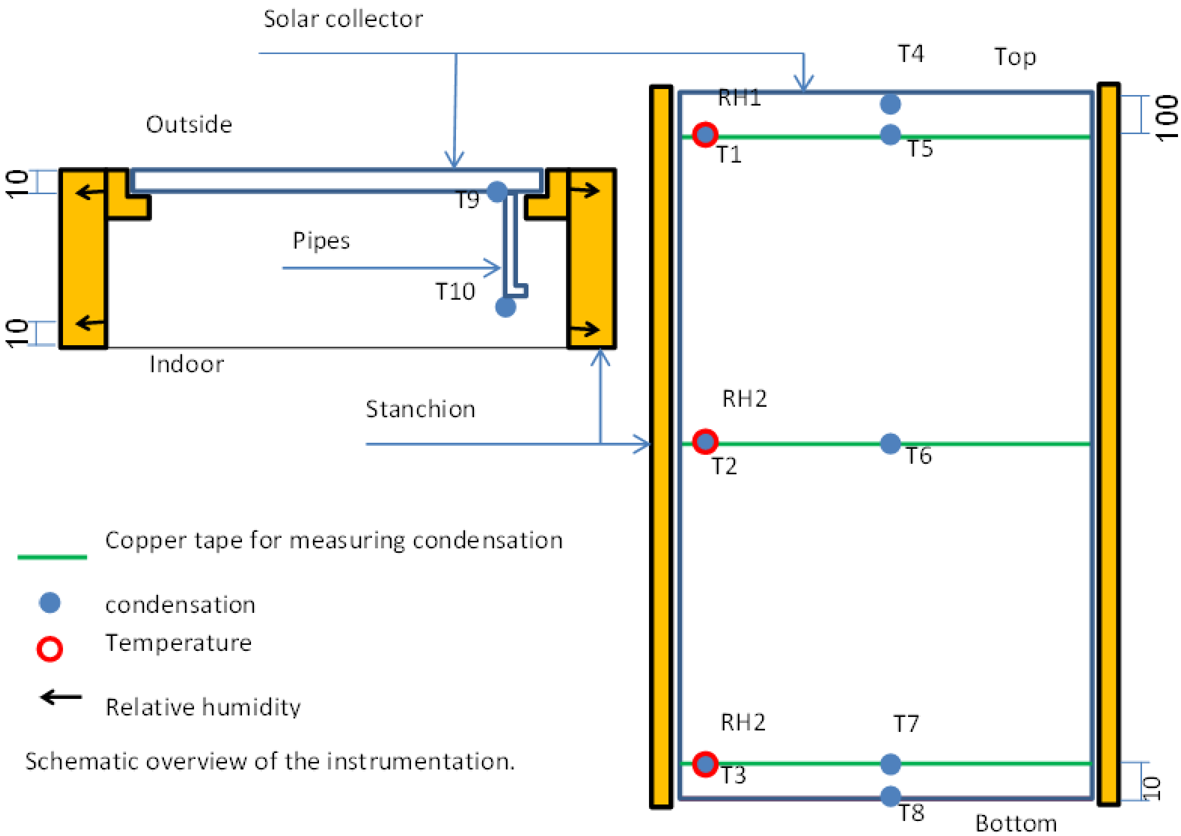

Figure 8 Schematic overview of the instrumentation.

Before the stanchions on each side of the solar collector were mounted into the wall they were moistened until they had 20 weight percent water contents so that they would act as a source for moisture to obtain high air humidity behind the solar collector. Such moisture contents in the wood frame components are typical values for wood parts after the construction period. On the sides facing away from the solar collector the stanchions were covered with a vapor barrier. The moisture has to evaporate through the solar collector.

The wall section model was then placed inside the ZEB laboratory climate simulator, see table below, to simulate typical Norwegian autumn and winter conditions. The climate simulator was used because the experiment was carried out in the spring. The research plan required winter temperatures to check the risk for moisture condensation.

