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REPORT

Determination of the contribution to the fire resistance of structural steel members by an applied profiled reactive water-based fire protective system type ENVIROGRAF® EP/FS/IN/EX, according to EN 13381-8:2013
Test report

Report no.	2019-Efectis-R000566
Sponsor	Intumescent Systems Ltd Envirograf House Barfrestone CT15 7JG DOVER UNITED KINGDOM
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1. SUBJECT

The purpose of this investigation is to assess the contribution of an applied ENVIROGRAF® EP/FS/IN/EX white water-based intumescent coating to the fire resistance of structural steel members. A number of tests on loaded beams, reference beams, short I and H section columns and a tall H section column were performed according to the European standard EN 13381-8:2013. The fire curve used was the standard temperature/time curve, described in the standard EN 1363-1:2012, for all the tests. This report contains the details of the reactive protection system and the test results.

2. INVESTIGATION

Contribution, according to EN 13381-8:2013, to the fire resistance of structural steel members by an applied profiled ENVIROGRAF® EP/FS/IN/EX white water-based intumescent coating with a nominal thickness range of 300 – 3000 µm.

3. SPONSOR AND MANUFACTURER

Intumescent Systems Ltd
Envirograf House
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UNITED KINGDOM

4. DATE AND PLACE OF THE INVESTIGATION

The tests were carried out at the laboratory of Efectis Nederland in Bleiswijk,
The Netherlands, on the following days:

- Test 1, 16th November 2018: 1 loaded beam and 1 reference beam
- Test 2, 20th November 2018: 1 loaded beam, 1 reference beam and 5 unloaded short columns
- Test 3, 23rd November 2018: 8 unloaded short columns and 1 unloaded tall column

5. TEST SPECIMENS

5.1 STEEL PROFILES

In total 2 loaded beams, 2 reference beams, 13 short unloaded columns and 1 tall unloaded column were tested. The overview of all test specimens is given in Table 1.
The actual steel yield strength was declared by the certificate of conformity delivered with the steel profiles.

5.1.1 Loaded beam

The investigated loaded beams were of profile type IPE 400.
The span of the beams was 4500 mm. The exposed length was approximately 4200 mm.

5.1.2 Unloaded reference beam

An unloaded reference beam was tested under the same conditions as the loaded beam and with the identical beam section and protection system.
The length of the unloaded reference beams was 1000 mm.

5.1.3 Unloaded short columns

Length of the short I and H section columns was 1000 mm.

5.1.4 Unloaded tall column

Length of the tall H section column was 2000 mm.

5.1.5 Dimensions of the test specimens

Table 1: Dimension of the test specimens

Specimen	Type	height h (mm)	width b (mm)	thickness web t_w (mm)	thickness flange t_f (mm)	perimeter P (mm)	area A (mm^2)	section factor A_m/V (m^{-1})
Loaded beam	IPE400	402	182	8.55	13.5	1333	8120	164
Reference beam	IPE400	402	182	8.45	13.45	1333	8065	165
Loaded beam	IPE400	402	182	8.55	13.35	1333	8068	165
Reference beam	IPE400	402	182	8.55	13.45	1333	8103	164
Short column 1	HEM 280	315	285	19.3	32.6	1731	23403	74
Short column 2	HEM 280	315	290	19.7	31.85	1751	23424	75
Short column 3	HEM 280	315	290	19.1	31.85	1752	23273	75
Short column 4	HEA 300	290	301	8.55	14.1	1767	10727	165
Short column 5	HEA 300	290	301	8.6	14	1767	10681	165
Short column 6	HEA 300	290	300	8.6	14.1	1763	10711	165
Short column 7	IPE 200	200	101	5.9	8.3	792	2759	287
Short column 8	IPE 200	200	101	6	8.15	792	2749	288
Short column 9	IPE 200	203	101	5.7	7.9	798	2663	300
Short column 10	IPE 200	200	101	5.8	7.95	792	2674	296
Short column 11	IPE 80	82	46	4.2	5.25	340	783	434
Short column 12	IPE 80	82	46	4.2	5.3	340	787	431
Short column 13	IPE 80	82	46	4.25	5.3	339	791	429
Tall column	HEA 300	290	300	8.6	14.1	1763	10711	165

5.2 FIRE PROTECTION SYSTEM

The applied profiled reactive fire protection system consists of fire protection of ENVIROGRAF® EP/FS/IN/EX white water-based intumescent coating on a single layer ENVIROGRAF®

EP/FS/WBP water-based primer. The method of application to the reference beams and the short columns was the same as that for the loaded beams and tall column.
The reactive protection system consisted of:

5.2.1 Coating

Table 2: Coating

Manufacturer	Intumescent Systems Ltd
Type	ENVIROGRAF® EP/FS/IN/EX white water-based intumescent coating for steel
Application method	Brush
Number of coating layers	Depending on the thickness max. 1 mm per coating layer

5.2.2 Primer

Table 3: Primer

Manufacturer	Intumescent Systems Ltd
Type	ENVIROGRAF® EP/FS/WBP water-based primer for steel
Application method	Brush
Number of primer layers	1

5.2.3 Thickness measurements

Table 4: Thickness measurements

Test specimen	Profile	Length (mm)	Average primer thickness (µm)	Average coating + primer thickness (µm)	Average coating thickness (µm)
Loaded beam	IPE 400	4500	22	286	264
Reference beam	IPE 400	1000	24	295	271
Loaded beam	IPE 400	4500	23	2956	2933
Reference beam	IPE 400	1000	27	2923	2896
Unloaded short column	HEM 280	1000	73	343	270
Unloaded short column	HEM 280	1000	73	1255	1182
Unloaded short column	HEM 280	1000	70	2428	2358
Unloaded short column	HEA 300	1000	30	315	285
Unloaded short column	HEA 300	1000	33	2204	2171
Unloaded short column	HEA 300	1000	34	3047	3013
Unloaded short column	IPE 200	1000	32	301	269
Unloaded short column	IPE 200	1000	29	1190	1161

Test specimen	Profile	Length (mm)	Average primer thickness (µm)	Average coating + primer thickness (µm)	Average coating thickness (µm)
Unloaded short column	IPE 200	1000	28	2322	2294
Unloaded short column	IPE 200	1000	27	2723	2696
Unloaded short column	IPE 80	1000	27	1153	1126
Unloaded short column	IPE 80	1000	26	2195	2169
Unloaded short column	IPE 80	1000	28	2703	2675
Unloaded tall column	HEA 300	2000	33	2971	2938

The measured thicknesses of applied reactive fire protection material are within the resulting permitted thickness tolerances in accordance with § 6.5.2 of EN 13381-8:2013.

5.3 OVERVIEW

Applied thicknesses with other data are shown in Table 4 and 5. The section factors are calculated on the basis of measured dimensions.

Table 5: Overview of test specimens

Test specimen	Profile	Length (mm)	Section factor (m^{-1})	Average protection thickness (µm)	Test date	Tested at
Loaded beam	IPE 400	4500	164	264	16-11-2018	Efectis
Reference beam	IPE 400	1000	165	271	16-11-2018	Efectis
Loaded beam	IPE 400	4500	165	2933	20-11-2018	Efectis
Reference beam	IPE 400	1000	164	2896	20-11-2018	Efectis
Unloaded short column	HEM 280	1000	74	270	23-11-2018	Efectis
Unloaded short column	HEM 280	1000	75	1182	23-11-2018	Efectis
Unloaded short column	HEM 280	1000	75	2358	23-11-2018	Efectis
Unloaded short column	HEA 300	1000	165	285	23-11-2018	Efectis
Unloaded short column	HEA 300	1000	165	2171	23-11-2018	Efectis
Unloaded short column	HEA 300	1000	165	3013	23-11-2018	Efectis
Unloaded short column	IPE 200	1000	287	269	23-11-2018	Efectis
Unloaded short column	IPE 200	1000	288	1161	20-11-2018	Efectis
Unloaded short column	IPE 200	1000	300	2294	20-11-2018	Efectis
Unloaded short column	IPE 200	1000	296	2696	23-11-2018	Efectis
Unloaded short column	IPE 80	1000	434	1126	20-11-2018	Efectis
Unloaded short column	IPE 80	1000	431	2169	20-11-2018	Efectis
Unloaded short column	IPE 80	1000	429	2675	20-11-2018	Efectis
Unloaded tall column	HEA 300	2000	165	2938	23-11-2018	Efectis

6. SAMPLING AND MANUFACTURING OF THE CONSTRUCTION

The materials and components used were inspected during application on the basis of the supplied data. Efectis Nederland BV was not involved in the manufacturing and sampling of the components.
The method of application is described in § 5.2.

7. CONDITIONING

From the moment the protection was applied till the test specimens were placed in the laboratory of Efectis Nederland BV with ambient conditions of (20 ± 5) °C and a relative humidity of (50 ± 10) %. On the test dates the equilibrium moisture content in the protection was reached.

8. METHOD OF INVESTIGATION

8.1 LOADED BEAM

The loaded beams were heated on three sides. Between the top flange of the loaded beam and the aerated concrete cover a layer of ceramic blanket of 25 mm thickness was placed.
The maximum stress in the loaded beam due to own weight and applied load was during both tests approximately 141 N/mm², which represented 60 % of the design moment resistance. Details of the calculations are in the Appendix C.
During the test the deformation was measured in the middle of the loaded beam. When a deformation of 1/30 of the span was reached ($\frac{L}{30}\ mm$) or when the rate of deflection exceeded ($\frac{L^2}{9000*d}\ mm/min$) the load was removed to ensure that the deformation did not increase any more.
The loaded beam was fitted with UNP 400 profiles at the ends to ensure lateral stability. To prevent unwanted heat flow to the beam through the UNP 400 profiles the UNP profiles were insulated with mineral wool.

8.2 UNLOADED REFERENCE BEAMS

The reference beams were heated on three sides and were mounted to the ceiling of the furnace with two threads M12. Between the top flange and the aerated concrete ceiling a layer of ceramic blanket of 25 mm thickness was placed. The ends of the reference beam were insulated to prevent unwanted heat transport through the ends.

8.3 SHORT COLUMNS

The short columns were placed on the furnace floor. The bottom was covered by sand and the top by ceramic wool and a concrete tile to prevent unwanted heat transport through the ends of the columns.

8.4 TALL COLUMN

The tall column were placed on the furnace floor. The bottom was covered by sand and the top by ceramic wool and a concrete tile to prevent unwanted heat transport through the ends of the columns.

9. FIRE TEST

9.1 CONDITIONS

The tests were carried out under the conditions as specified in EN 13381-8:2013 and EN 1363-1:2012. The specimens were exposed to the standard temperature/time curve specified in EN 1363-1:2012.
Notwithstanding § 5.6 of EN 1363-1:2012 the ambient air temperature at the commencement of the tests was below 10 °C. The steel temperatures at the commencement of the tests were in accordance with § 10.3 of EN 1363-1:2012. Because of this, we believe that it is still allowed to start the test.
The temperatures in the furnace were measured using plate thermometers in accordance with 9.2 of EN 13381-8:2013.

The overpressure in the furnace was according to the conditions as specified in EN 1363-1:2012.

9.2 TEMPERATURE MEASUREMENTS OF STEEL

During heating the steel temperatures were measured and recorded by thermocouples in accordance with § 9.3 of EN 13381-8:2013.

9.2.1 Loaded beam

The temperatures were measured in the upper flange, web and bottom flange with in total 17 thermocouples.

9.2.2 Reference beam

The temperatures were measured in the upper flange, web and bottom flange with in total 9 thermocouples.

9.2.3 Unloaded short columns

The temperatures were measured in the flanges and web with in total 9 thermocouples.

9.2.4 Unloaded tall column

The temperatures were measured in the flanges and web with in total 15 thermocouples.

10. RESULTS

10.1 OBSERVATIONS DURING HEATING

10.1.1 Test 1, 16 November 2018

Table 6: Observations during test 1

Time (min)	Observation
0	Start of heating
18	The rate of deflection exceeded
19	The applied load was removed
20	Max. deformation of the loaded beam reached
27	End of heating

Table 7: Compliance with the validity criteria given in § 11.1 of EN 13381-8:2013

Profile	d_p (µm)	Location	Failure of thermocouple	Validity
Loaded beam IPE 400	264	Upper flange	TkLig7 and TkLig12	Results valid
		Web	No failure	Results valid
		Lower flange	TkLig10	Results valid
Reference beam IPE 400	271	Upper flange	No failure	Results valid
		Web	No failure	Results valid
		Lower flange	No failure	Results valid

10.1.2 Test 2, 20 November 2018

Table 8: Observations during test 2

Time (min)	Observation
0	Start of heating
15	It seems that material is falling of the lower flange of the loaded beam.
37	The rate of deflection exceeded
38.5	Max. deformation of the loaded beam reached
40	The applied load was removed
67	End of heating

Table 9: Compliance with the validity criteria given in § 11.1 of EN 13381-8:2013

Profile	d_p (µm)	Location	Failure of thermocouple	Validity
Loaded beam IPE 400	2933	Upper flange	No failure	Results valid
		Web	No failure	Results valid
		Lower flange	TkLig4 and TkLig16	Results valid
Reference beam IPE 400	2896	Upper flange	TkRef4	Results valid
		Web	TkRef5	Results valid
		Lower flange	No failure	Results valid
Unloaded short column IPE 80	1126	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column IPE 80	2169	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid

Unloaded short column IPE 80	2675	Flange	Tk26	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column IPE 200	1161	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column IPE 200	2294	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid

10.1.3 Test 3, 23 November 2018

Table 10: Observations during test 3

Time (min)	Observation
0	Start of heating
66	End of heating

Table 11: Compliance with the validity criteria given in § 11.1 of EN 13381-8:2013

Profile	d_p (µm)	Location	Failure of thermocouple	Validity
Unloaded short column HEM 280	270	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column HEM 280	1182	Flange	Tk11	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column HEM 280	2358	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column HEA 300	285	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column HEA 300	2171	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded	3013	Flange	No failure	Results valid

Profile	d_p (µm)	Location	Failure of thermocouple	Validity
short column HEA 300		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column IPE 200	269	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded short column IPE 200	2696	Flange	No failure	Results valid
		Web	No failure	Results valid
		Flange	No failure	Results valid
Unloaded tall column HEA 300	2938	All locations	No failure	Results valid
		200 mm from the top	No failure	Results valid
		⅓ of heated length	No failure	Results valid
		⅔ of heated length	No failure	Results valid

10.2 TEST RESULTS

The test results are given in graphs and tables in Appendix B.

10.3 UNCERTAINTY OF MEASUREMENT

Because of the nature of fire resistance testing and the consequent difficulty in quantifying the uncertainty of measurement of fire resistance, it is not possible to provide a stated degree of accuracy of the result.

11. VALIDITY OF TEST RESULTS

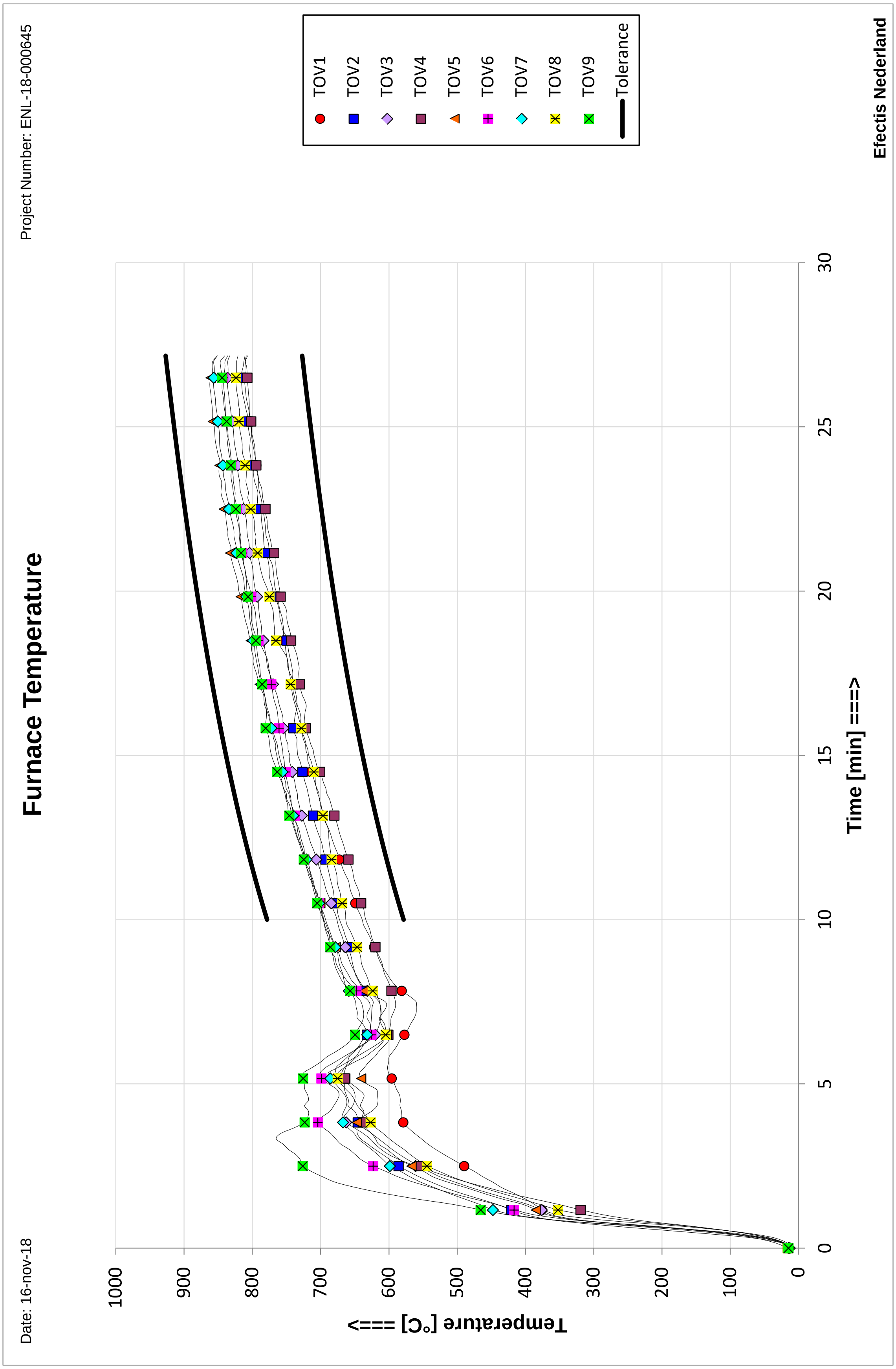
“This report provides the constructional details, the test conditions, the results obtained and the interpolated data obtained when the specified fire protection system described herein was tested following the procedures of EN 13381-8:2013. Any deviation with respect to thickness of fire protection material and constructional details, loads, stresses, edge or end conditions other than those allowed under the field of application could invalidate the test results”.

