

Study on critical places for maximum temperature rise on unexposed surface of curtain wall test specimens

Paweł Sulik, Bartłomiej Sędkak and Jacek Kinowski

Fire Research Department of Building Research Institute, Ksawerów 21, 02-656 Warsaw, Poland

Abstract. The paper discusses the main issues related to the fire resistance of glazed curtain walls including the tests methodology and way of classification of this type of building elements. Moreover, the paper presents an attempt to determine the weak points of aluminium glazed curtain wall test specimens regarding to the maximum temperature rise measurements, based on the fire resistance tests performed in recent years by Fire Research Department of Building Research Institute. The paper analyse the results of temperature rise on unexposed surface of 17 aluminium glazed curtain wall specimens tested for internal fire exposure in accordance with EN 1364-3:2006 [3] and EN 1364-3:2014 [4], which achieved the fire resistance class of min. EI 15.

1. INTRODUCTION

Curtain wall is a type of wall which usually consists of vertical and horizontal structural members, connected together and fixed to the floor supporting structure of the building to form a lightweight space enclosing continuous skin, which provides, by itself or in conjunction with the building construction all the normal functions of the external wall but doesn't take on any of the loadbearing characteristics of the building.

In case of buildings for a specific purpose, (e.g. hotels, schools, hospitals, malls) or those with significant height [31] non-loadbearing elements of building, such as curtain walls should be designed and constructed in a way that in case of fire it will limit the spread of fire inside the building, ensure the safety of rescue team and allow the evacuation of users. Those specific requirements are not usually considered individually (e.g. ensuring proper evacuation is connected with the structural load bearing capacity as well as fire and smoke propagation within the building), therefore individual elements of buildings can play several roles during a fire.

This refers also to the curtain walls which are usually required in terms of design and execution to ensure that in case of fire they shall for a specific period of time prevent its development between the adjacent floors of the building, between the adjacent objects, and in a specific situations also between the adjacent rooms in the building (connection of the curtain wall with inner wall of the building). Moreover, the fixing of the curtain walls shall be made in a way that prevents falling of the parts of element during the rescue team activities and evacuation of the users [8, 11, 27, 30].

e-mail: p.sulik@itb.pl, b.sedlak@itb.pl, j.kinowski@itb.pl

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Glazed curtain walls with a specific fire resistance class are usually made as mullion – transom structures in which the areas between the aluminium or steel profiles are filled with fire resistant glass units. The loadbearing members in those structures are mullions, typically in the form of box section profiles (commonly with additional reinforcement – steel or aluminium stiffening profiles). *In order to improve thermal insulation, the profiles are also filled with special insulating inserts. Material of the inserts as well as the filling volume is dependent on the destination to use for the specific class of fire resistance of the curtain wall. The materials used for insulation inserts are usually gypsum plasterboards, silicate – cement or silicate – calcium.* [10]

The glazing as well as solution of profile insulation is selected depending on the expected fire resistance class of the curtain wall. The most commonly used in practice are glass units comprising a fireproof glass (toughened glass panes divided by the special gel or foil expanding under the influence of high temperature) coupled with the outer glass pane. Glass units are usually fixed in the curtain wall by means of pressure plates screwed to the main aluminium profile. [26] The solution of the glazing fixing method has a key role in achieving the appropriate fire resistance class especially in the case of increasingly common glass units of large dimensions [20, 21, 25].

Important elements in the profile structure are intumescent gaskets placed on the perimeter of the glass panes. Intumescent gasket expands under the influence of high temperatures and closes the spaces through which the fire could get to the other side of the partition. [18]

It is worth mentioning that solutions of this type are also used for roofing [12, 13] – glazed roofs are made of exactly the same profile as those used in curtain walls.

The fire resistance class of curtain wall cannot be calculated or assessed based on its project or other specification, therefore the only way to determine this characteristic is to perform the fire resistance test.

2. FIRE RESISTANCE TESTS AND CLASSIFICATION

The fire resistance test of glazed curtain wall in full configuration, according to the European Union provisions, shall be performed in accordance with EN 1364-3:2014 [5], following the procedures outlined in EN 1363-1:2012 [2] and where appropriate EN 1363-2:1999 [3].