The indoor temperature was held constant at 20 °C and 40 % RH during the whole test while the outdoor temperature was held constant in seven days intervals starting at 10 °C to set a stable moisture level in the construction parts before the winter exposure started. After seven days the outdoor temperature was reduced to 0 °C and after another seven days to -10 °C to see if any condensation occurred behind the solar collector. Then the temperature was raised to 5 °C, and at the end the temperature was raised to 10 °C to see whether the moisture dried out. An RH level below 80 % after the drying out period means that the risk for mould growth is low, even in a wood frame construction.

4. Results

4.1 Air tightness

The test period lasted from October 2014 to April 2015. The results from the air tightness test show that the air permeability of the NorDan solar collector fulfils class 4 according to EN 12210. Detailed results are given in appendix 2.

4.2 Rain tightness

The test period lasted from October 2014 to April 2015. No leakages were detected during the rain tightness tests. The element fulfils class 9A according to EN 12111. Details are given in appendix 3.

4.3 U-value

Results from the U-value calculations are shown in Table 3.

Table 3. Calculated U-values and linear edge losses of the frame profiles and U-value of the solar collector unit.

Description	U-value frame (W/(m²K))	Linear edge loss (W/(mK))	U-value solar collector (W/(m²K))
Head and jambs	0.3335	0.0054	0.3392
Sill	0.3424	0.0000	

The calculated U-value of the solar collector is 42 % higher than an uninterrupted insulation layer (of mineral wool with thermal conductivity, λ = 0.037 W/(mK)), which has a theoretical U-value = 0.234 W/(m²K). The percentage will be lower for walls with thicker insulation. The higher U-value will only be valid for the solar collector area of the facade, typically 6 – 8 m^2 for dwellings, constituting a small fraction of the total facade area.

4.4 Moisture performance

The demonstration activity started in January 2015, and continued until the end of April 2015. The test chamber simulating indoor conditions held a constant temperature of 20 °C and RF of 40 % during the whole climate exposure. In the climate chamber the outdoor temperature was held constant at different levels for given periods. Table 3 shows the results from the climate exposure of the NorDan solar collector. The same data is also presented in the diagram in figure 9. The exposure lasted 77 days. The indoor temperature was kept at 20 °C, while the outdoor temperature varied to simulate winter conditions the first 21 days followed by spring temperatures of 5 – 10 °C the rest of the exposure period.

Table 1 Temperature, relative humidity, condensation measurements, resulting wood moisture and change in wood moisture. The wood moisture is calculated as the average of three sensors. The wood moisture measurements were done close to both the inward and outward facing surface of the stanchions.

Measurements	Days after start														
	1	7	8	14	15	21	22	28	35	36	43	56	62	72	77
T indoor [°C]	19.8	19.6	19.6	19.7	19.6	19.6	19.8	19.8	19.8	20	20	20.3	20	20.2	20.1
T outdoor [°C]	10	9.9	-0.2	-0.2	-10.4	-10.4	5.4	5.3	5.3	10	10	10	10	10.2	10.1
Average RF behind solar collector [%]	66	76	87	89	94	93	98.2	83	84	81	81	80	81	81	80
Average wood moisture in the stanchions, inward facing side [%]	36	25.7	25.7	20.6	19.9	16.8	16.4	15.6	14.2	14.2	16.2	13.8	12.9	11.4	10.8
Average wood moisture in the stanchions, outward facing side [%]	48.4	43.7	47.3	41.8	32.8	30.1	44.4	45.8	45.4	45.4	46.5	36.3	35.2	30.9	29.1
Average condensation	9.1	11.3	-	17.8	20.8	20.7	57.2	16.1	15.8	-	17.7	13.2	13.2	13.1	13
Change in average wood moisture, inward facing side [%]		-28.5		-20.1		-22.5		-7.4		-8.7	-14.1	-14.6	-6.9	-11.3	-5.5
Change in average wood moisture, outward facing side [%]		-9.7		-4.2		-39.1		52.4		-0.8	2.3	-21.8	-3.2	-12.2	-5.7