P.W.M. Kortekaas
Senior Project leader resistance to fire

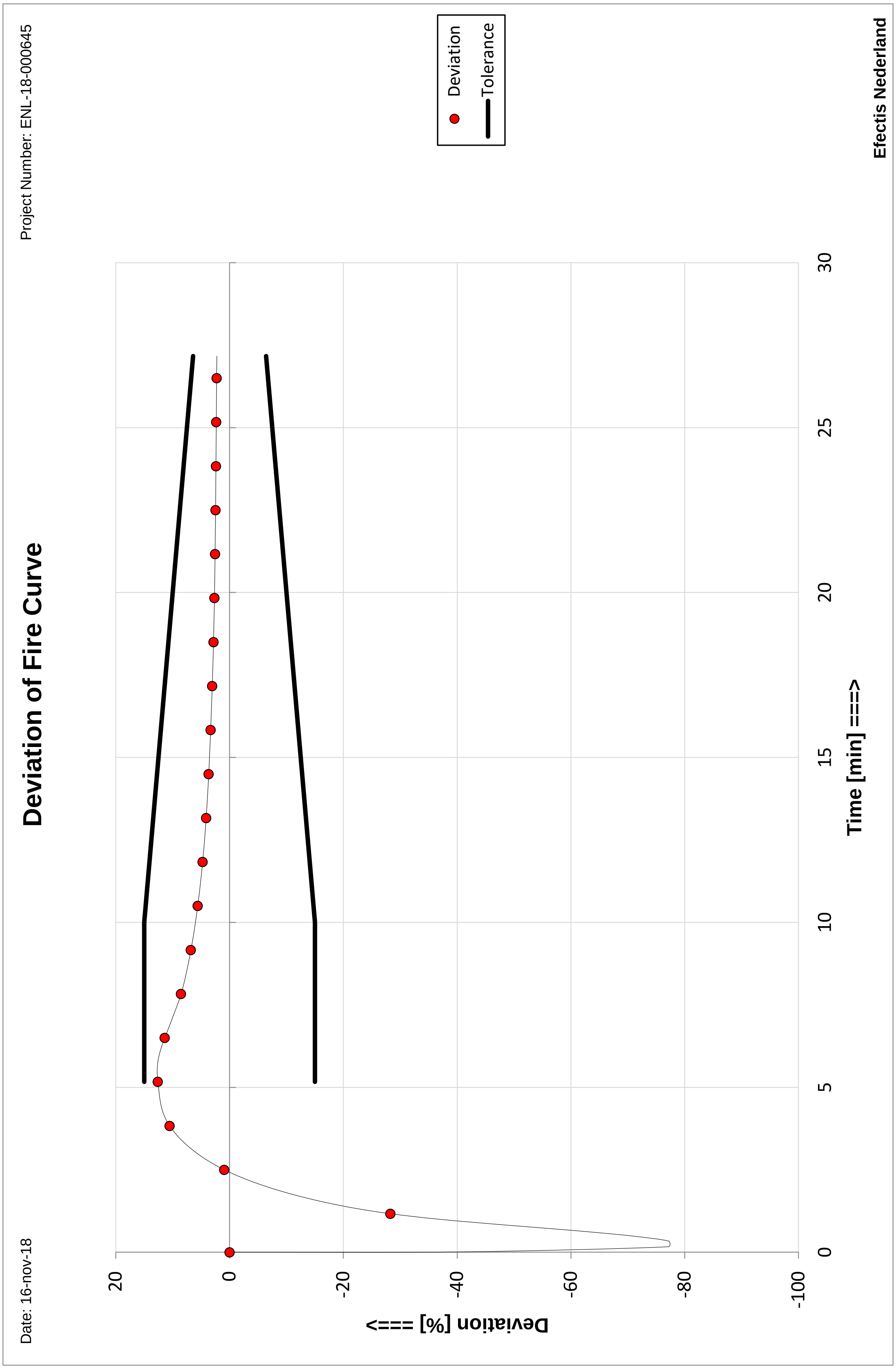
Ir. T. Rakovec
Project leader fire engineering

M. van der Meulen B.Sc.
Project leader resistance to fire

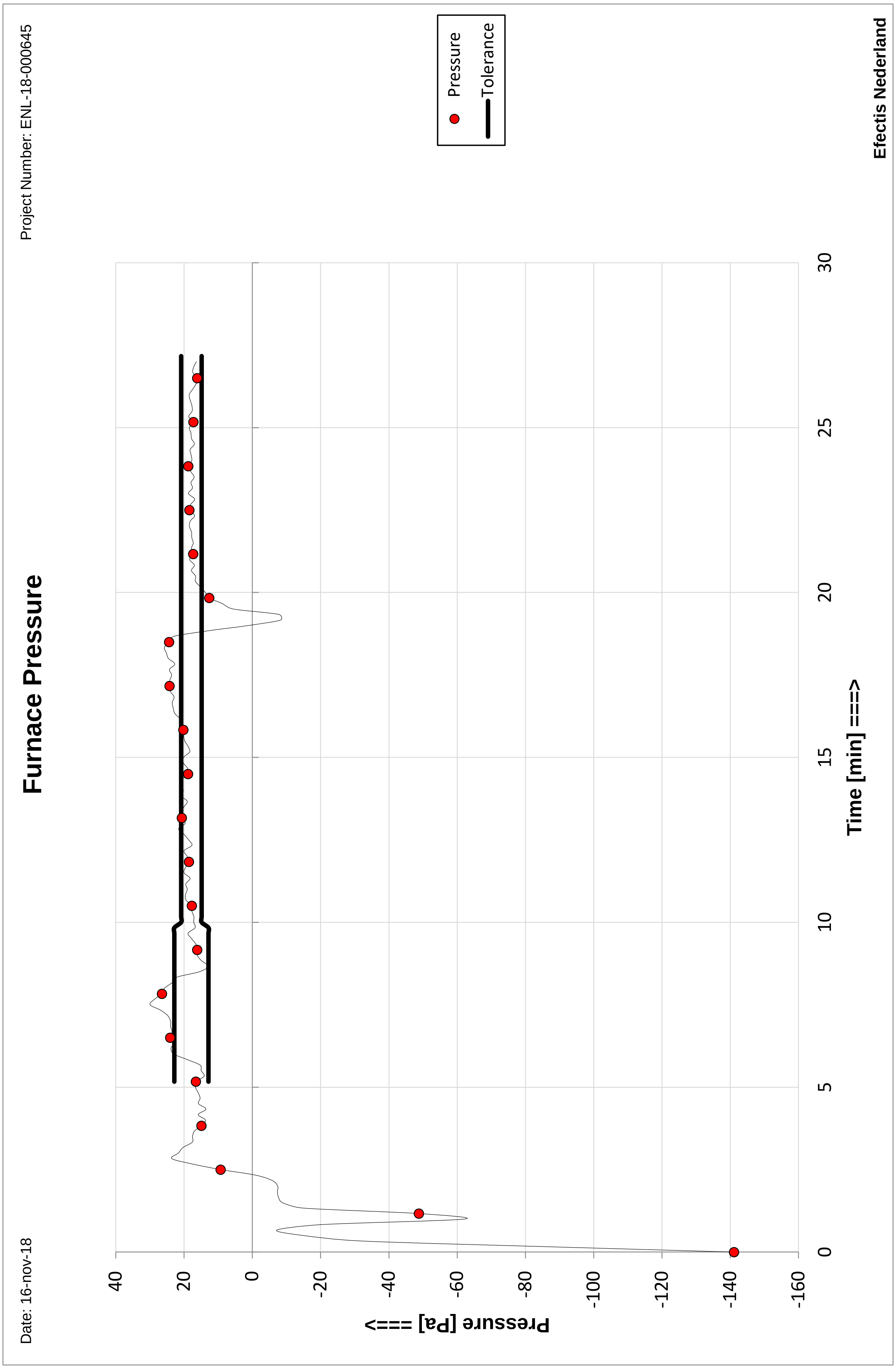
APPENDIX A: FURNACE AND AMBIENT CONDITIONS



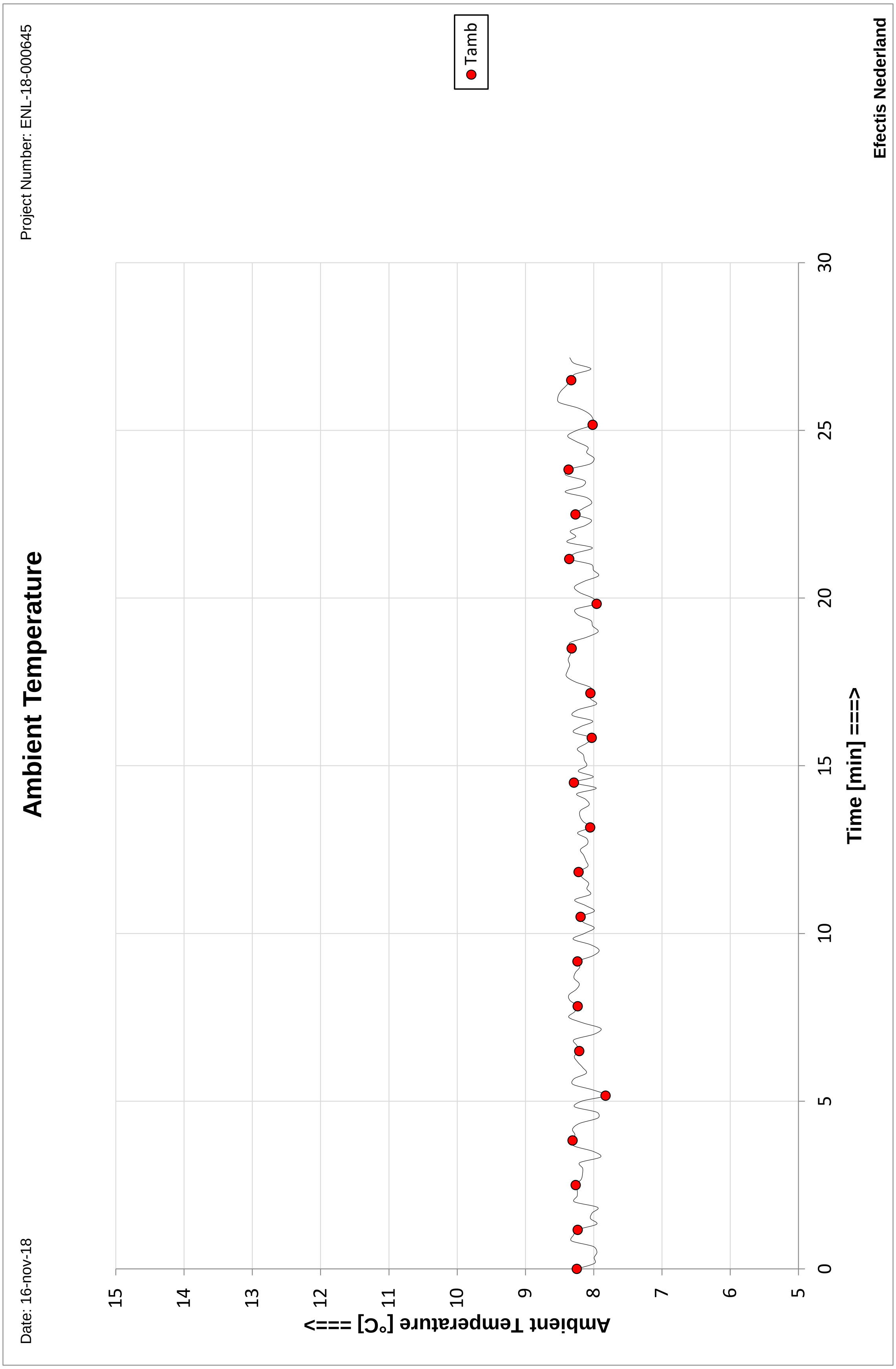
Figuur A.1 Test 1: gas temperatures in the furnace



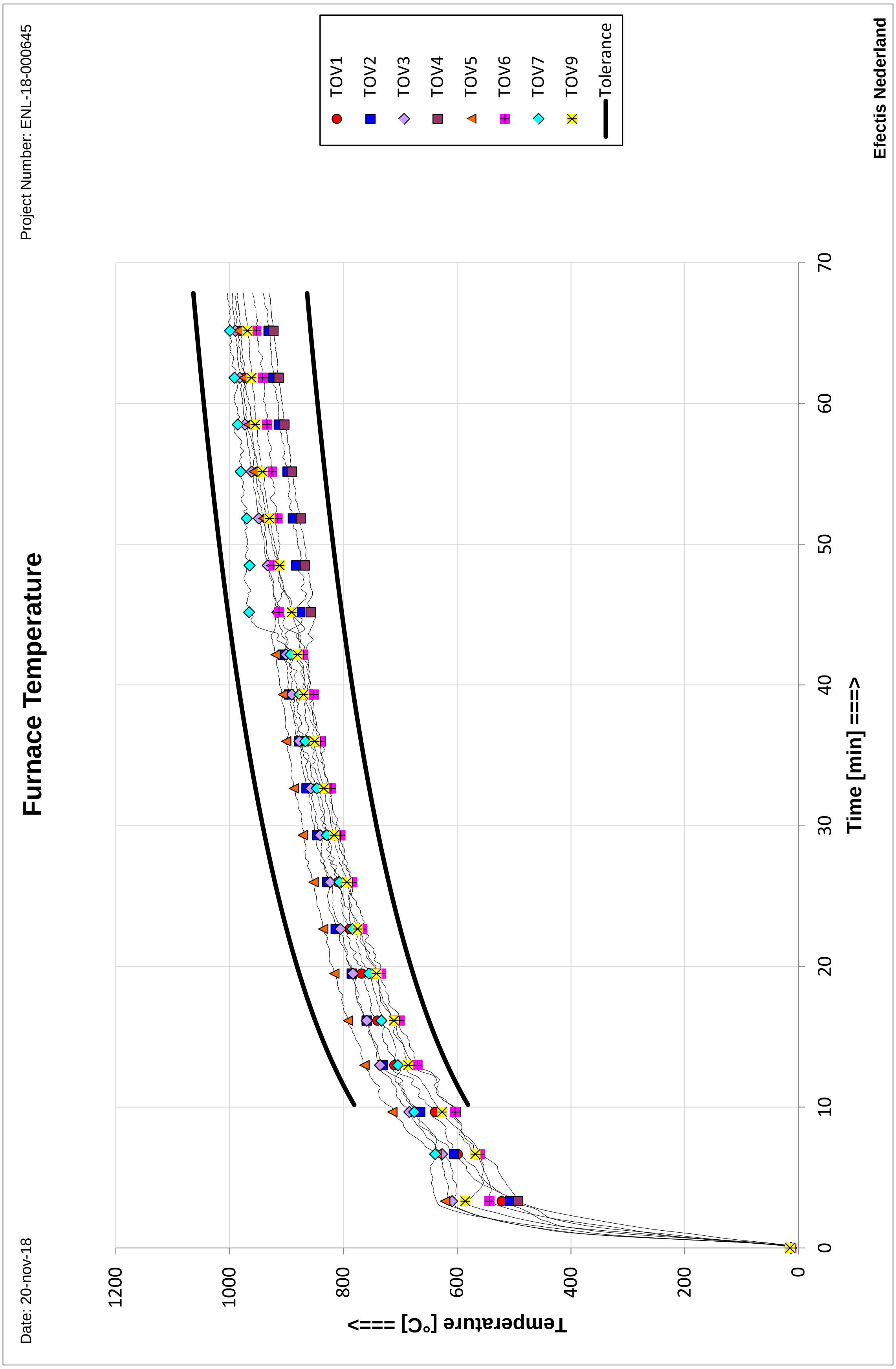
Figuur A.2 Test 1: relative deviation of the furnace temperatures



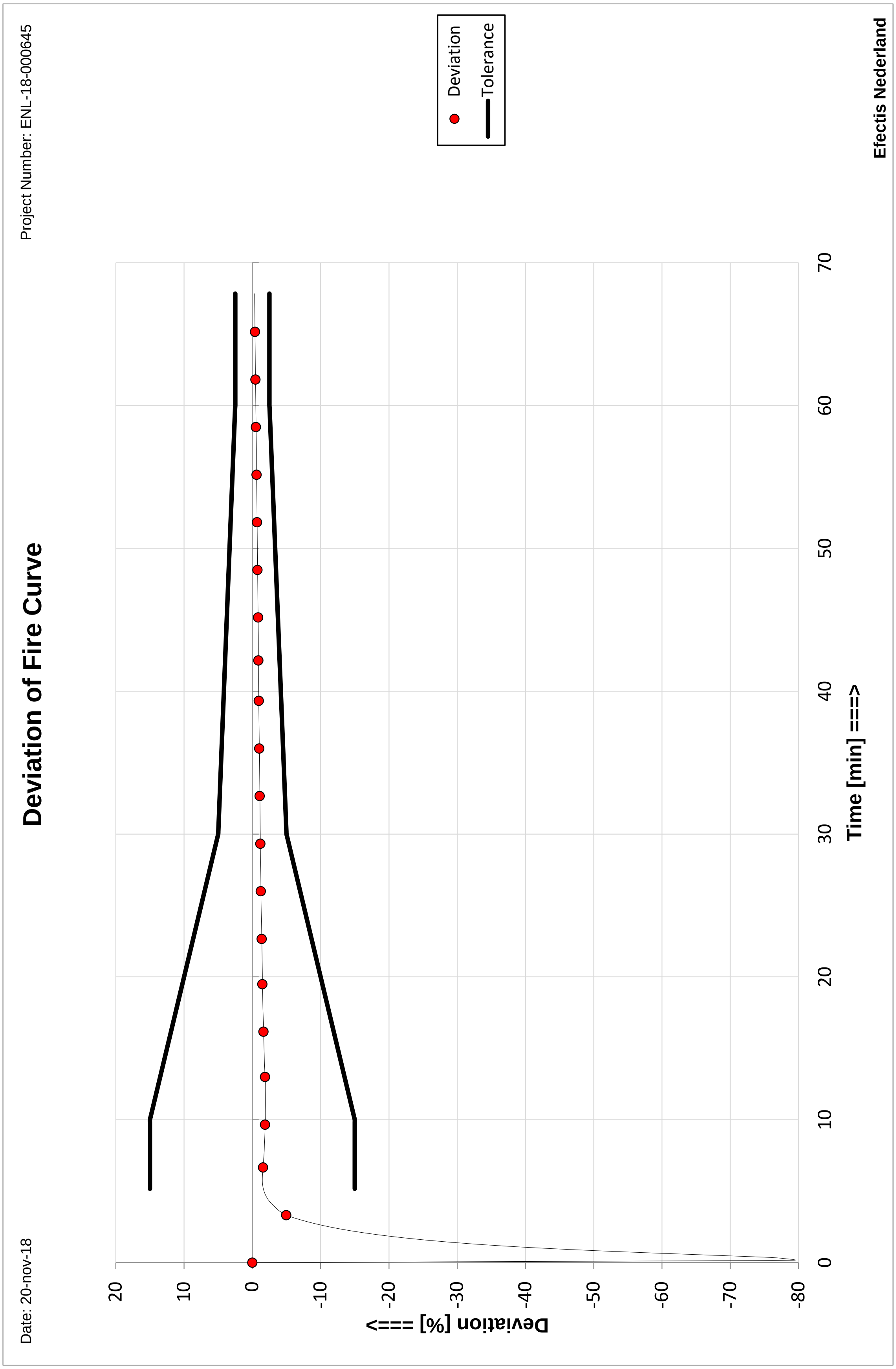
Figuur A.3 Test 1: pressure in the furnace on the underside of the beams