The standard presents two different methods of heating and test specimen configuration depending on the side of fire exposure (external or internal). In case of internal fire exposure heating of the test specimen is held by the standard temperature-time curve, taken as an appropriate to reflect the fully developed, following the flashover fire inside the building (presented by the solid line in Fig. 1). For external fire exposure heating of the test specimen can be held by external temperature-time curve, which is relevant for the fire outside the building (presented by the dashed line in Fig. 1) or by the standard temperature-time curve. The influence of the heating conditions to the fire resistance of glazed curtain walls is presented in papers [1, 9, 22, 23].

The testing structure for the internal test shall comply of testing specimen and supporting construction made of two floor slabs and two associated wall constructions. For external fire exposure the testing structure is composed only of the test specimen and testing frame (optionally). [19] *The specimen for the test shall be fully representative of the curtain wall intended for use in practice (including any surface finishes and fittings which are essential and may influence its behavior in the test) or be designed to obtain the widest applicability of the test result to other similar constructions.* [16]

During the fire resistance test performance criteria of integrity, insulation and radiation can be verified.

Integrity is the ability of tested element to prevent the passage through it of flames and hot gases and to prevent the occurrence of flames on the unexposed side. In the test integrity is verified:

- by means of gap gauges (integrity fails if the 6 mm gap gauge can be passed through the crack in curtain wall and can be moved a distance of 150 mm along the gap, or if the 25 mm gap gauge can be passed through the crack in the specimen such that it projects into the furnace),

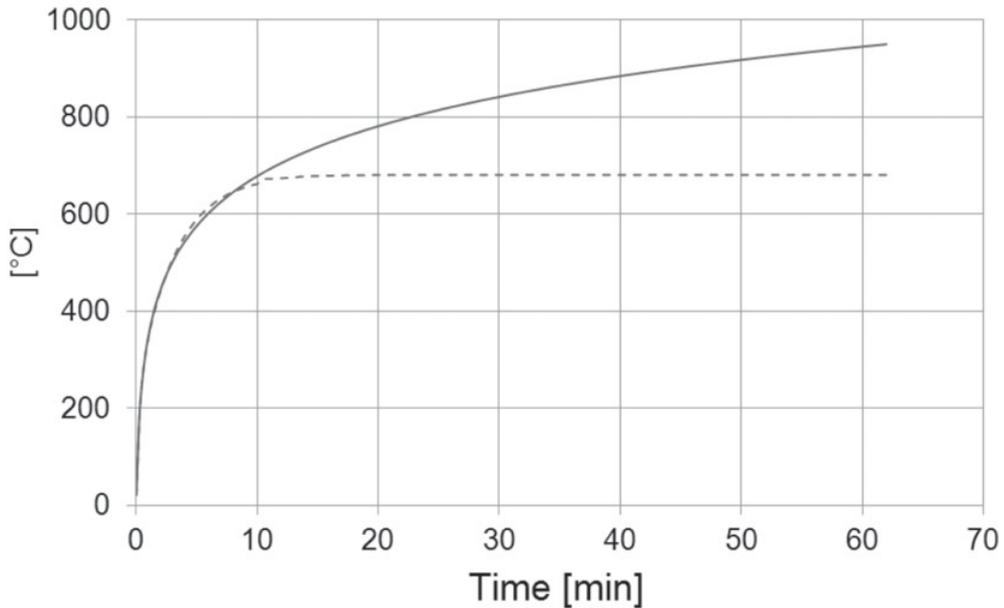


Figure 1. Temperature-time curves, solid line – standard curve, dashed line – external fire curve [20].

- visually (integrity fails when flaming longer than 10 s occurs on the unexposed surface of curtain wall),
- by means of cotton pad used on the unexposed surface of tested specimen, for max. of 30 s, or until ignition.

Insulation is the ability of glazed curtain wall to restrict the temperature rise of the unexposed face to below specified levels. The temperature rise on the unexposed surface of tested specimen is checked with thermocouples attached with use of heat resistant adhesive. Thermocouples are attached in the specific places given in the testing standard, arranged in the specific surfaces of the curtain wall, perimeter seal and vertical linear gap seal (if applicable). In order to maintain insulation – average temperature rise on the unexposed surface of test specimen cannot be greater than 140 K and the maximum temperature rise cannot be greater than 180 K.

Radiation is the ability of glazed curtain wall to prevent the passage of the fire, due to the transfer of significant heat through the element to the adjacent materials. Radiation in the test is measured with the radiometer placed in the 1 m distance from the geometric center of the unexposed surface of heated part of curtain wall. Radiation is evaluated on the basis of the time at which the maximum radiation measured does not exceed 15 kW/m².