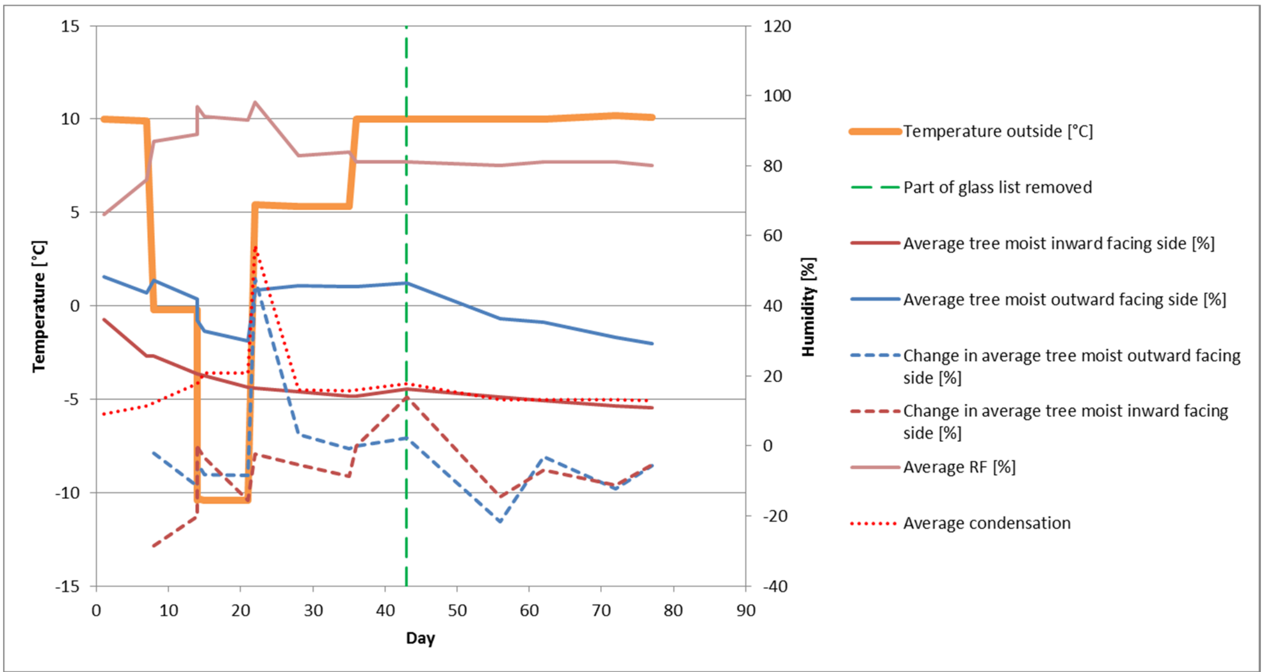

Figure 9 Temperature, relative humidity and wood moisture for the climate exposure of the NorDan solar collector.

A general comment regarding the wood moisture is that because the stanchions contain most water close to the surface and less towards the middle of the stanchion, the measured water content in the stanchions is higher than the 20 weight percent obtained by weighing. This is because the method used for measuring the moisture in the wood reports the wettest condition. When the test was finished, samples of the stanchions were taken where the wood moisture was measured. These samples were weighed and then dried to constant mass to find the moisture content. The measured values have been used to normalize the logged values from the exposure. Table 10 and figure 9 present corrected values.

The blue dotted line shows the change in wood moisture on the outward facing surface. In the initial seven days the measured water content in the stanchions are dropping (blue and red continuous line) while the measured RH in the same period is rising, indicating that the water in the stanchions vaporize and diffuses into the void behind the solar collector. The RH increases from 76 % till 89 % when the outdoor temperature is lowered from 10 °C till 0 °C and then to 94 % when the outdoor temperature is lowered to -10 °C. This process continues for the first 21 days of the experiment.