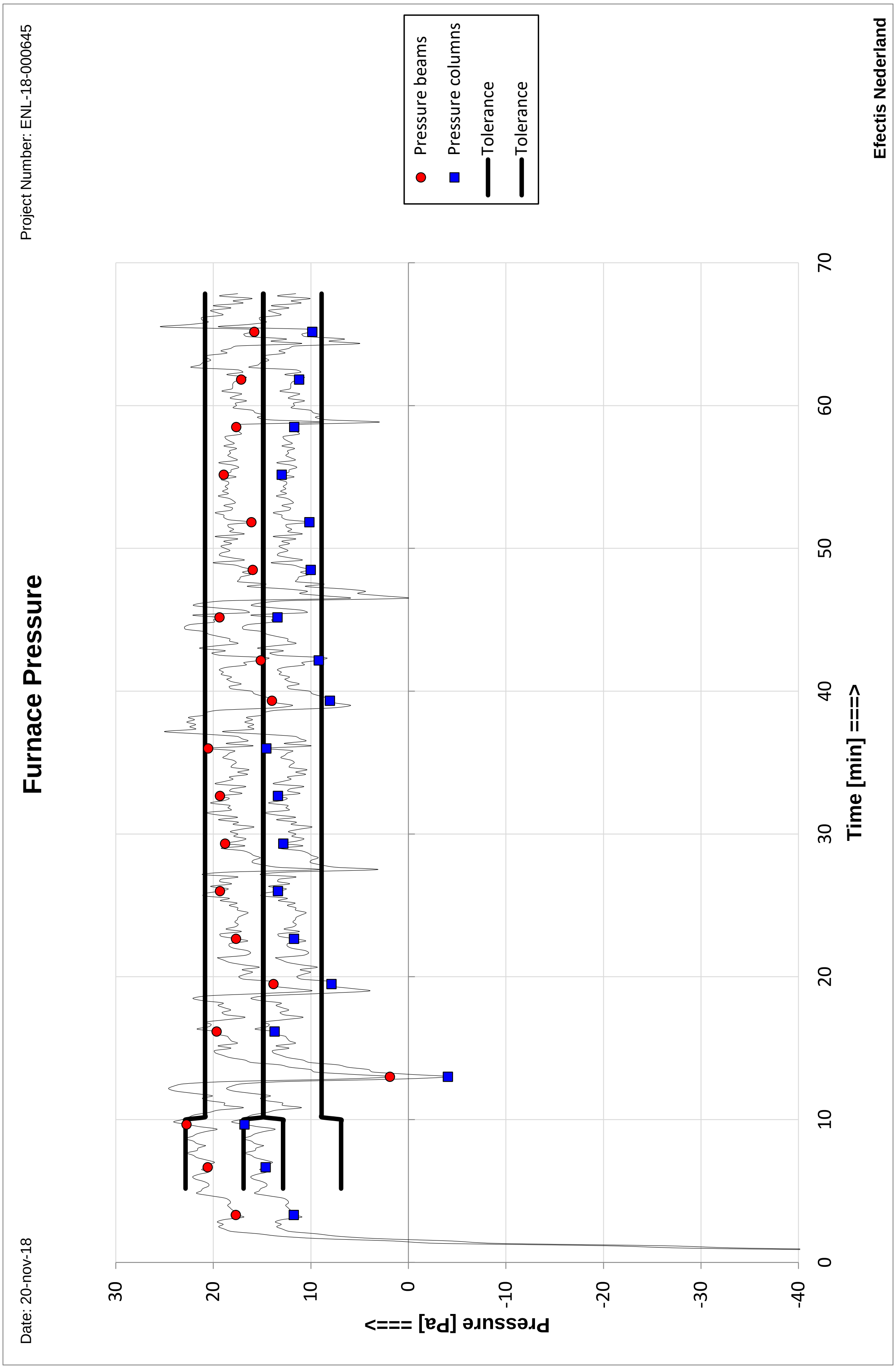
Figuur A.4 Test 1: ambient temperatures



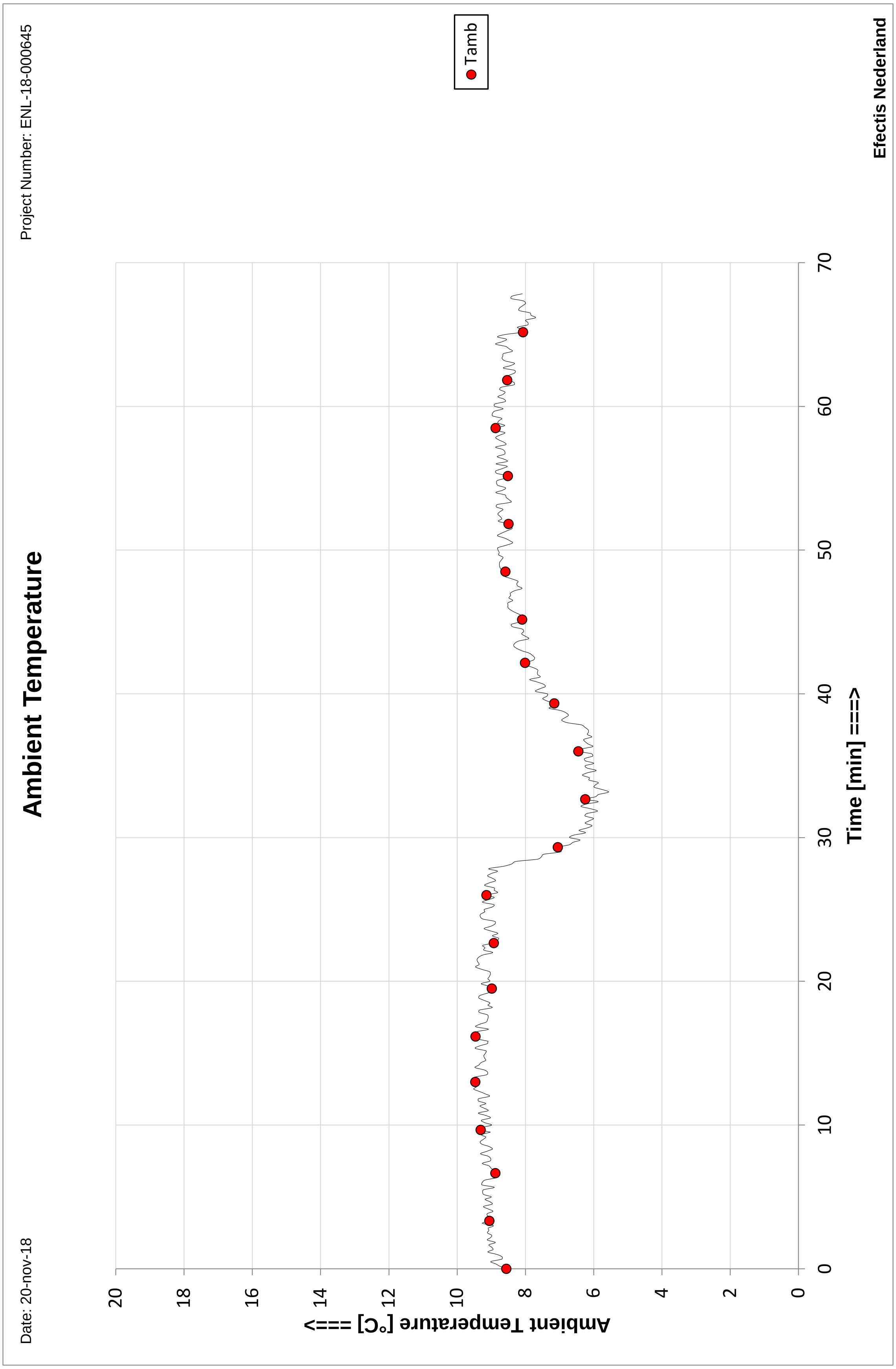
Figuur A.5 Test 2: gas temperatures in the furnace



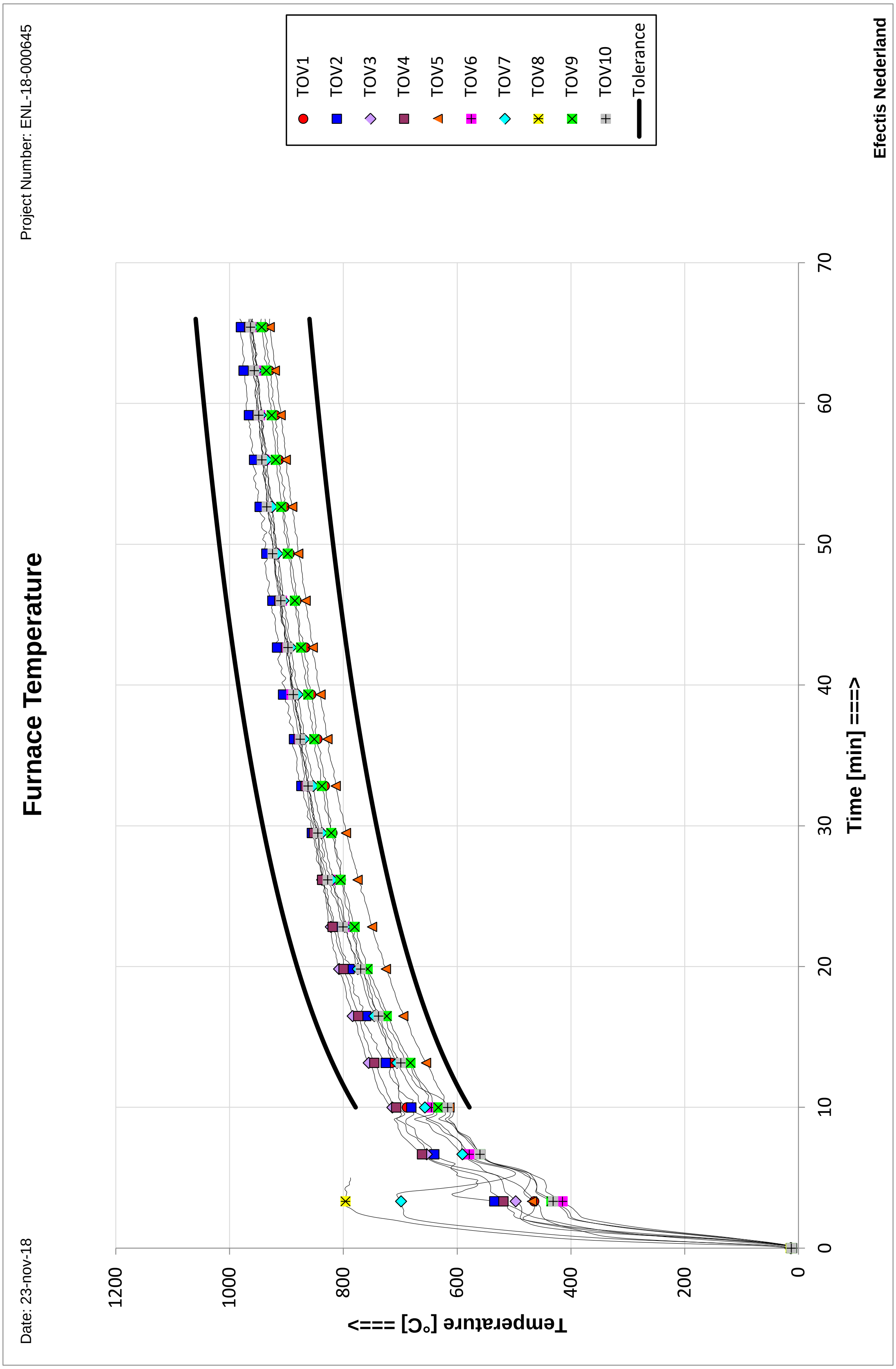
Figuur A.6 Test 2: relative deviation of the furnace temperatures



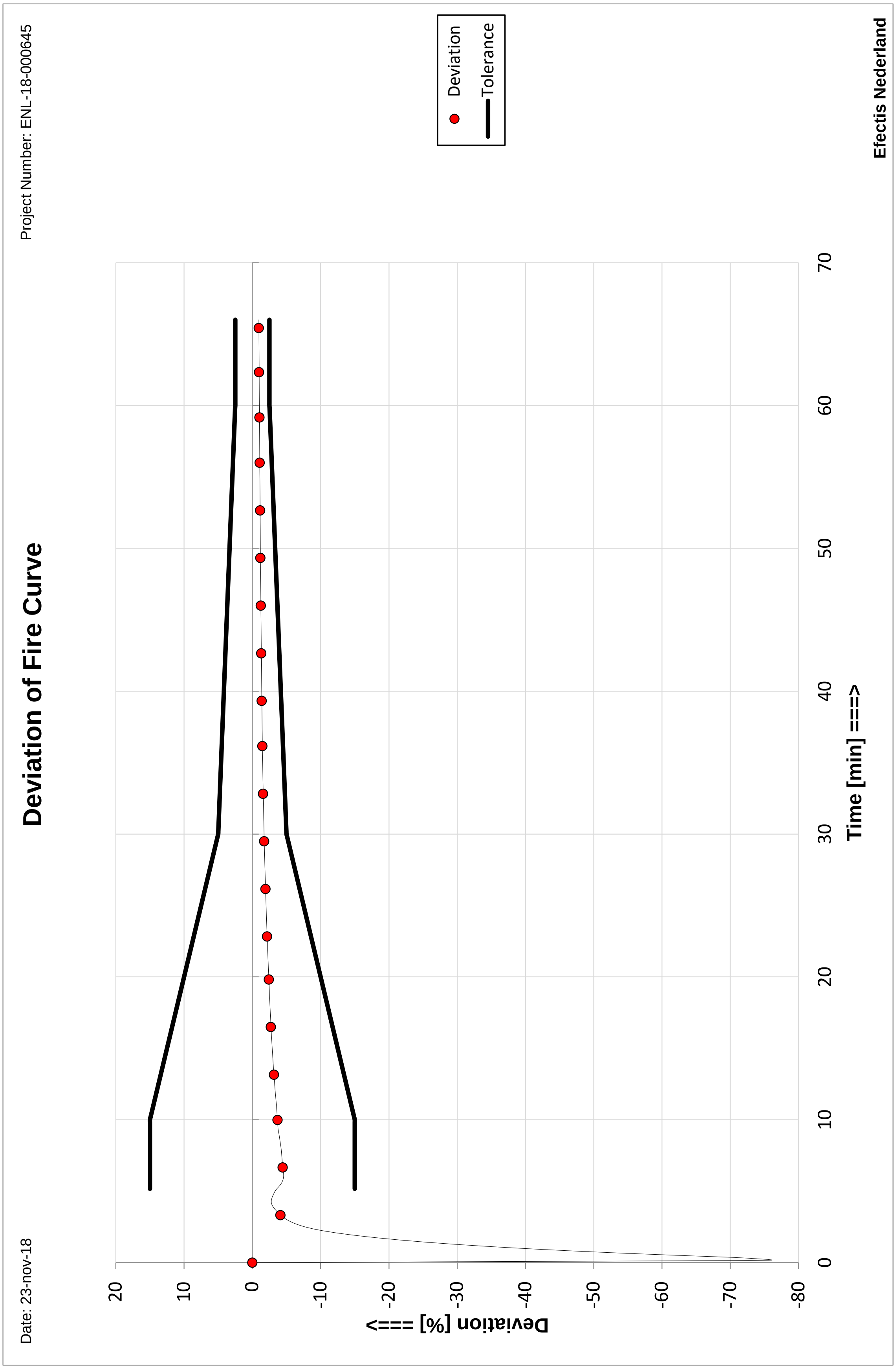
Figuur A.7 Test 2: pressure in the furnace on the underside of the beams and at the top of the columns



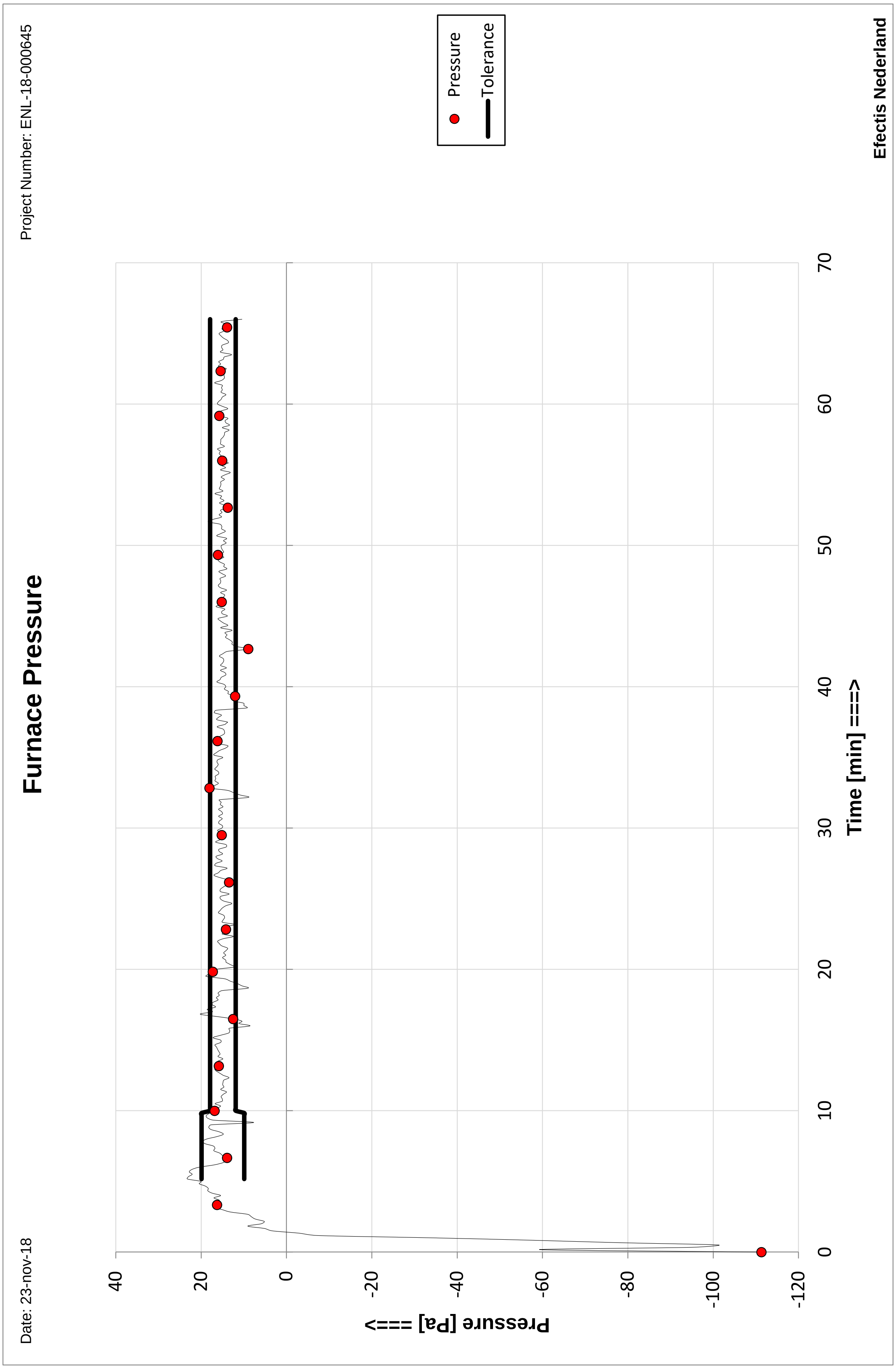
Figuur A.8 Test 2: ambient temperatures



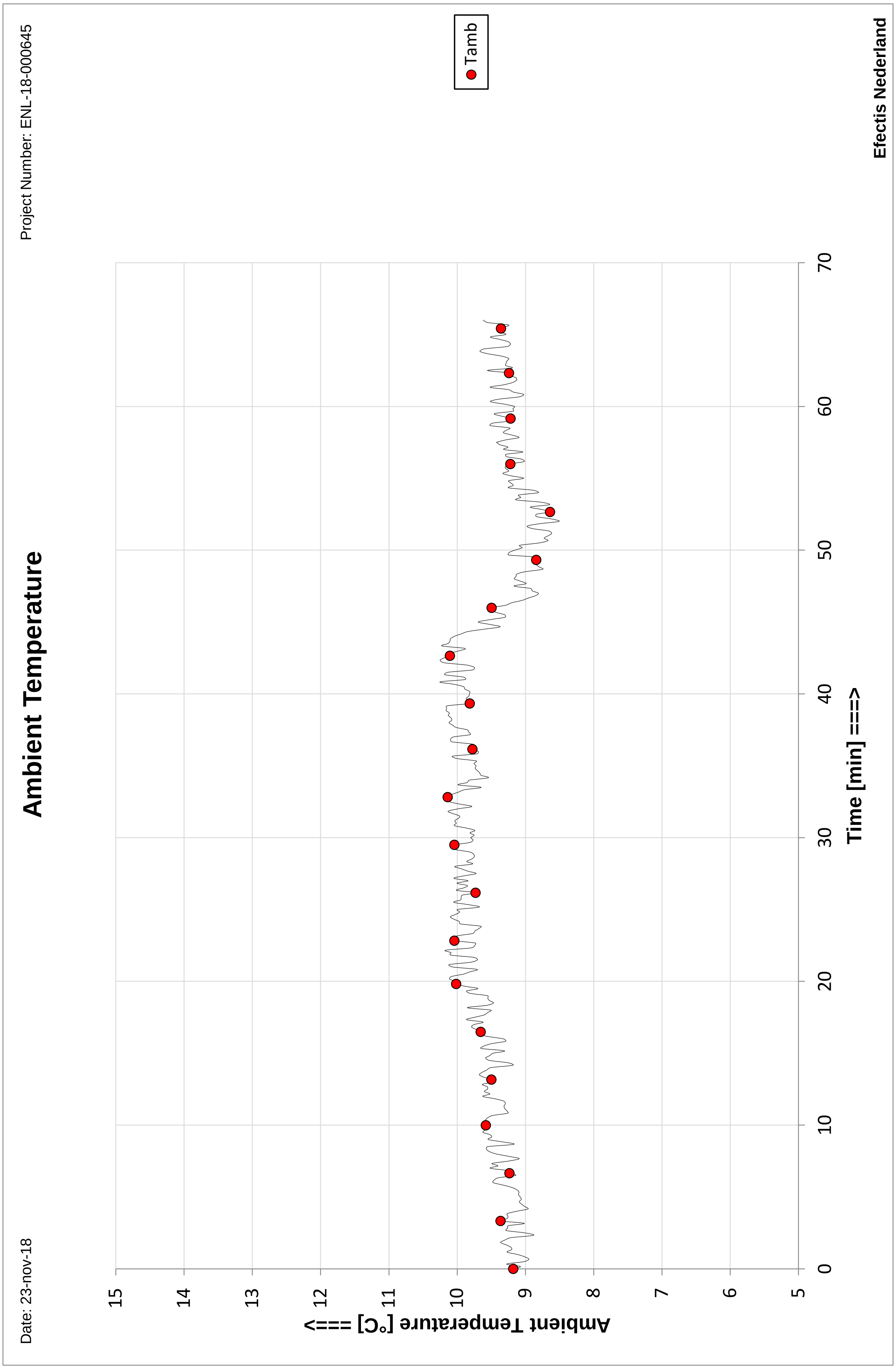
Figuur A.9 Test 3: gas temperatures in the furnace