Test methodology as well as detailed information regarding the selection of appropriate test specimens has been widely discussed in the existing papers [16, 17, 22, 29].

Classification of glazed curtain wall fire resistance is prepared in accordance with the requirements given in EN 13501-2:2009 [6], basing on the test results presented in test report. Fire resistance classes defined by the standard are presented in Table 1. Moreover each fire resistance class given in the Table 1 shall be supplemented by additional marking defining the side of fire exposure in the test.

3. TEST SPECIMENS

For the preparation of this paper 17 fire resistance tests of aluminium glazed curtain walls in full configuration (complete assembly) conducted in Fire Testing Laboratory of Building Research Institute

Table 1. Fire resistance classes [24].

E	15		30	60	90	120
EI	15		30	60	90	120
EW		20	30	60		

(*E* – integrity, *I* – insulation, *W* – radiation)

Table 2. Test specimens dimensions and characteristic.

No.	Test date	Test duration duration [min]	System	Type of insulation inserts	Type of glazing	Width [mm]	Height [mm]	Span length [mm]
1	2007-02-05	47	1	4	11	3822	4100	3536
2	2007-07-09	62	1	1	12	3822	4100	3536
3	2009-06-05	66	1	1	1	3822	4952	3536
4	2010-09-30	36	1	4	9	3822	4952	3536
5	2010-10-15	63	1	1	10	3822	4952	3536
6	2013-01-14	62	4	1	3	5825	5725	5000
7	2013-01-21	36	4	3	4	5825	5725	5000
8	2014-07-09	33	6	1	6	4522	5667	4700
9	2014-07-15	63	6	1	7	4522	5667	4700
10	2014-10-23	50	7	1	8	4730	5426	4700
11	2015-01-12	66	5	1	5	4122	5667	4700
12	2015-02-12	68	7	1	8	4730	5426	4700
13	2015-06-17	70	3	2	2	4520	4550	3900
14	2015-10-16	55	1	1	14	4122	5667	4700
15	2015-10-23	34	1	1	15	4122	5667	4700
16	2015-12-08	56	1	1	14	4122	5667	4700
17	2016-01-18	19	3	no insulation	13	4970	5350	4700

in Warsaw and Pionki in the last few years has been analyzed. All of the selected specimens were tested for internal fire exposure in accordance with EN 1364-3:2006 [4] or EN 1364-3:2014 [5] and achieved the fire resistance class of min. EI 15. The analysis has been prepared for 7 different systems of curtain walls with 4 types of insulation inserts and 15 types of glass units, with span length from 3536 mm up to 5000 mm. Tested specimens dimensions and characteristics are presented in Table 2.

4. FIRE RESISTANCE TESTS RESULTS

For the purpose of attempt to identify the weak points of aluminium glazed curtain wall test specimens (regarding to the maximum temperature rise) there were selected 7 places, related with thermocouple arrangement presented in the EN 1364-3:2006 [4] and EN 1364-3:2014 [5]:

- T1 – thermocouples placed on the glass panes for average and maximum temperature measurements,
- T2 – thermocouple placed in the level of upper simulated floor soffit, in the middle width of the test specimen,
- T3 – thermocouples placed in the level of upper simulated floor soffit, in the line with the mullions,
- T4 – thermocouples placed at the junction of mullions and transoms,
- T5 – thermocouples placed on transoms at middle way between two mullions,
- T6 – thermocouples placed on the mullion at middle way between two transoms,
- T7 – thermocouples placed on the glass panes 20 mm from the mullion or transom edge (checked only for specimens 10–17 tested in accordance with EN 1364-3:2014 [5]).

Table 3. Temperature rises in 15th minute of the test.