At day 21, when the temperature was raised from -10 °C to 5 °C, the wood moisture increases rapidly. The reason for this is that ice on the cold side melts and results in water formation on the outside surface, something which again results in increased wood moisture.

The outdoor temperature was held at 5 °C for 1 week, and afterwards the temperature was raised to 10 °C. The blue and red dotted lines show that this did not result in any drying out process of the wood moisture. It was then decided to increase the ventilation of the cavity surrounding the solar collector pipes. 5 cm of the glazing gasket on the top in both sides were removed at day 42 (figure 10).

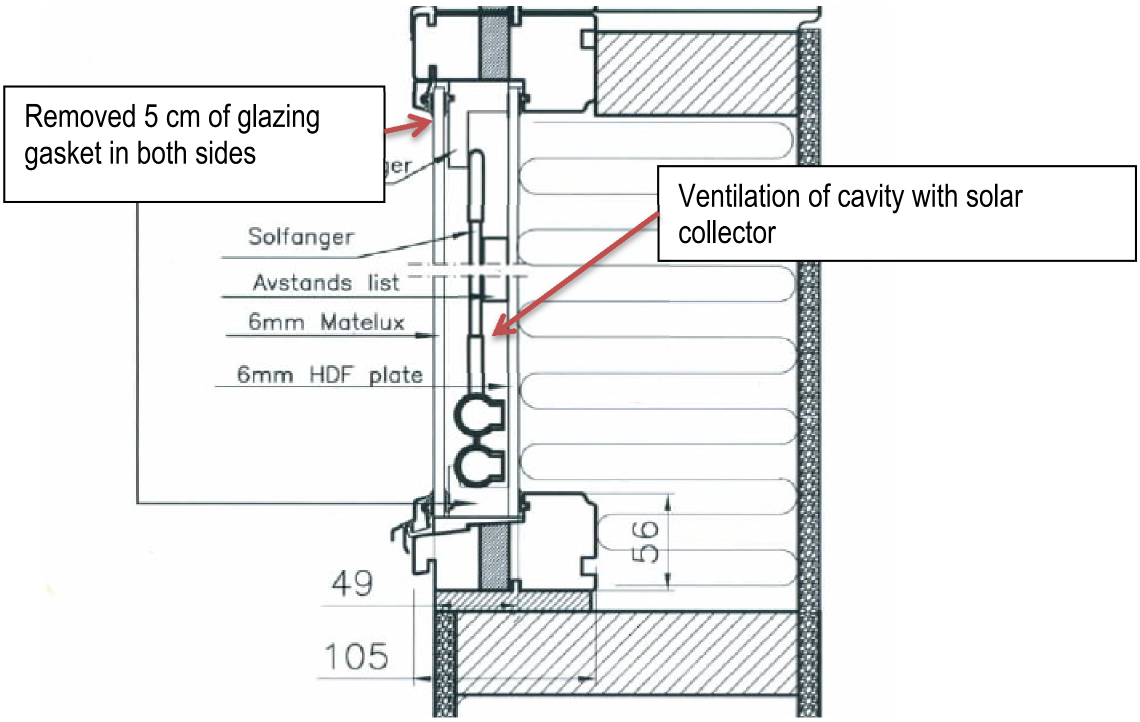

Figure 10 Ventilation of the cavity between the outside glass and the HDF plate by removing outside glazing gaskets.

By ventilating the cavity with the solar collector, moisture that is transported through the HDF board is allowed to dry out towards the outside. The action to increase the ventilation resulted in a rapid decrease in the wood moisture, and the moisture level continued to decrease until the exposure ended at day 77.

The climate exposure test show that the NorDan solar collector may be integrated with thermal insulation on the inward facing side of the collector without any air gap between the element and the insulation. However, this requires that the HDF board is permeable to moisture and that the solar collector cavity is ventilated to allow moisture to dry out toward the outside.