Figuur A.10 Test 3: relative deviation of the furnace temperatures

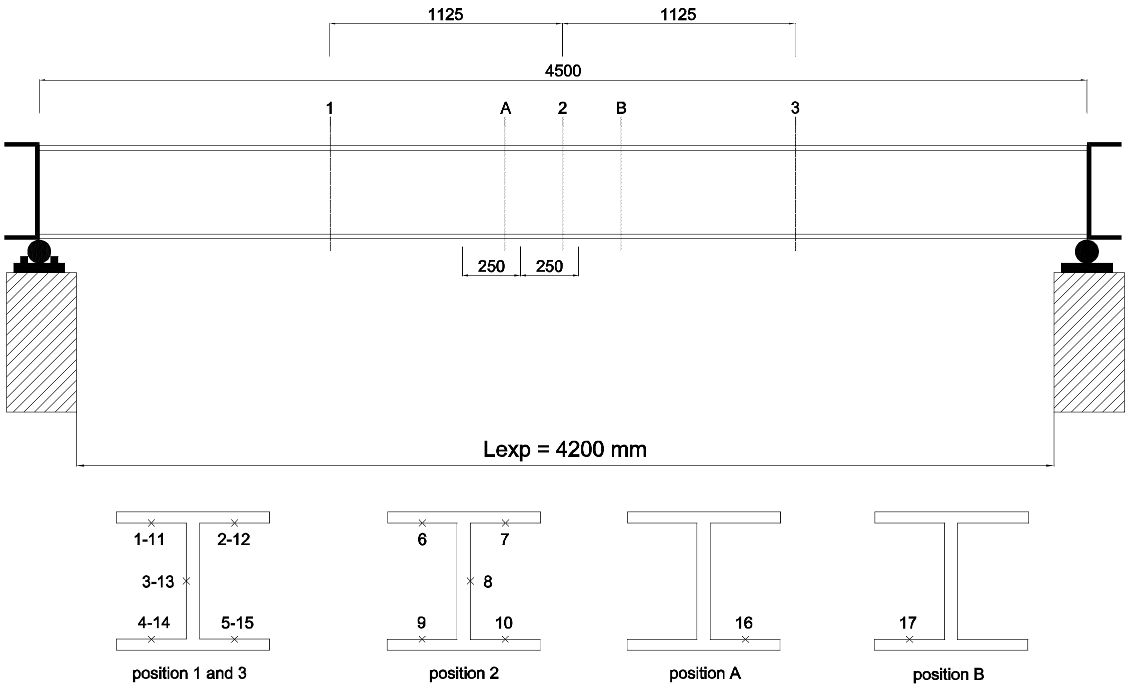


Figuur A.11 Test 3: pressure in the furnace at the top of the columns



Figuur A.12 Test 3: ambient temperatures

APPENDIX B: TEST RESULTS



Figuur B.1 thermocouple positions on the loaded beams

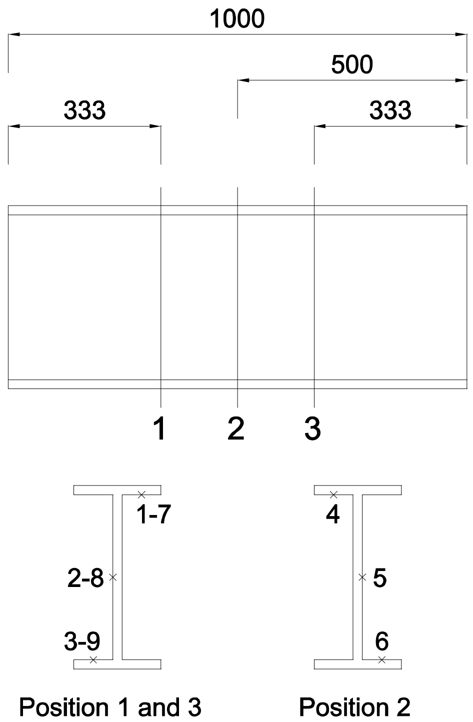


Figure B.2 thermocouple positions on the reference beams

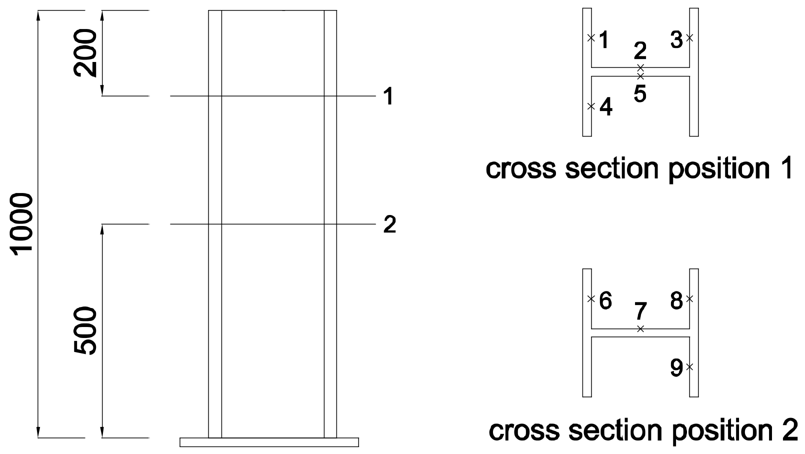


Figure B.3 thermocouple positions on the unloaded short columns

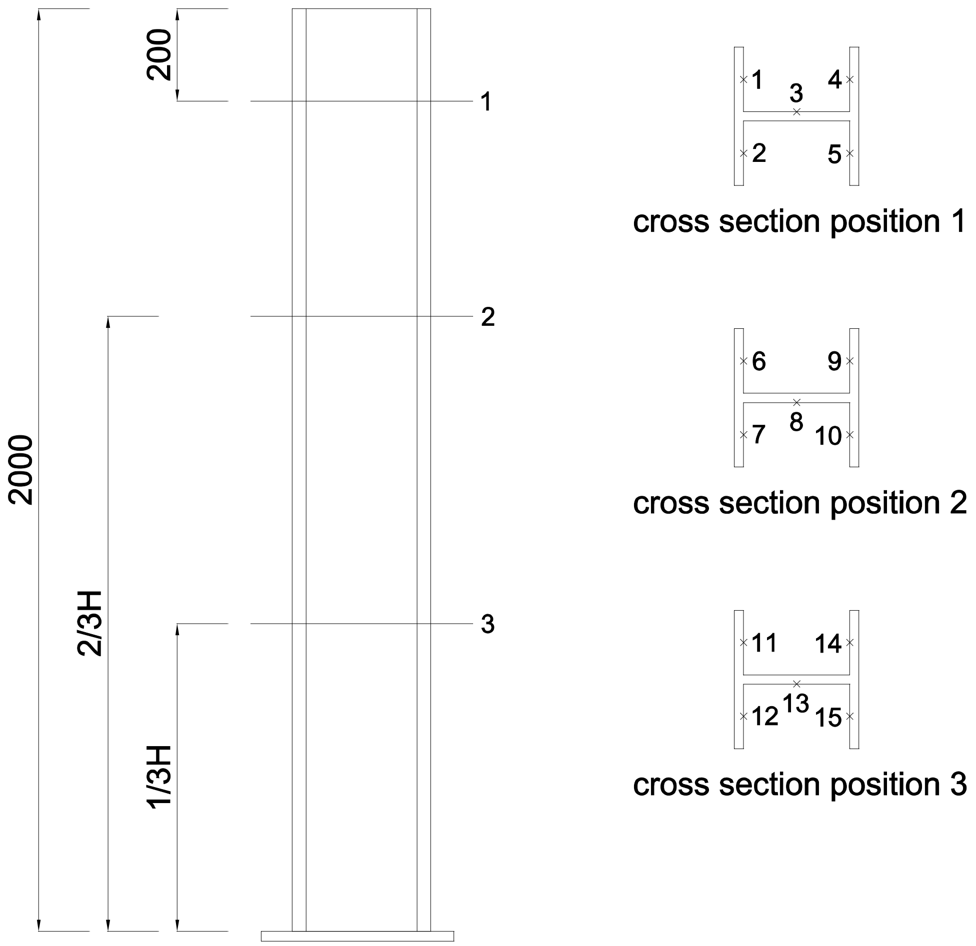


Figure B.4 thermocouple positions on the unloaded tall column

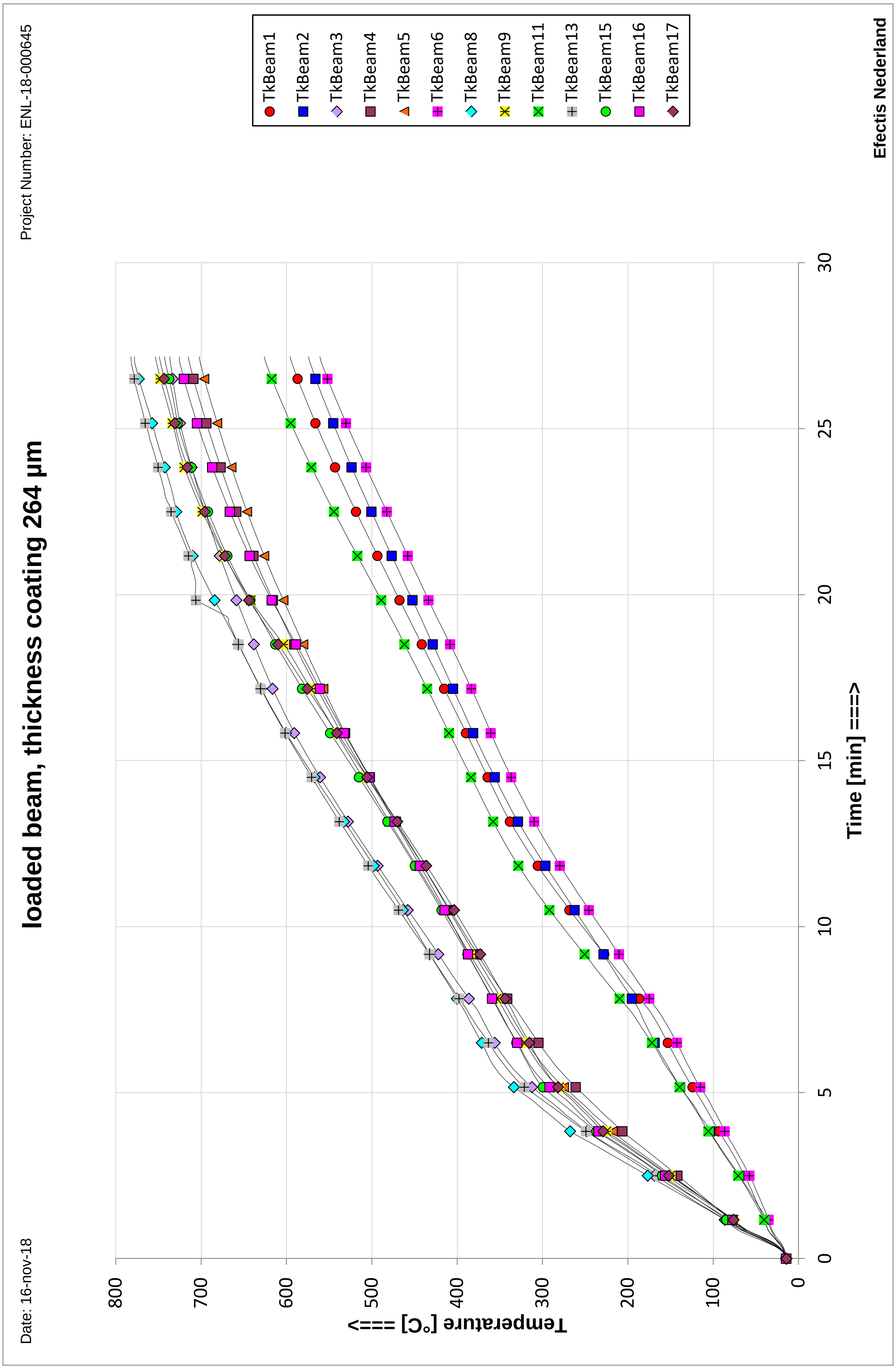


Figure B.5 Test 1: Loaded beam IPE 400, coating thickness 264 µm

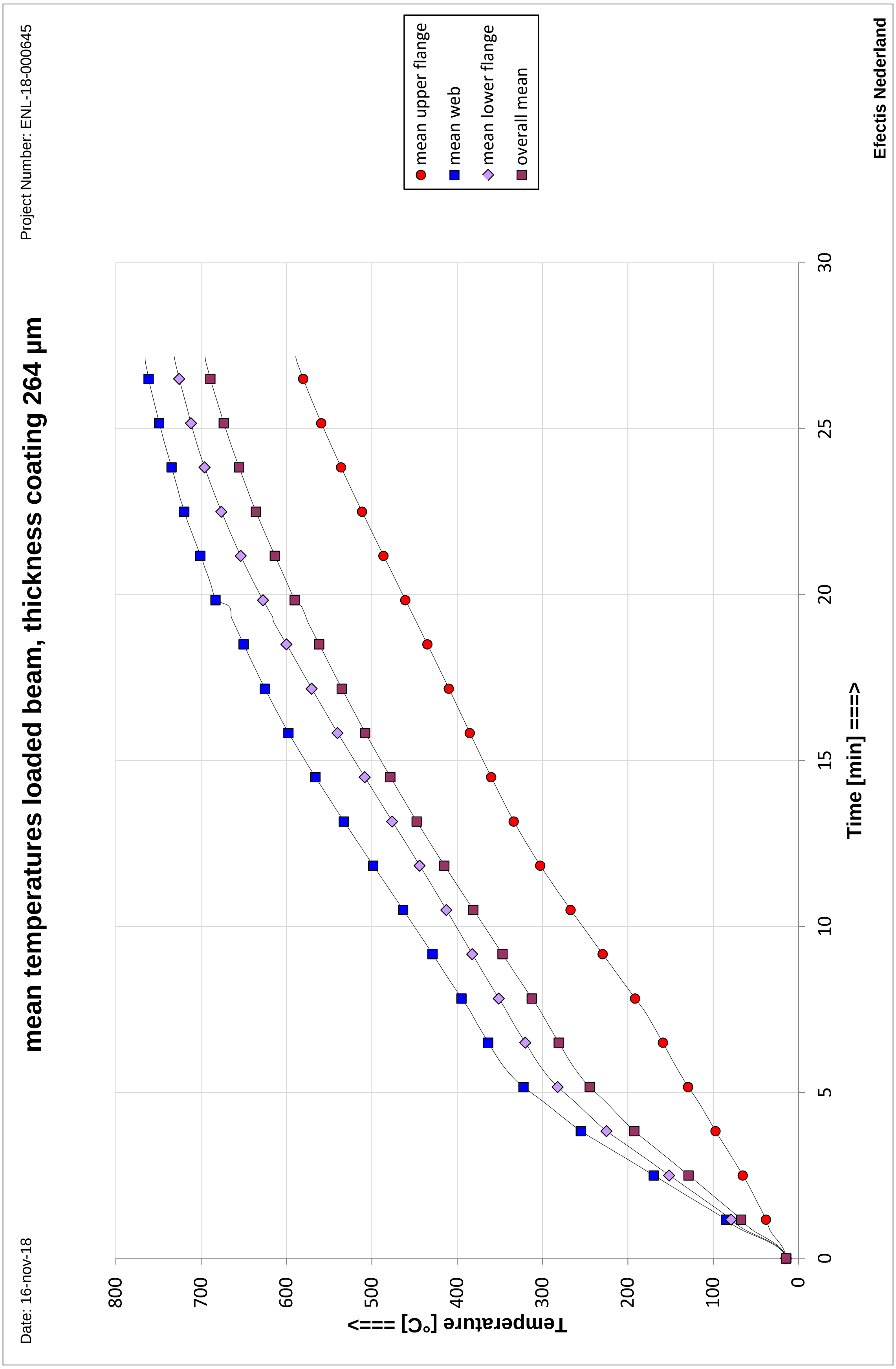


Figure B.6 Test 1: mean temperatures loaded beam IPE 400, coating thickness 264 µm