Test No.	T1 [K] (15 min)	T2 [K] (15 min)	T3 [K] (15 min)	T4 [K] (15 min)	T5 [K] (15 min)	T6 [K] (15 min)	T7 [K] (15 min)
1	27.0	0	10.0	66.0	12.0	31.0	x
2	10.0	0	30.0	70.0	59.0	44.0	x
3	9.0	1.0	22.0	62.0	31.0	17.0	x
4	7.3	0.5	60.5	72.4	74.7	72.3	x
5	1.9	0	10.9	45.7	4.8	21.0	x
6	9.1	6.7	9.9	28.6	11.1	13.2	x
7	75.3	69.5	68.1	81.3	81.7	78.2	x
8	18.2	34.6	35.9	65.8	54.8	55.8	x
9	12.8	0.2	52.4	70	71.1	65.6	x
10	14.4	1.4	0.4	10.1	0.3	0.7	74.1
11	9.1	0.2	4.6	13.2	15	28.6	12.9
12	11.9	0.7	61.4	77.7	12.1	77.6	22.5
13	9.5	8.8	29.5	74.2	30.1	17.6	12.6
14	4.8	0.1	0.2	35	8.9	7.5	6.8
15	10.9	0.3	8.2	21.3	21.8	9	14.9
16	4.7	0.1	0.8	8	14.8	5	6.2
17	60	33.8	36	69.3	37.5	25.2	27.8

“x” – no data available.

Table 4. Temperature rises in 30th minute of the test.

Test No.	T1 [K] (30 min)	T2 [K] (30 min)	T3 [K] (30 min)	T4 [K] (30 min)	T5 [K] (30 min)	T6 [K] (30 min)	T7 [K] (30 min)
1	65	3	75	99	76	93	x
2	30	2	73	71	74	72	x
3	26	5	69	78	83	56	x
4	28	4.7	62.3	80.5	80	83.2	x
5	14.9	2	73.5	74.8	72.2	74.7	x
6	25.5	21.2	37	41.6	69	36.9	x
7	78.7	74.7	92.5	137	127.9	146.1	x
8	46	56.1	66.6	68.1	66.8	81.2	x
9	35.3	5.3	69.7	70.6	74.7	74.3	x
10	60.8	8	1	62.4	1.4	32.1	73.6
11	25.5	2.6	17.7	34.6	29.3	38.1	36.9
12	33.7	65.9	70.8	79.3	67.5	79	58.1
13	25.9	35.4	81.3	110.2	79.2	80	48.8
14	23.8	8.2	13.6	43.4	31.5	33.8	30
15	33.2	4.5	26.3	42	46	22.1	40.4
16	24.7	9.1	19.4	32.6	35.6	31.3	29.3
17	x	x	x	x	x	x	x

“x” – no data available.

The results of temperature rise measurement in all of the locations listed above, in the 15th, 30th, 45th and 60th minute of the test are presented in tables 3–6, respectively. The temperature rise on unexposed surface of the test specimens was measured with surface thermocouples type K specified in PN-EN 1363-1:2012 [2].

5. DISCUSSION

Analysing the test results presented in Tables 3–6 it can be observed that the greatest temperature rise was recorded only in points T4–T7. The percentage of greatest temperature occurrence in specific place, in respect to all of the tests and available data at given time is presented in Table 7. Because in many

Table 5. Temperature rises in 45th minute of the test.

Test No.	T1 [K] (45 min)	T2 [K] (45 min)	T3 [K] (45 min)	T4 [K] (45 min)	T5 [K] (45 min)	T6 [K] (45 min)	T7 [K] (45 min)
1	79	6	78	175	96	166	x
2	45	4	74	81	86	87	x
3	36	10	73	96	101	80	x
4	x	x	x	x	x	x	x
5	31.5	6.2	76.9	100.9	81.3	81.6	x
6	33.9	29.2	36.4	47.6	70.2	54.7	x
7	x	x	x	x	x	x	x
8	x	x	x	x	x	x	x
9	58.9	15.1	70.5	87.1	80.9	109.6	x
10	62.3	22.5	1.9	60.1	6.2	54.1	73.4
11	33.9	9.8	27.5	50	42.1	43.4	54.7
12	54.9	67.5	71	98.7	69.7	72.8	68.1
13	36.9	51.1	103.5	127.5	72	84.7	88.5
14	36.4	24.2	29.6	64.4	57.7	54.1	44
15	x	x	x	x	x	x	x
16	38.3	26.6	30.8	69.3	62.7	72.6	45.6
17	x	x	x	x	x	x	x

“x” – no data available.

Table 6. Temperature rises in 60th minute of the test.