5. Discussion and conclusion

The NorDan window solar element is a prefabricated element for wall retrofitting. The element replaces the outer cladding of the wall. Laboratory testing, numerical simulations and a large scale climate exposure test have shown that the window solar element satisfies requirements regarding:

- Air permeability. The element fulfils class 4 according to EN 12210
- Water resistance. The element fulfils class 9A according to EN 12111.
- Moisture. Possible moisture inside the wall construction can be ventilated out though the solar collector. This requires that the HDF board is permeable to moisture and that the solar collector cavity is ventilated to allow moisture to dry out toward the outside.
- The U-value of a 150 mm thick wall element insulated with mineral wool and a solar collector has been calculated to 0,339 W/m²K, which is 42 % higher than an uninterrupted insulation layer with the same thickness. The percentage will be lower for walls with thicker insulation. The higher U-value will only be valid for the solar collector area of the facade, typically 6 – 8 m^2 for dwellings, constituting a small fraction of the total facade area.
- Energy performance. A solar collector of 8 m² system generates approximately 2400 kWh per year when installed in a building in Norway.

APPENDICES

Appendix 1

Equipment information for the climate simulator at SINTEF Byggforsk			
Equipment	Climate simulator	Partner laboratory	SINTEF
Area of application			
Climate exposure testing of vertical building envelope elements with dimensions up to height x width 3.9 x 3.6 m and thicknesses from 100 – 800 mm. The wall element is positioned between two climate chambers. The outdoor climate chamber can include temperature exposure, water spraying, UV and solar radiation. The climate can be cycled dynamically. The climate on the interior side can include temperature and humidity variations Area of application is climate exposure testing of exterior walls and elements including testing of walls with integrated technologies as photovoltaics and ventilation ducts.			
Photograph			
			
Potential and accuracies			
Outdoor chamber:		*Indoor chamber:*	
Temperature:-28/+80^{o}C, ± 0.3^{o}C		Temperature: +5/+50^{o}C, ± 0.3^{o}C	
Relative humidity: 20 – 95%, ± 3 % (no solar radiation) 20 – 50%, ± 3 % (with solar radiation)		Relative humidity: 20 – 95%, ± 3 %	
Radiation UVB 280- 320 nm, UVA 320 – 400 nm VIS 400 – 800 nm, NIR 800-3000 nm Irradiation 1000 W/m^2			
Water spray 10 – 100 dm^3/(m^{2}h)			
Validated for measurements according to the following norms			
NA			