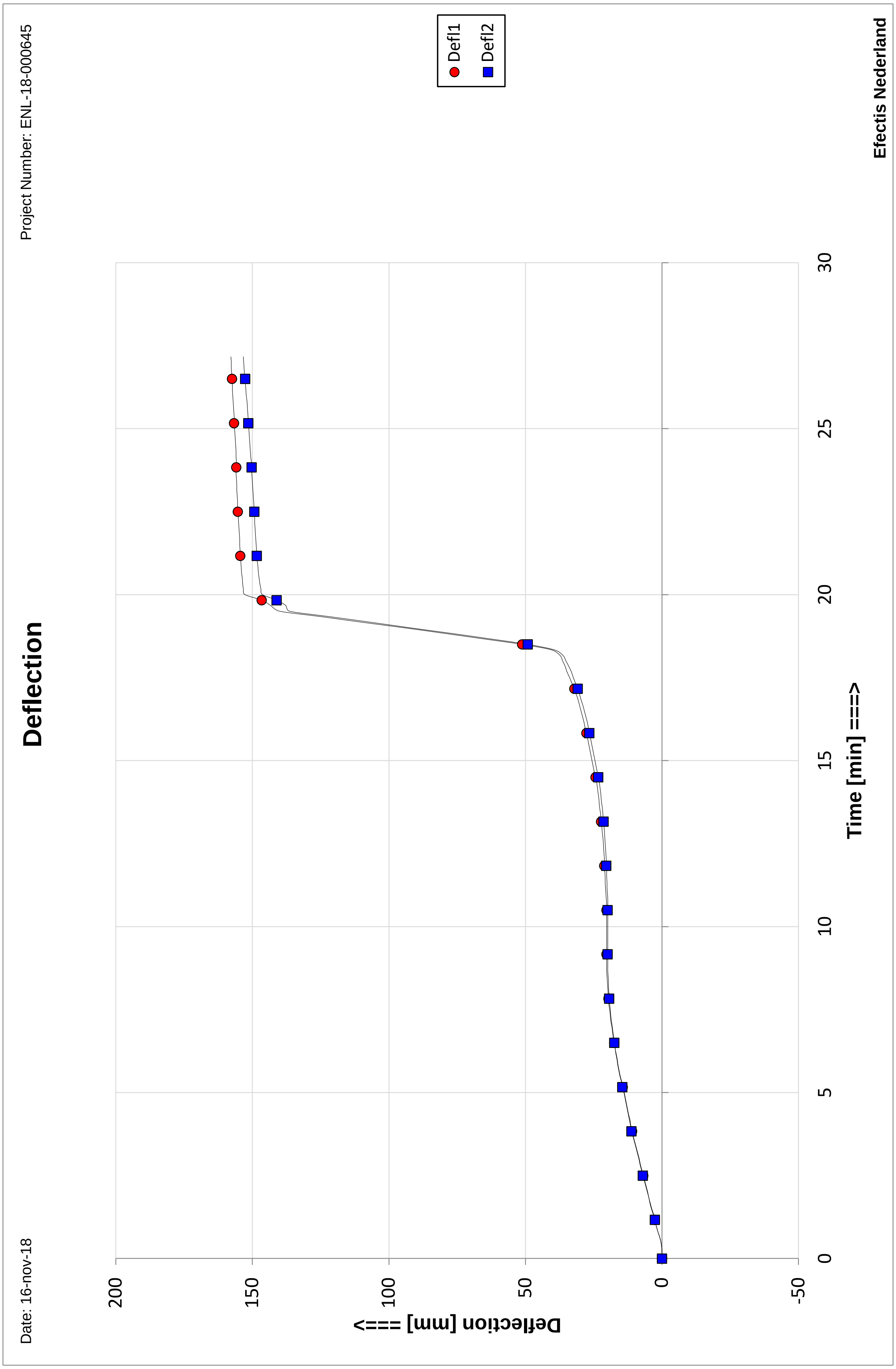


Figure B.7 Test 1: deformation of the loaded beam with coating thickness 264 µm

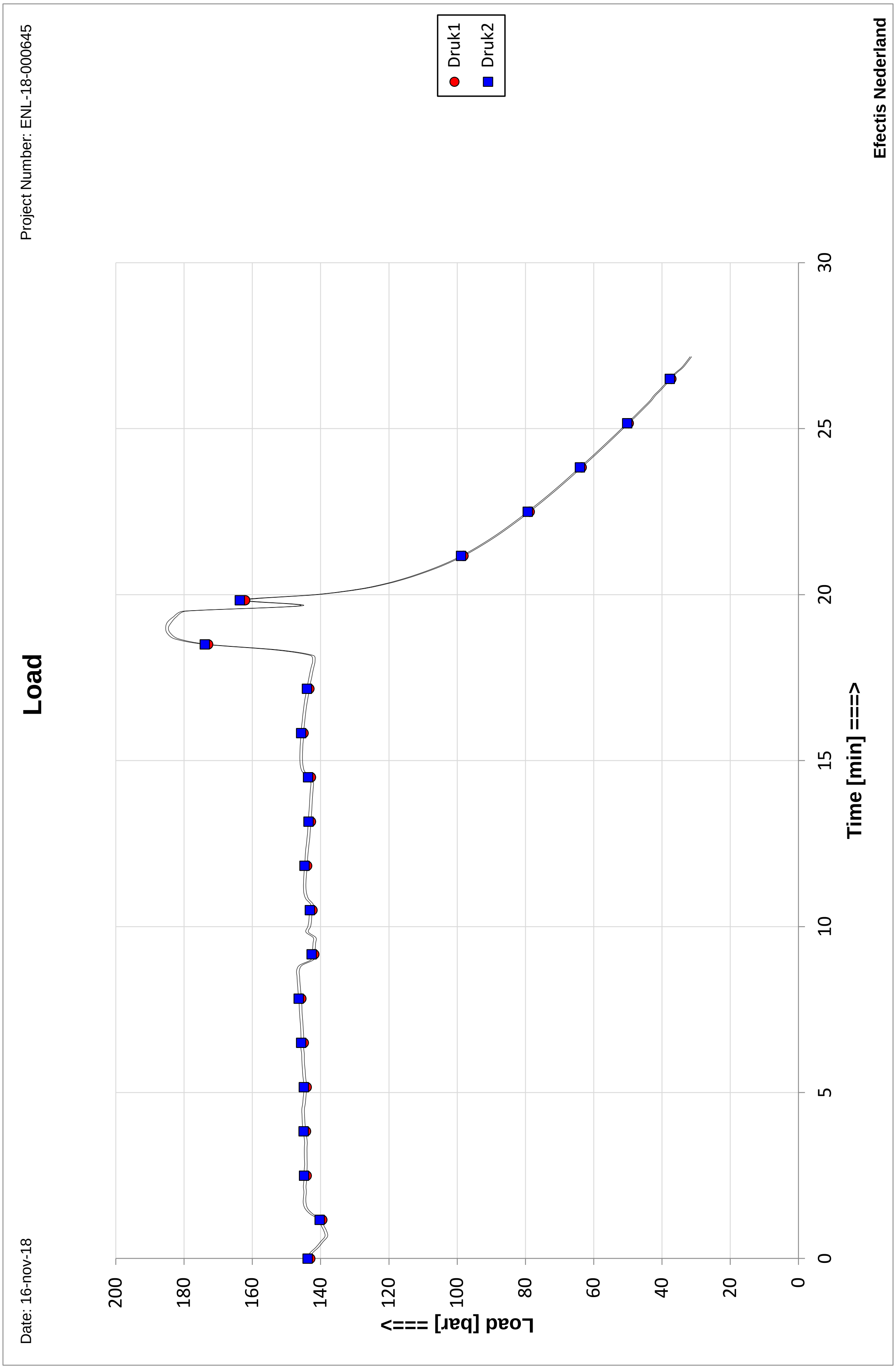


Figure B.8 Test 1: load applied on the loaded beam with coating thickness 264 µm

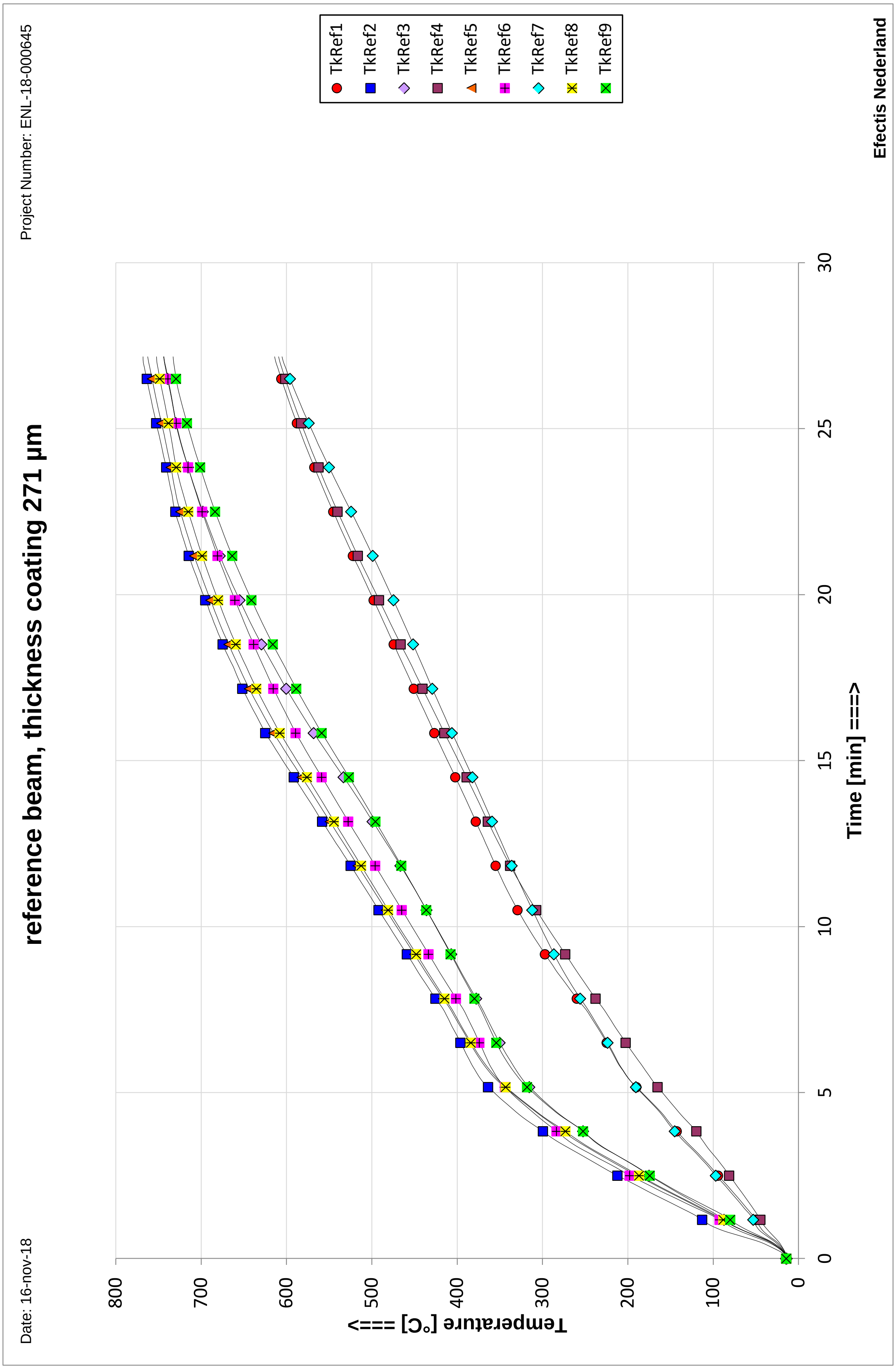


Figure B.9 Test 1: Reference beam IPE 400, coating thickness 271 µm

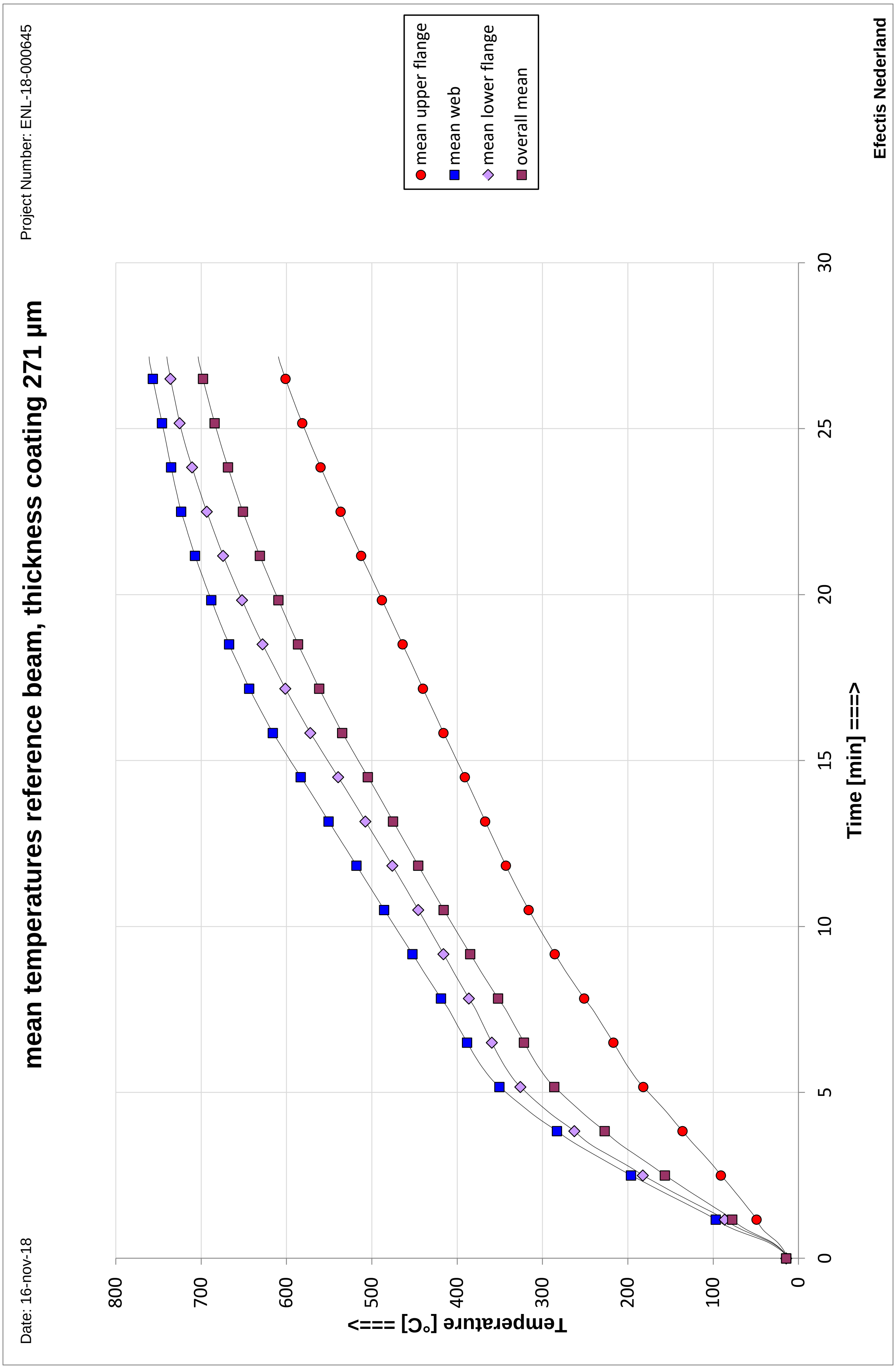


Figure B.10 Test 1: mean temperatures reference beam IPE 400, coating thickness 271 µm

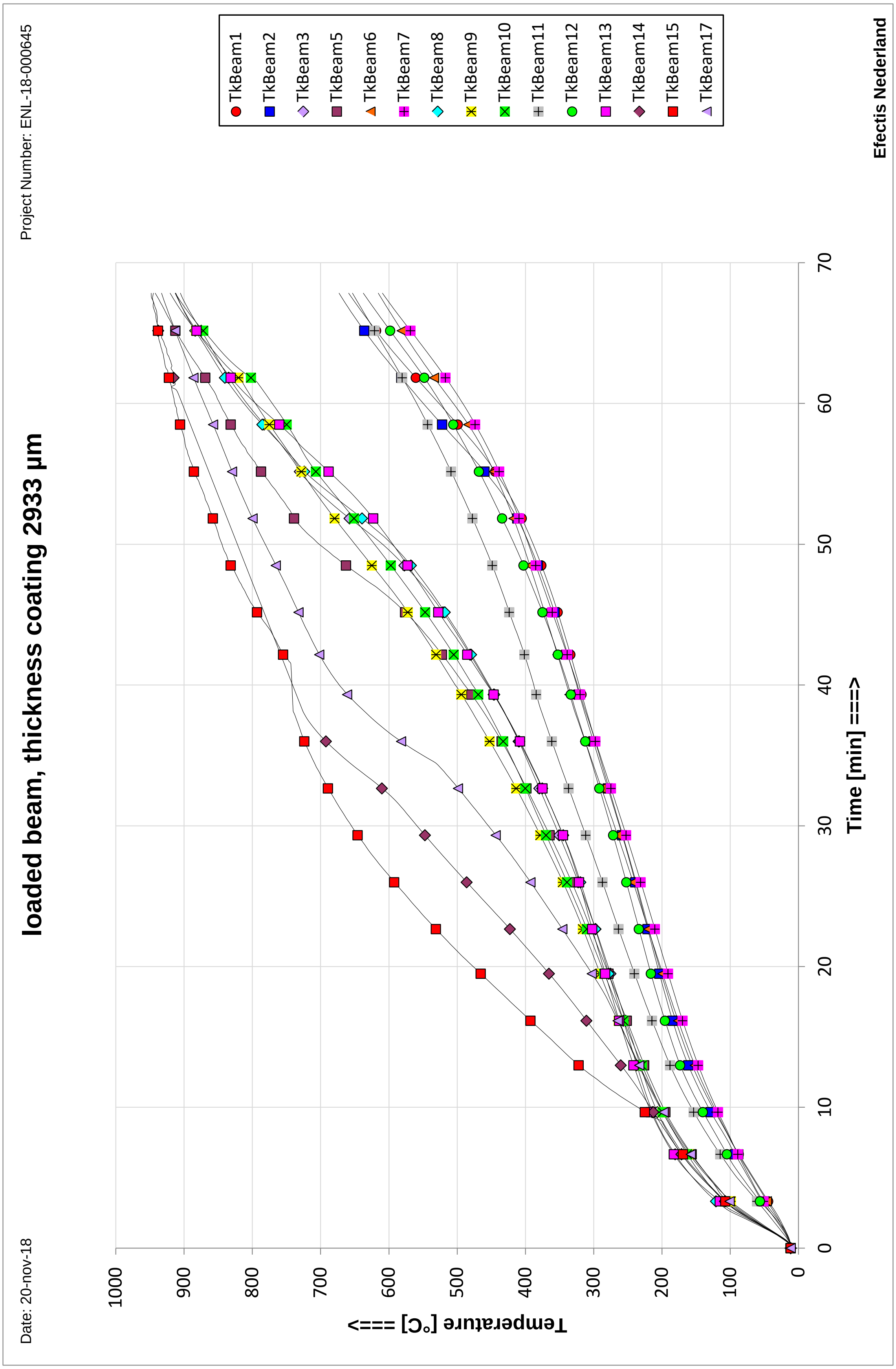


Figure B.11 Test 2: Loaded beam IPE 400, coating thickness 2933 µm

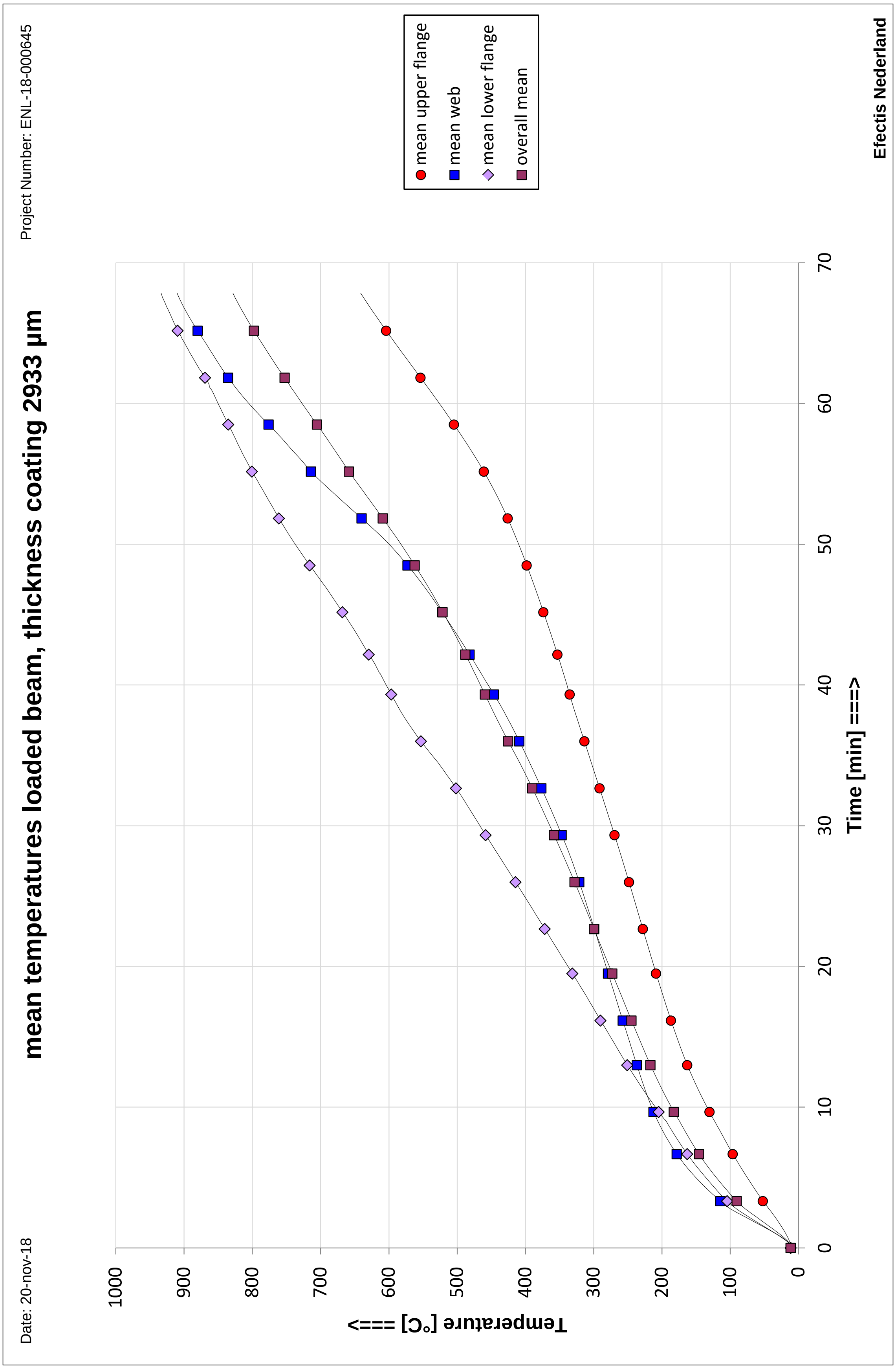


Figure B.12 Test 2: mean temperatures loaded beam IPE 400, coating thickness 2933 µm