Test No.	T1 [K] (60 min)	T2 [K] (60 min)	T3 [K] (60 min)	T4 [K] (60 min)	T5 [K] (60 min)	T6 [K] (60 min)	T7 [K] (60 min)
1	x	x	x	x	x	x	x
2	56	7	74	104	99	121	x
3	41	16	77	127	119	103	x
4	x	x	x	x	x	x	x
5	42.7	12.1	78.1	117.1	93.8	104.3	x
6	45.1	47.4	64.5	62.1	71.9	63.4	x
7	x	x	x	x	x	x	x
8	x	x	x	x	x	x	x
9	52.9	24.3	81.7	122.1	116.4	146.2	x
10	x	x	x	x	x	x	x
11	45.1	18.9	31.3	64.7	51.1	62.1	65.5
12	68.4	68.8	73.7	102.8	70.3	93.5	83.1
13	44.6	58.9	125.7	136	92.8	90.3	122.9
14	x	x	x	x	x	x	x
15	x	x	x	x	x	x	x
16	x	x	x	x	x	x	x
17	x	x	x	x	x	x	x

“x” – no data available.

cases the recorded temperatures differed slightly further calculation was prepared on the basis of scores given for the temperature level (1 – for the lowest temperature up to 6–for the greatest) – this calculation was evaluated only for places T1–T6, which occurs in all of the tests. Example of the scoring for the 15th min of the test is presented in Table 8 and the percentage of greatest temperature occurrence in specific place based on the scoring is presented in Table 9.

As it can be observed in the Tables 7 and 9 the lowest temperatures were recorded in the places T1–T3. This phenomenon can be explained in a simple way. Thermocouples T1 were placed in the middle part of the glazing where the temperature rise is low due to the glass unit structure. The glass units are composed of the fire resistant glass pane as an internal layer coupled by means of the steel frame with the external glazing (usually toughened or laminated). The first part of glazing – fire resistant glass pane

Table 7. Percentage of greatest temperature occurrence in specific place.

Time	T1	T2	T3	T4	T5	T6	T7 ^{*)}
15 min	0.00%	0.00%	0.00%	58.82%	29.41%	5.88%	12.50%
30 min	0.00%	0.00%	0.00%	31.25%	37.50%	25.00%	14.29%
45 min	0.00%	0.00%	0.00%	41.67%	16.67%	25.00%	33.33%
60 min	0.00%	0.00%	0.00%	50.00%	12.50%	25.00%	33.33%

^{*)} The percentage for the T7 was calculated only from the tests No. 10–17.

Table 8. Example of the scoring for 15th minute of the test.

No.	T1	T2	T3	T4	T5	T6
1	4	1	2	6	3	5
2	2	1	3	6	5	4
3	2	1	4	6	5	3
4	2	1	3	5	6	4
5	2	1	4	6	3	5
6	2	1	3	6	4	5
7	3	2	1	5	6	4
8	1	2	3	6	4	5
9	2	1	3	5	6	4
10	6	4	2	5	1	3
11	3	1	2	4	5	6
12	2	1	4	6	3	5
13	2	1	4	6	5	3
14	3	1	2	6	5	4
15	4	1	2	5	6	3
16	3	1	2	5	6	4
17	5	2	3	6	4	1

Table 9. Percentage of greatest temperature occurrence in specific place based on the scoring.

Time	T1	T2	T3	T4	T5	T6
15 min	13.45%	6.44%	13.17%	26.33%	21.57%	19.05%
30 min	10.98%	6.23%	15.43%	24.63%	21.07%	21.66%
45 min	11.90%	6.35%	13.10%	25.40%	19.84%	23.41%
60 min	8.33%	6.55%	16.67%	25.60%	20.24%	22.62%

were generally the same ones as used for the tests of doorsets [7, 28] or glazed partitions [13, 14]. Due to the specific of this elements testing the mentioned glass pane has to be prepared for stopping the increase of average temperature rise to a level of 140 K. This fire glass together with the additional air space and external glass panes creates a good insulating barrier and cause the low temperature rise in place T1. The temperature rises in points T2 and T3 were low, because those thermocouples were placed in the spandrel area, which is usually very accurately sealed and insulated.

In most of the examined cases the greatest temperature rise was recorded on the mullion transom connections (T4) and these places can be regarded as critical. The great temperature rise in those junctions can be explained by the large deformations of the facade specimens during the fire test. The deformation causes unplugging the transoms of the mullions which facilitates the flow of hot gases. Additionally, in those places often occur the special connectors, which limiting the space of insulation inserts.

An interesting phenomenon is fairly high temperature rise in place T7. Temperature measurements in this places were added in the new version of the standard (EN 1364-3:2014 [5]) and as it can be observed it was the correct move, because that also can be a places of the greatest temperature rise.

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