SINTEF

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Air Permeability test

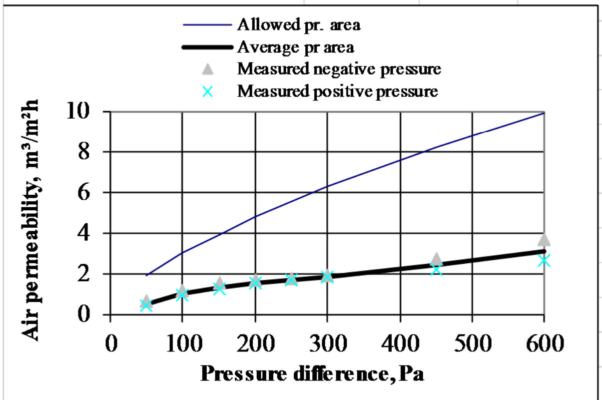
Test method standard: NS-EN 1026

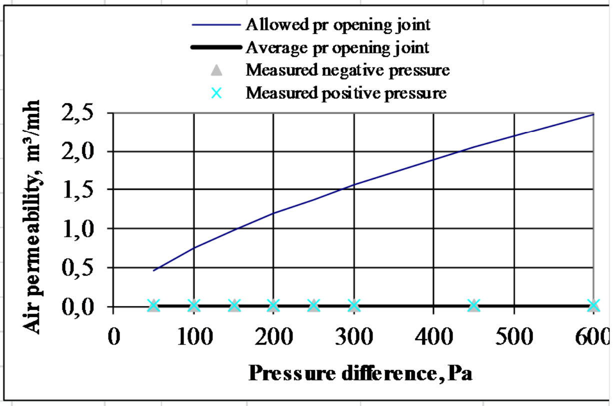
Classification standard: NS-EN 12207

Air permeability testing by:	OEH	Project number	102000684-1
Product	Solar collector	Test date	2015-01-12
Producer	NorDan	frame width, m	0,76
Arrival number / date	276-14 // xxxx	frame height, m	2,088
Ambient temperature at testing:	19	casement width, m	0
Atmospheric pressure at testing:	101	casement height, m	0
Relative humidity in %	18	Nr. of casements	0
Area, m²	1,59	Length of opening joint, m	0,00

Measured air leakage according to NS-EN 1026 and allowed values for class 4 according to NS-EN 12207

Pressure difference	Pa	50	100	150	200	250	300	450	600
Allowed pr. area	m³/m²h	1,9	3,0	3,9	4,8	5,5	6,2	8,2	9,9
Measured negative pressure	m³/m²h	0,6	1,1	1,5	1,6	1,7	1,9	2,7	3,6
Measured positive pressure	m³/m²h	0,4	0,9	1,2	1,4	1,6	1,7	2,2	2,6
Average pr area	m³/m²h	*0,5*	*1,0*	*1,3*	*1,5*	*1,7*	*1,8*	*2,4*	*3,1*
Allowed pr opening joint	m³/mh	0,5	0,8	1,0	1,2	1,4	1,6	2,0	2,5
Measured negative pressure	m³/mh	NA	NA	NA	NA	NA	NA	NA	NA
Measured positive pressure	m³/mh	NA	NA	NA	NA	NA	NA	NA	NA
Average pr opening joint	m³/mh	NA	NA	NA	NA	NA	NA	NA	NA





Appendix 3

SINTEF

Høgskoleringen 7, N- 7491 Trondheim
Phone + 47 73593390

Test report rain tightness

Test object:

Product: Window with solar collector			*Arrival no./date* 276-14 // xxxx
Type: Fixed frame window			*Drawing:*
Manufacturer: NorDan AS			*Dimension (mm x mm)* 760 x 2088
Joint width between sash and frame on exterior side)			*Material:* Pine/spruce in frame
	Minimum (mm)	*Maximum (mm)*	
Top *Bottom* *Hinge side* *Lock side*			*Surface treatment:* *Painted* *Functioning prior to testing:* Good

Testing:

Testing done at: SINTEF's laboratory in Trondheim	*Storage conditions:* 20 ºC and 50 %RF		
Test method: NS-EN 1027 Method A: X Method B: .	*Test climate:*		
	Humidity: Temperature: Air pressure:		% °C Pa
Date of testing: 12.01.2015	*Deviation from test method:* None		

Results:

NS-EN 1027 Method A

Overpressure [Pa]	Time [min]	Observations of leakages during testing according to NS-EN 1027 NS-EN 1027
0	15	No leakages observed
50	5	No leakages observed
100	5	No leakages observed
150	5	No leakages observed
200	5	No leakages observed
250	5	No leakages observed
300	5	No leakages observed
450	5	No leakages observed
600	5	No leakages observed

By the reference to the product's left or right side in the table, the definition is as seen towards the product's interior side.

The Research Centre on Zero emission Buildings (ZEB)

The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre will encompass both residential and commercial buildings, as well as public buildings.

NTNU – Trondheim
Norwegian University of Science and Technology

SINTEF

ZEB The Research Centre on Zero Emission Buildings

FME Forskningssenter for miljøvennlig energi

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www.snoarc.no

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Statsbygg
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Husbanken
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Byggenæringens Landsforening
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Norsk Teknologi
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Direktoratet for byggkvalitet
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