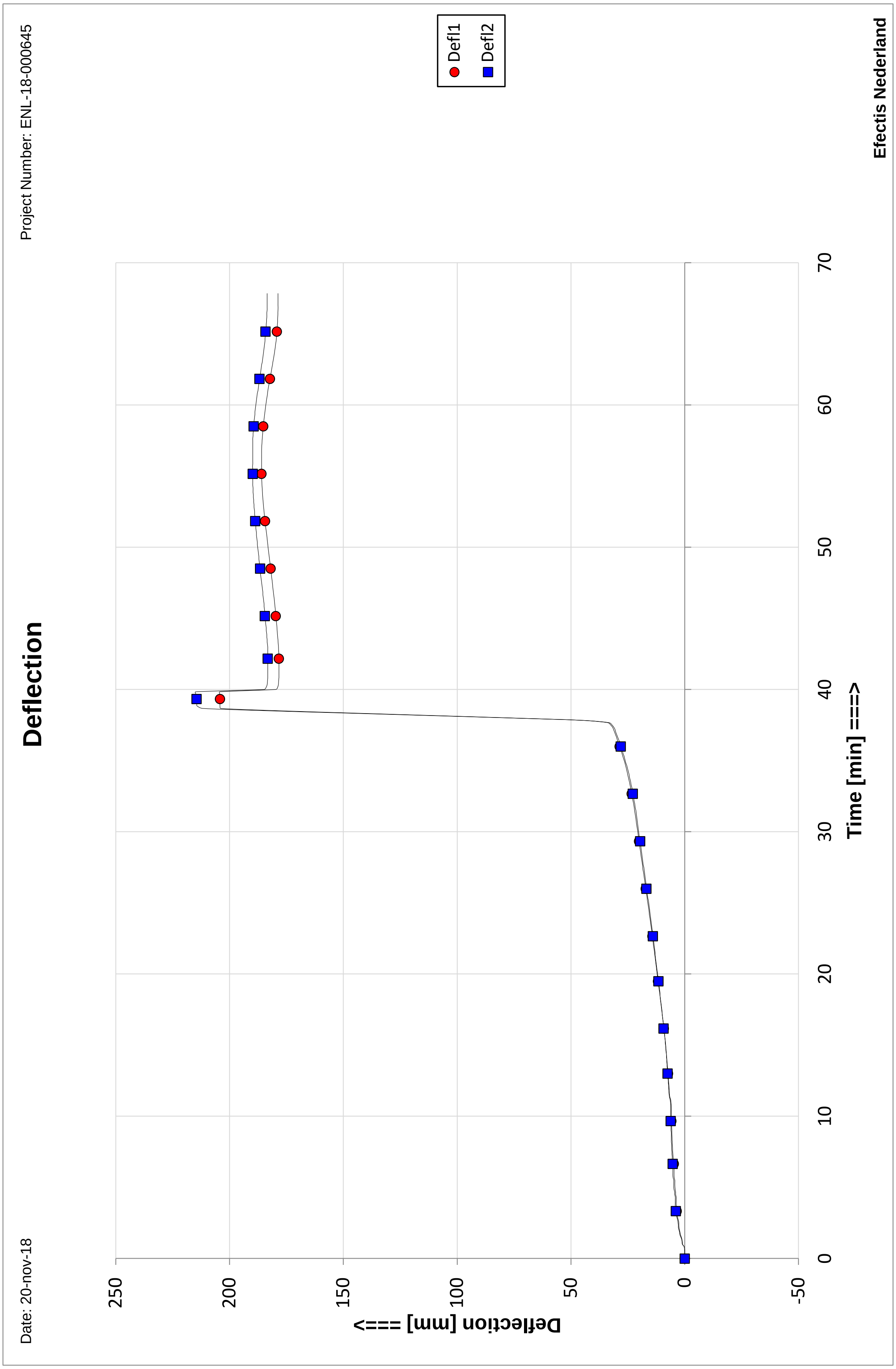


Figure B.13 Test 2: deformation of the loaded beam with coating thickness 2933 µm

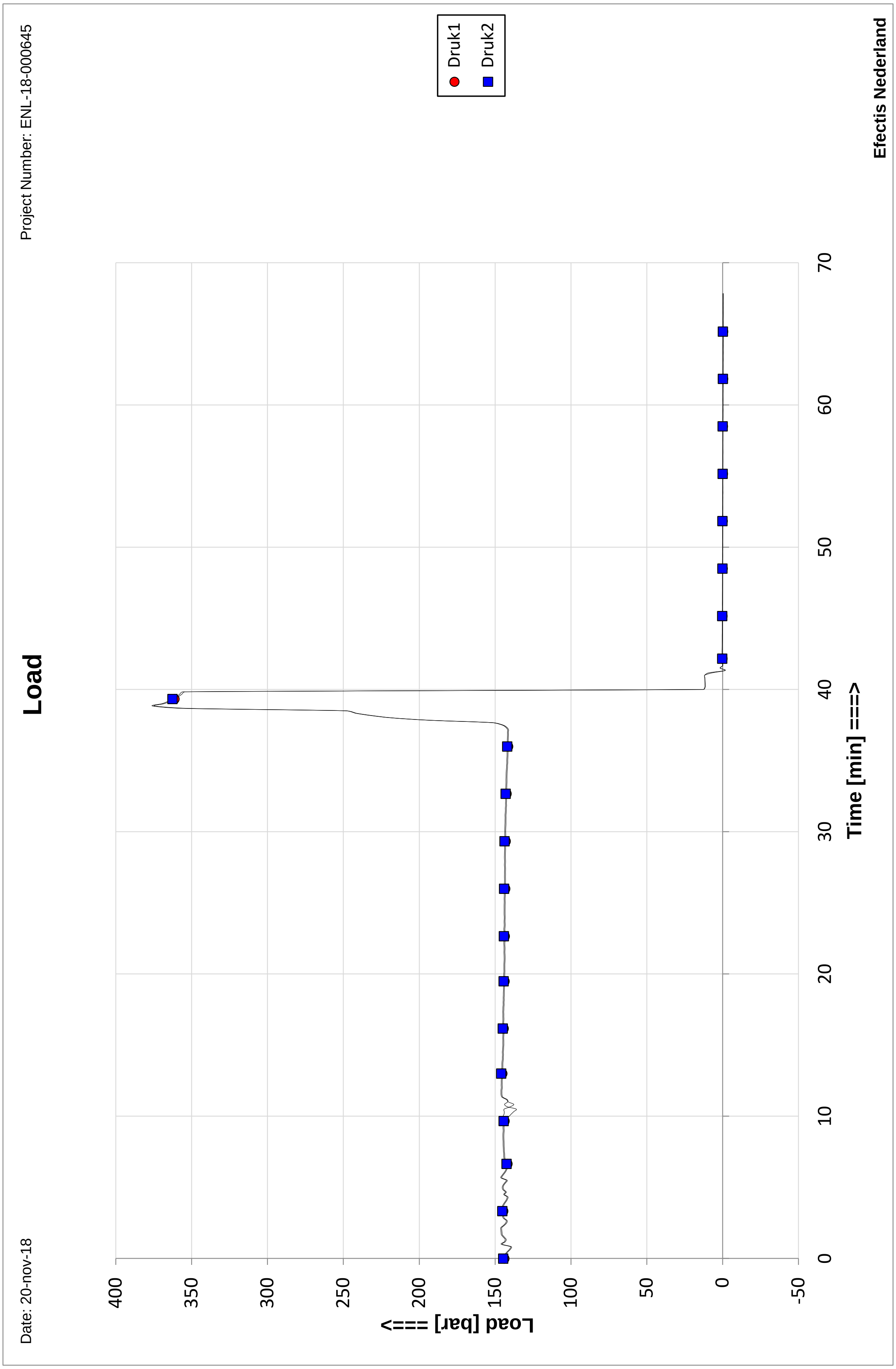


Figure B.14 Test 2: load applied on the loaded beam with coating thickness 2933 µm

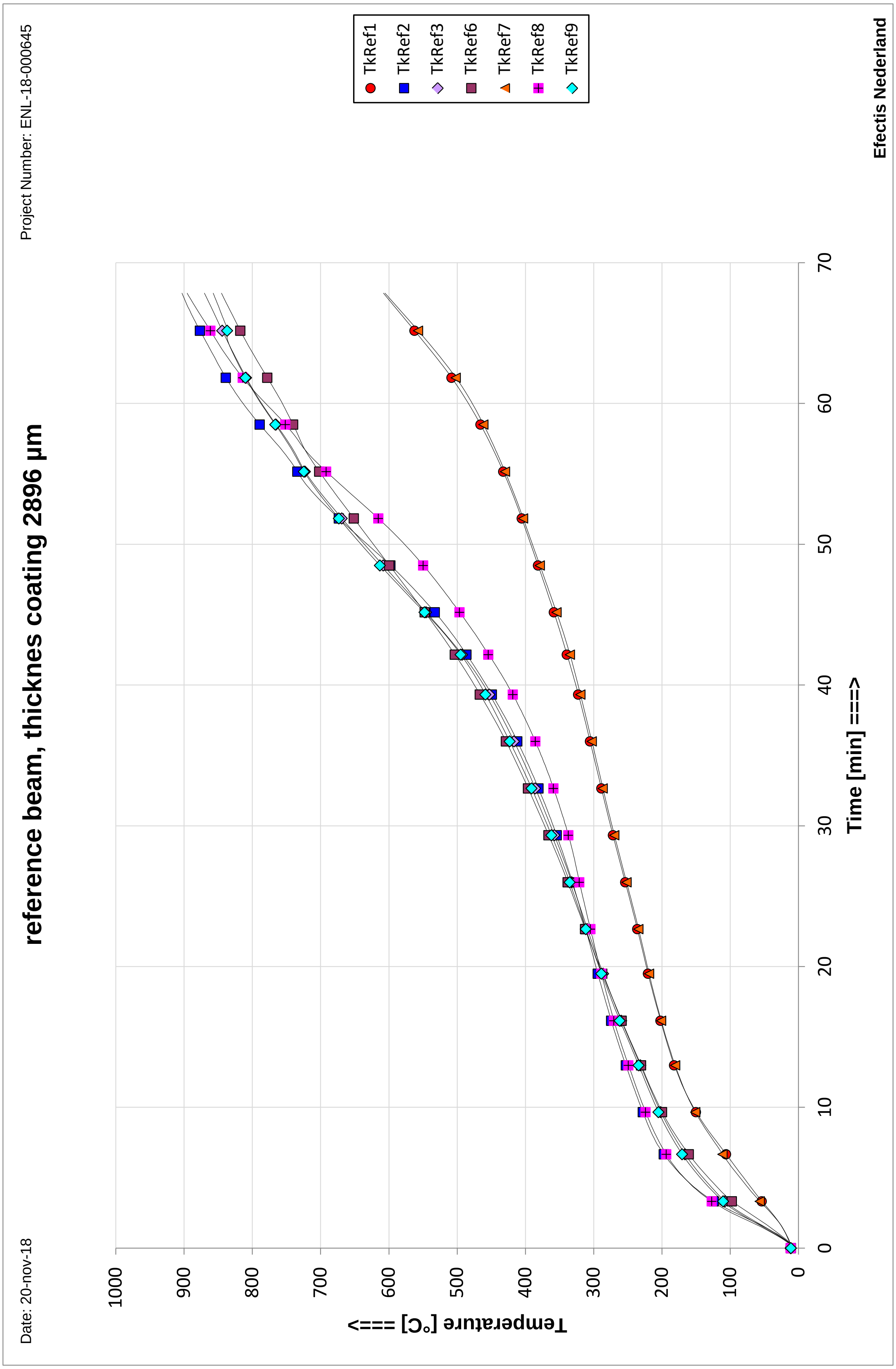


Figure B.15 Test 2: Reference beam IPE 400, coating thickness 2896 µm

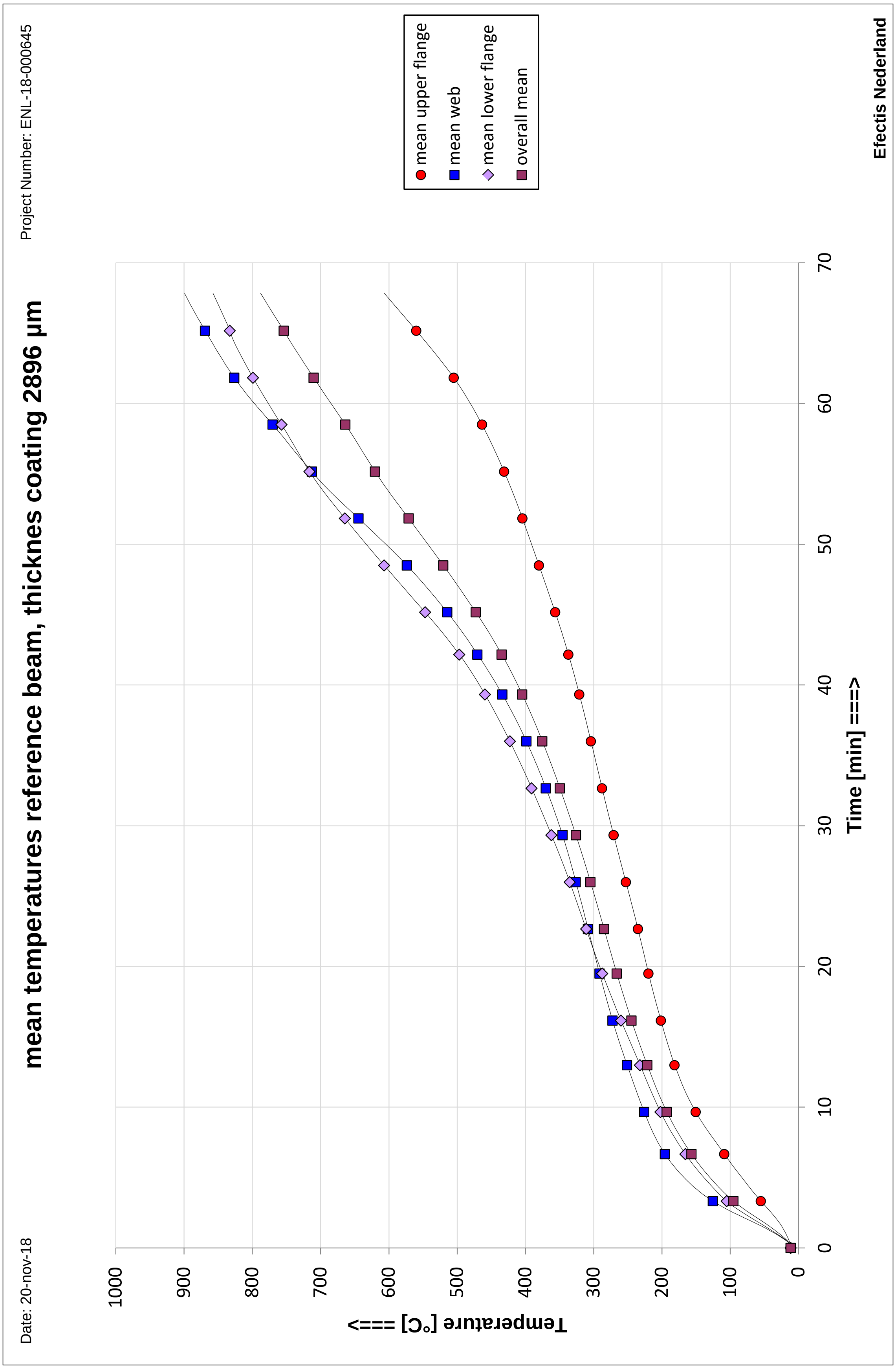


Figure B.16 Test 2: mean temperatures reference beam IPE 400, coating thickness 2896 µm

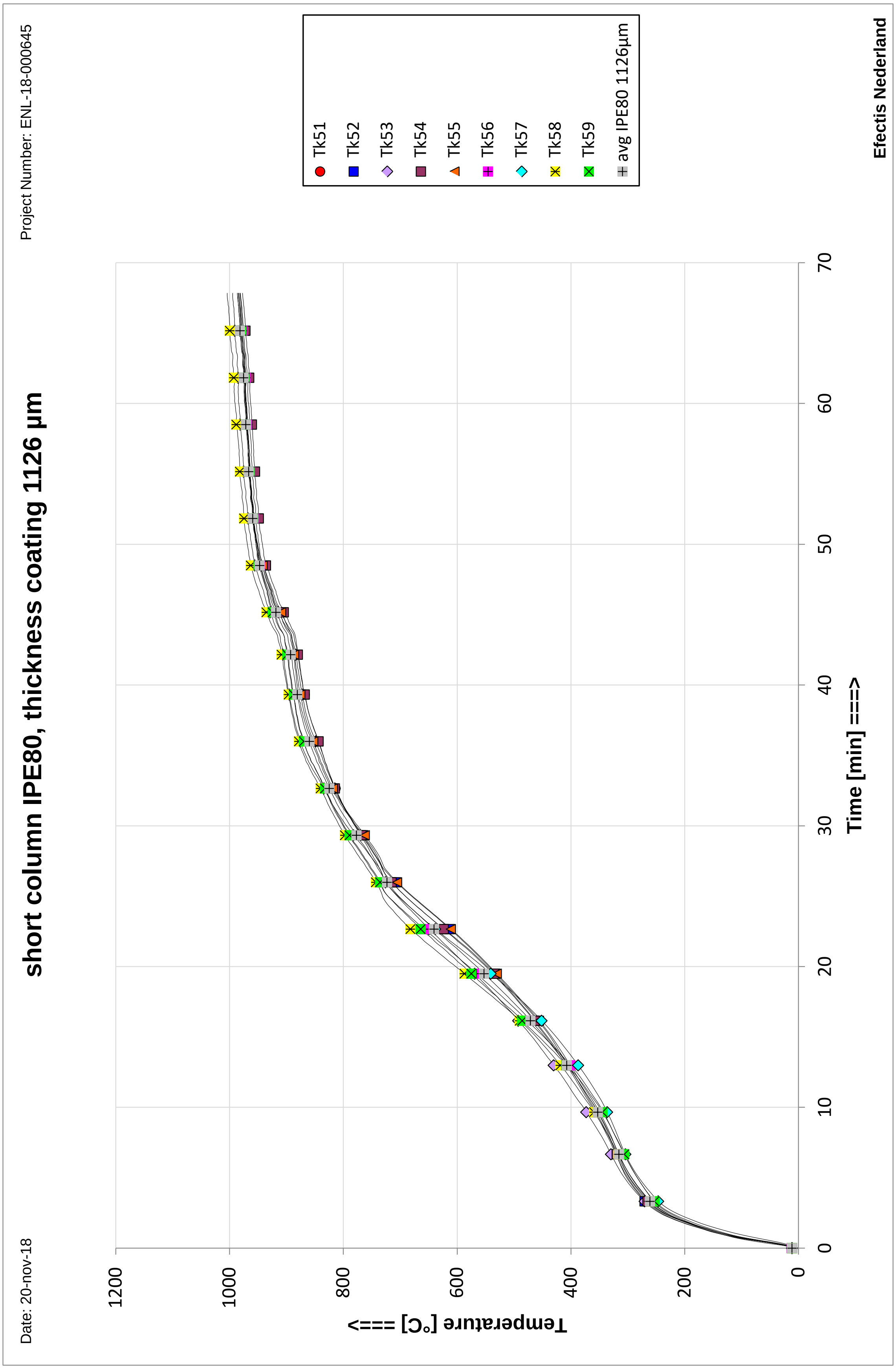


Figure B.17 Test 2: Unloaded short column IPE 80, coating thickness 1126 µm

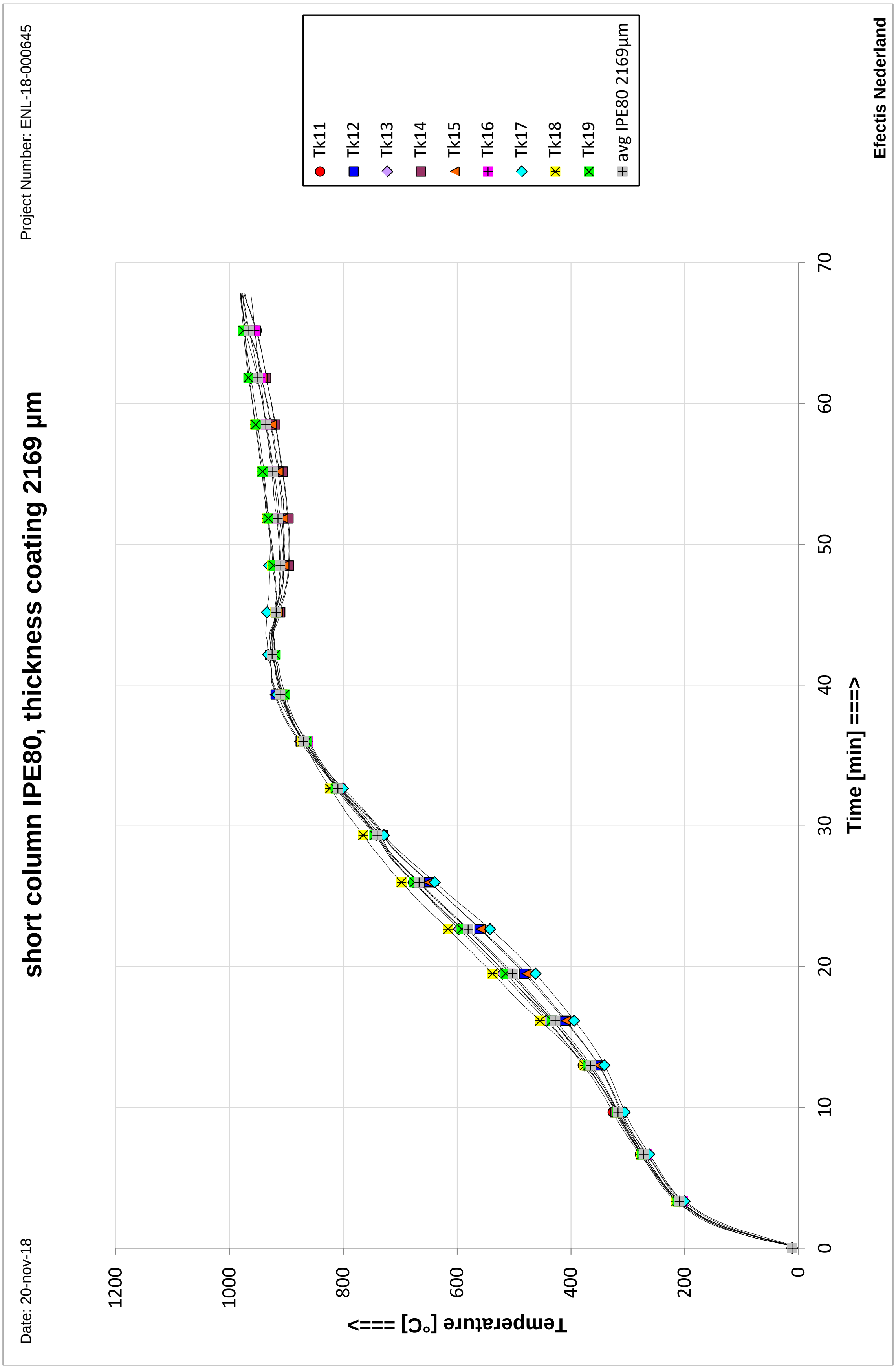


Figure B.18 Test 2: Unloaded short column IPE 80, coating thickness 2169 µm

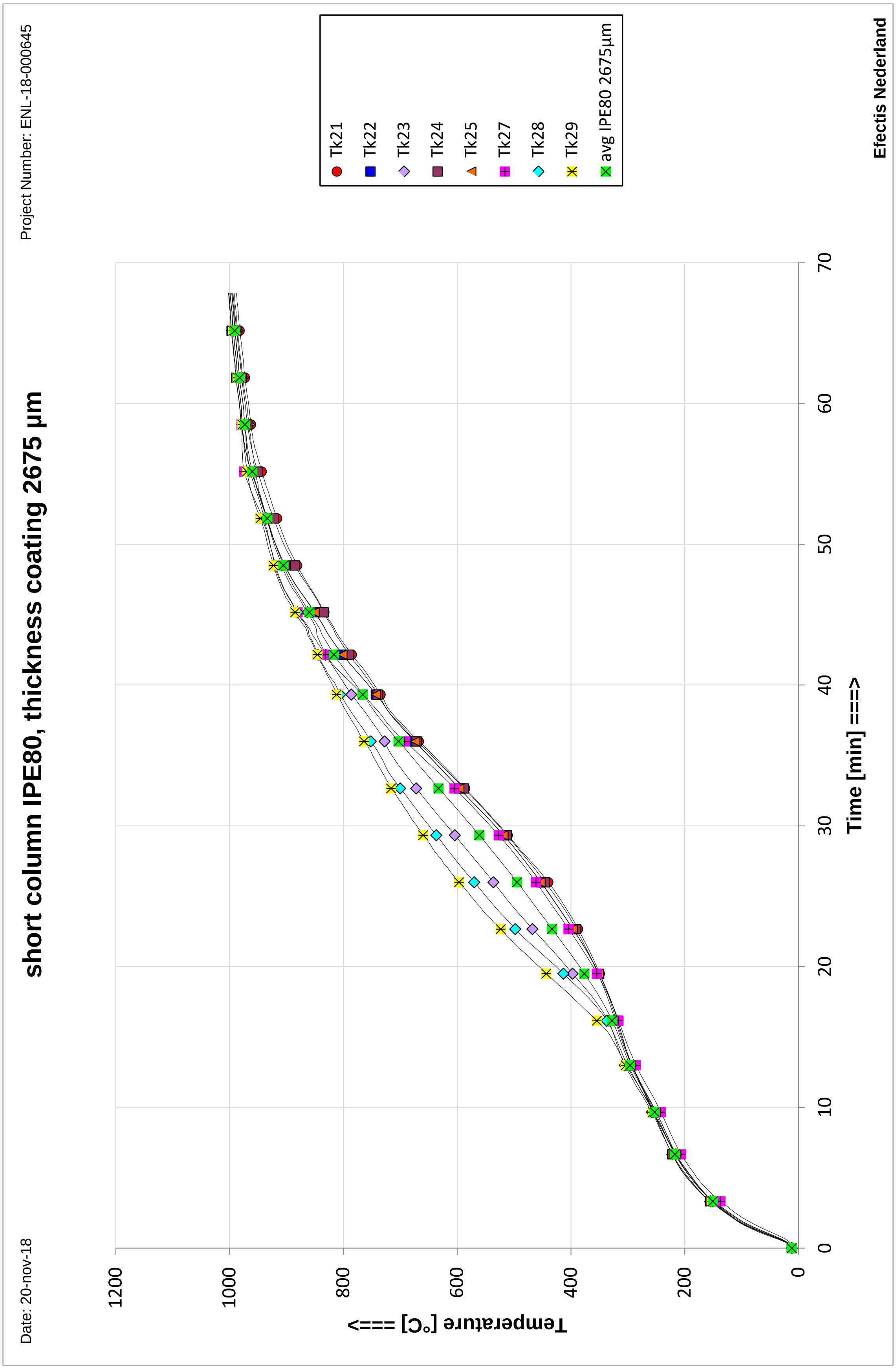


Figure B.19 Test 2: Unloaded short column IPE 80, coating thickness 2675 µm

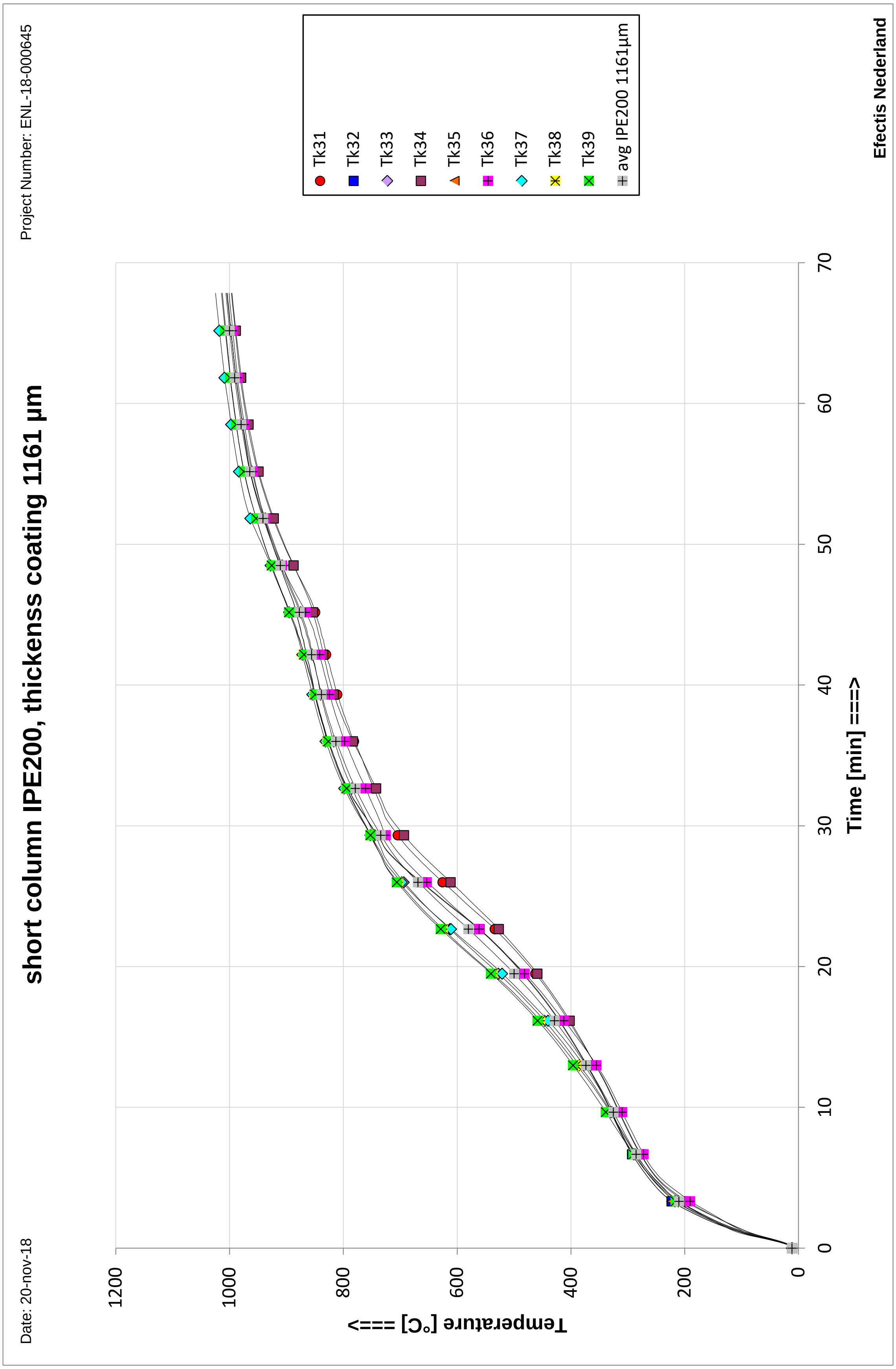


Figure B.20 Test 2: Unloaded short column IPE 200, coating thickness 1161 µm

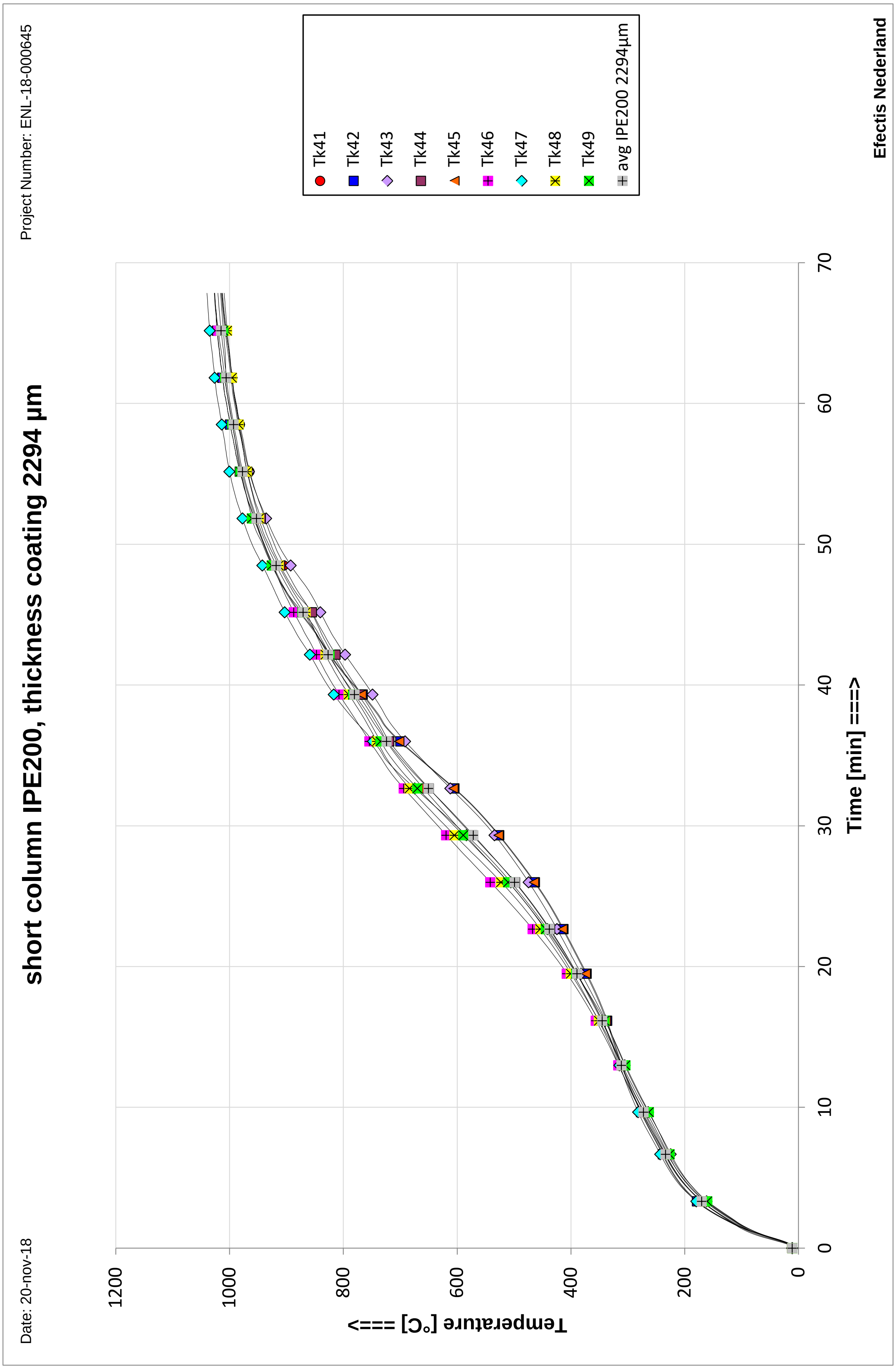


Figure B.21 Test 2: Unloaded short column IPE 200, coating thickness 2294 µm

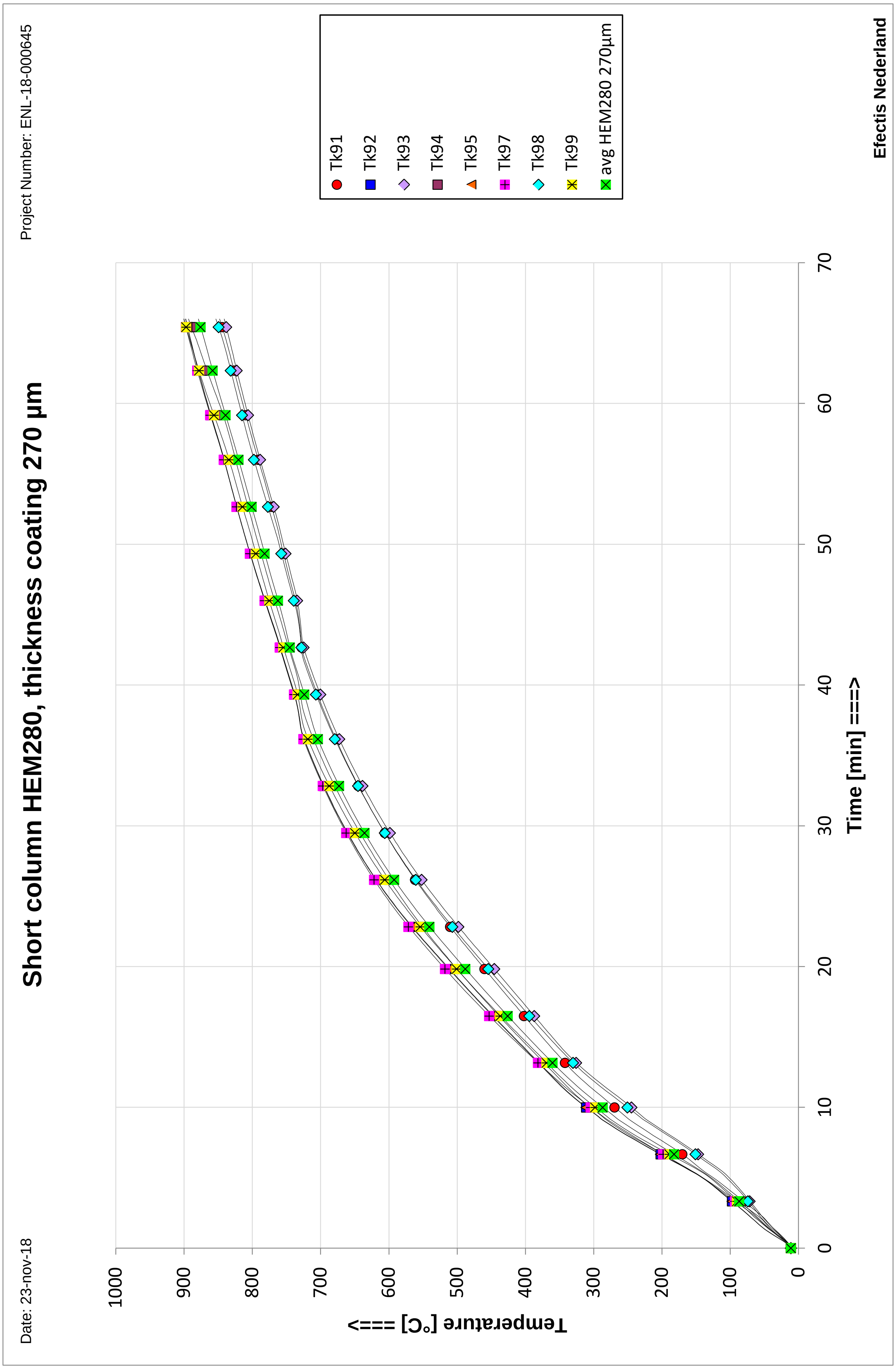


Figure B.22 Test 3: Unloaded short column HEM 280, coating thickness 270 µm

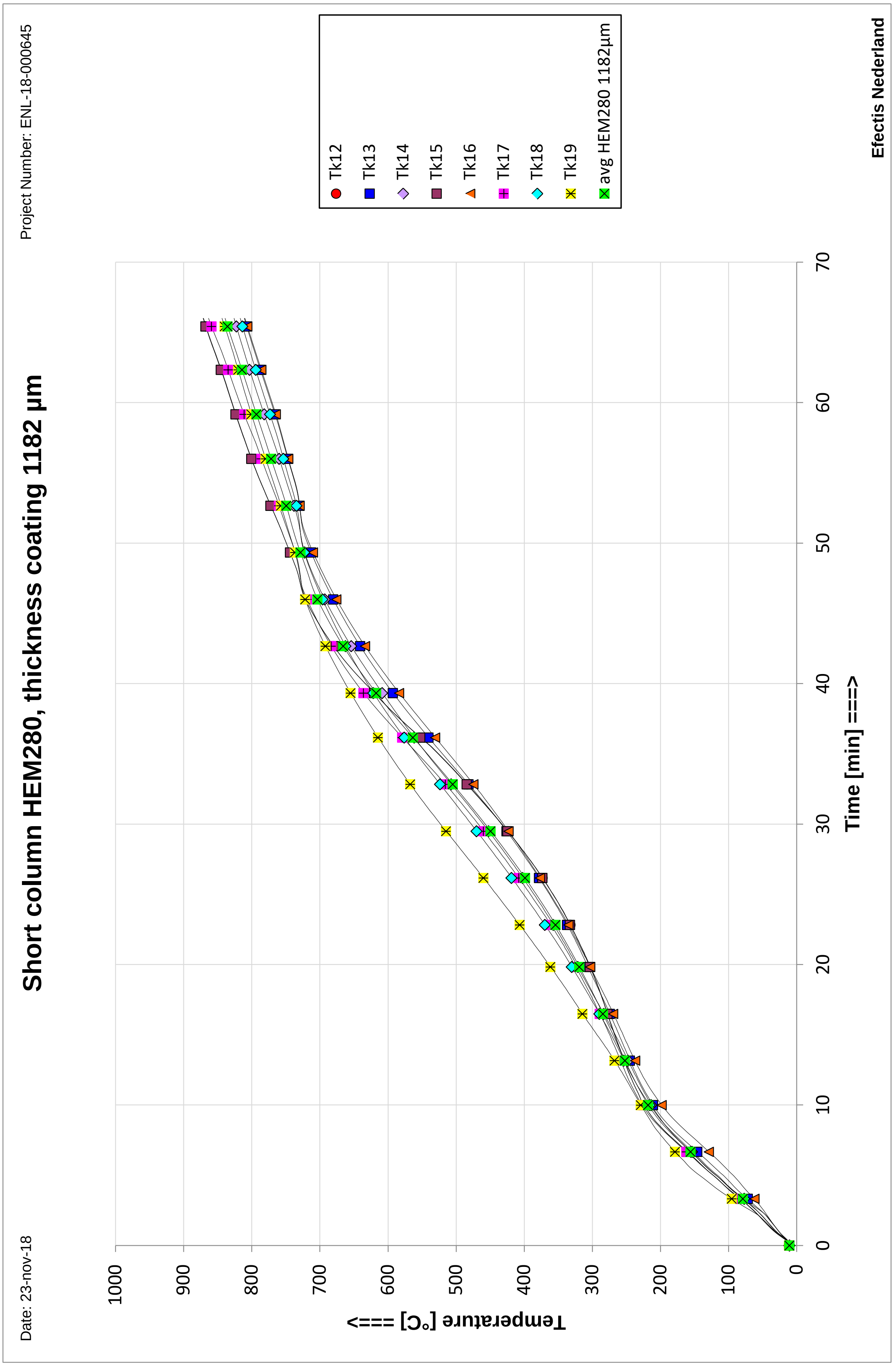


Figure B.23 Test 3: Unloaded short column HEM 280, coating thickness 1182 µm

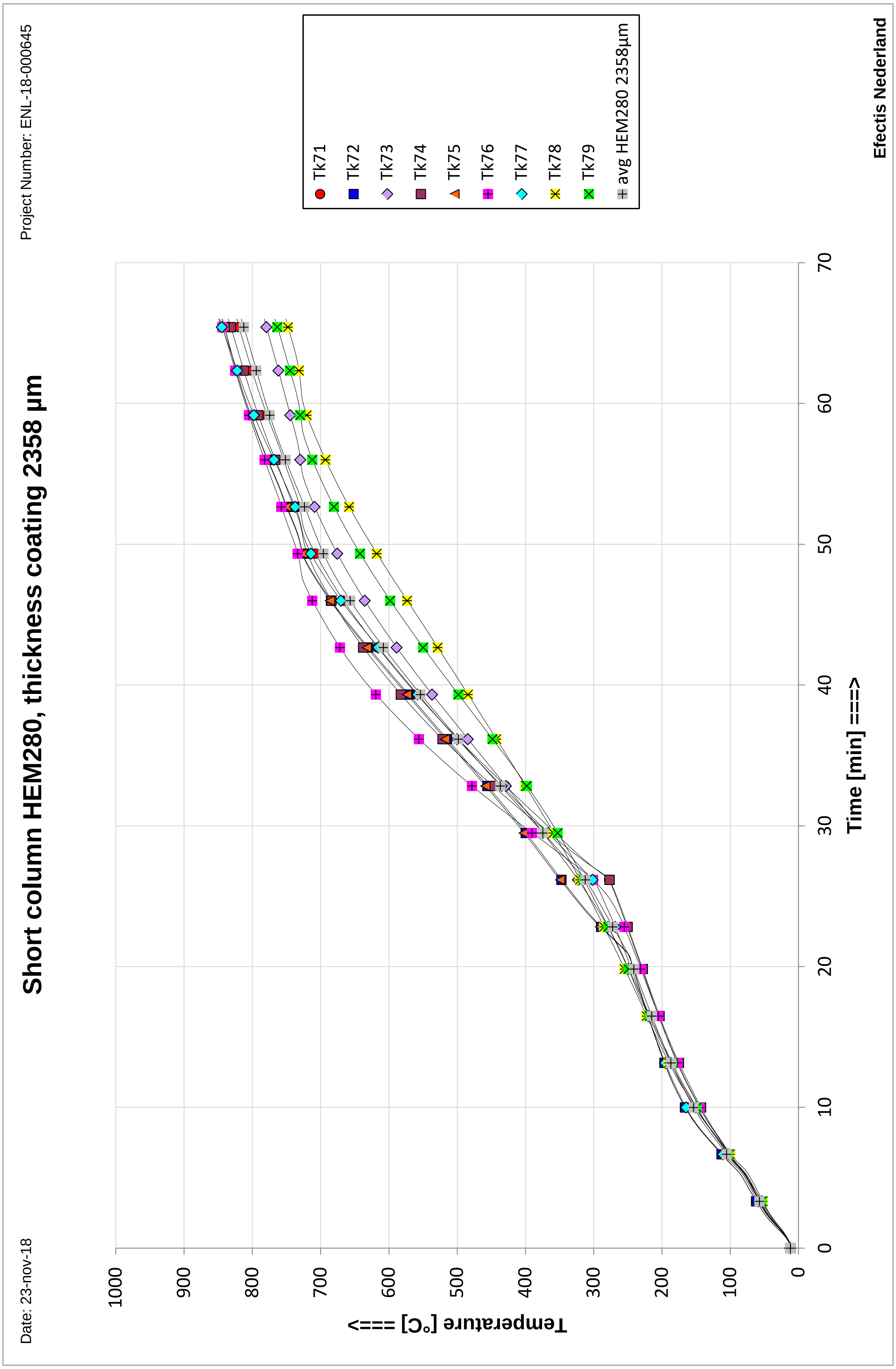


Figure B.24 Test 3: Unloaded short column HEM 280, coating thickness 2358 µm

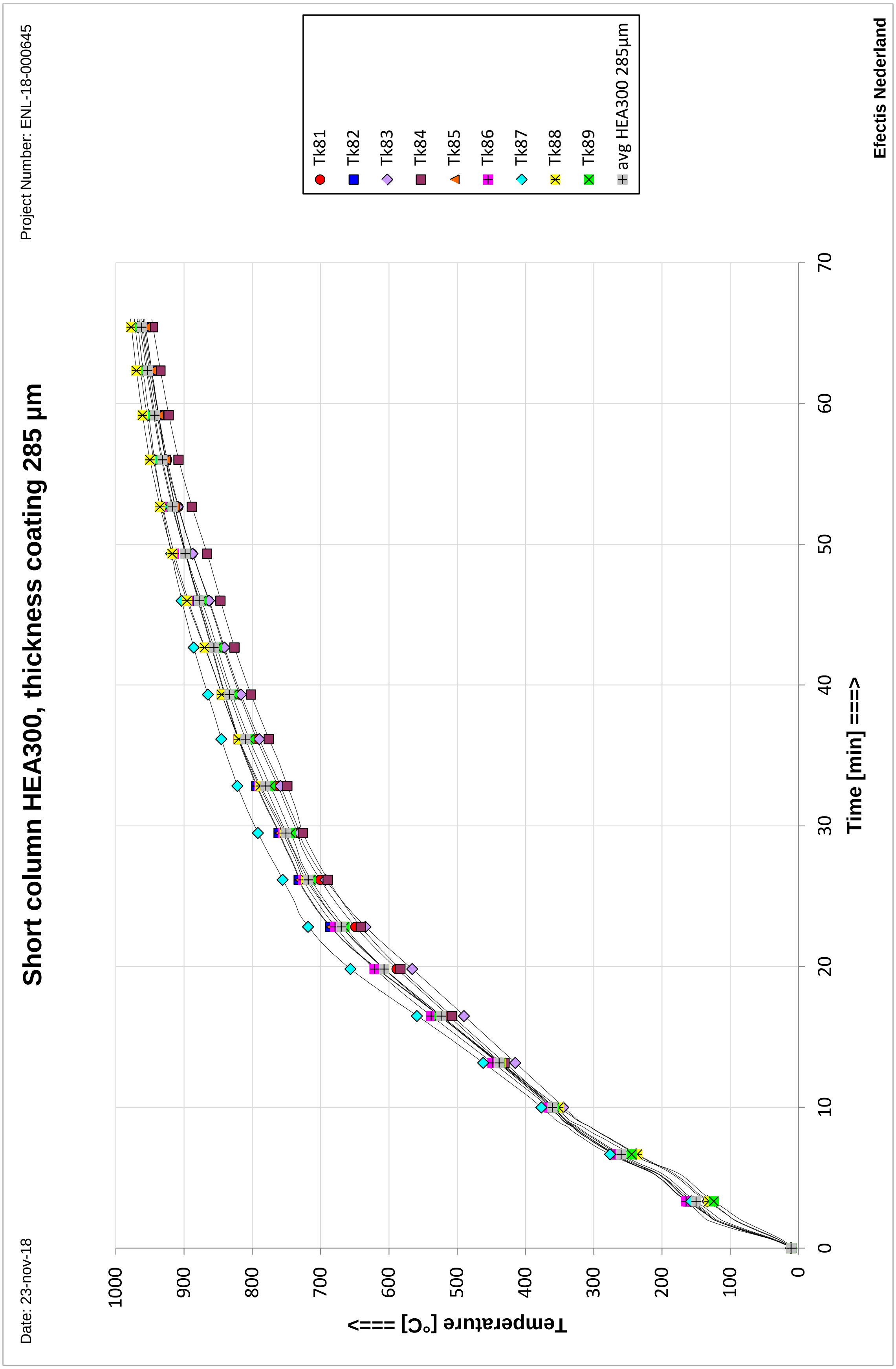


Figure B.25 Test 3: Unloaded short column HEA 300, coating thickness 285 µm

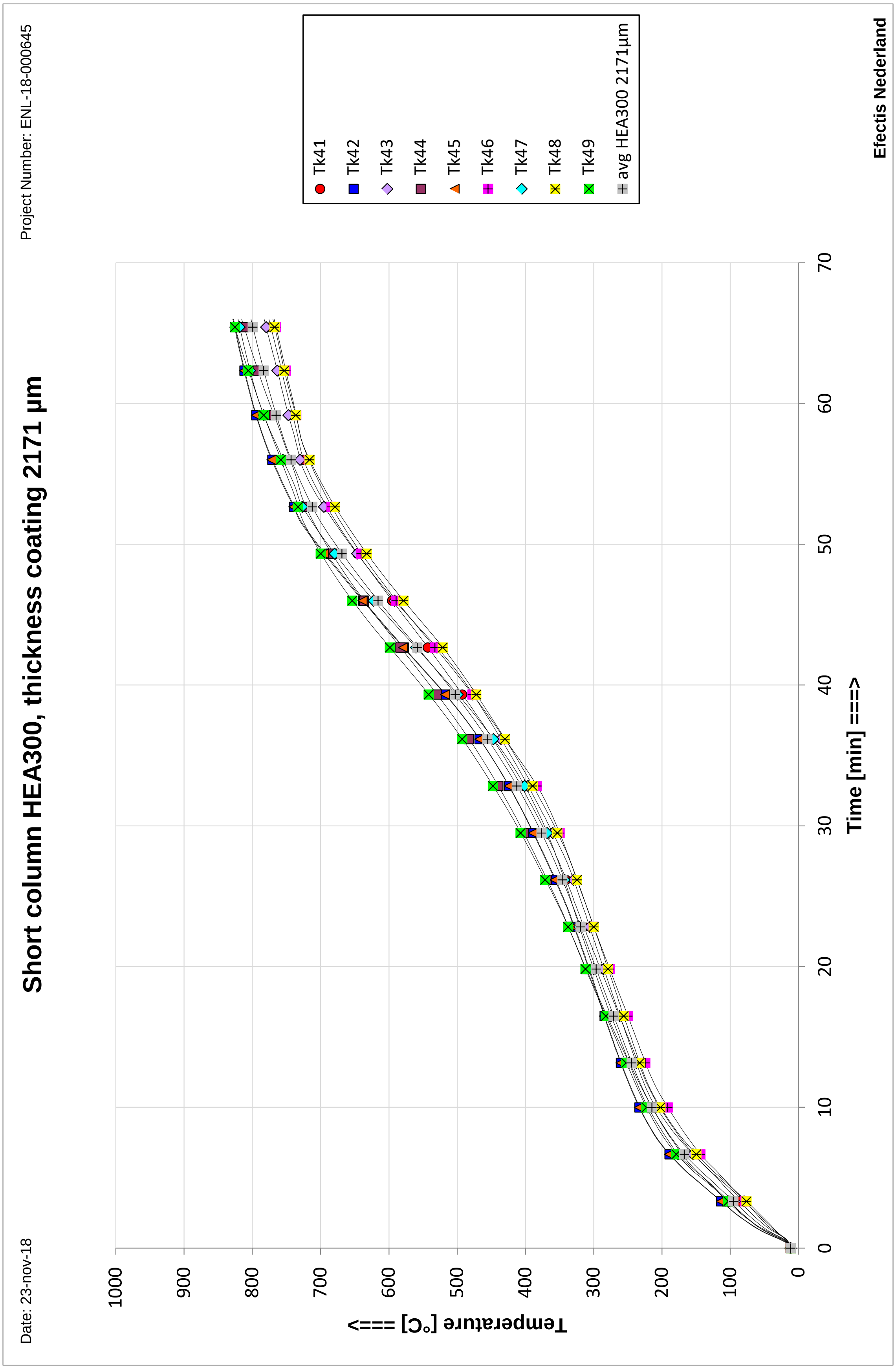


Figure B.26 Test 3: Unloaded short column HEA 300, coating thickness 2171 µm

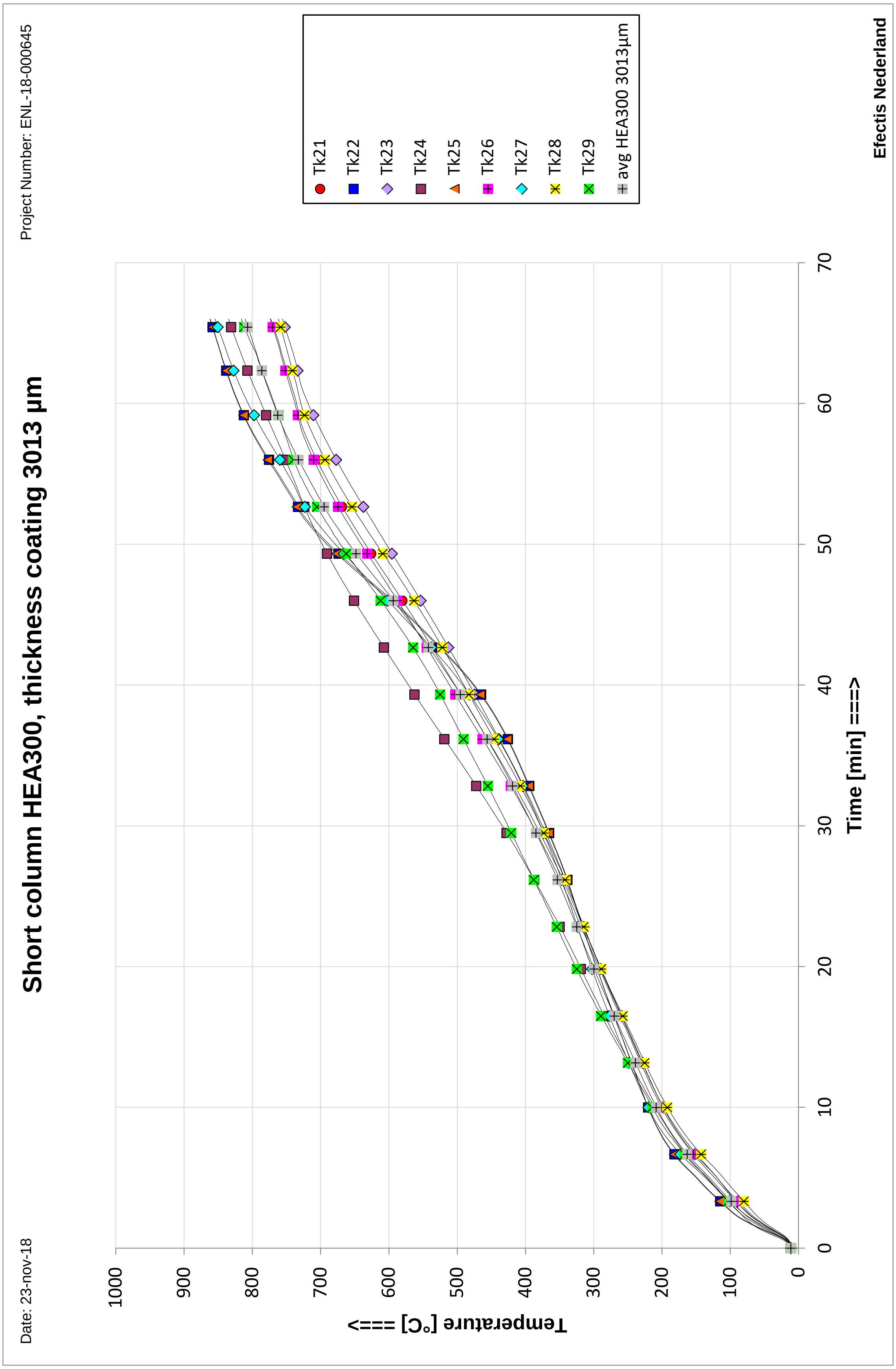


Figure B.27 Test 3: Unloaded short column HEA 300, coating thickness 3013 µm

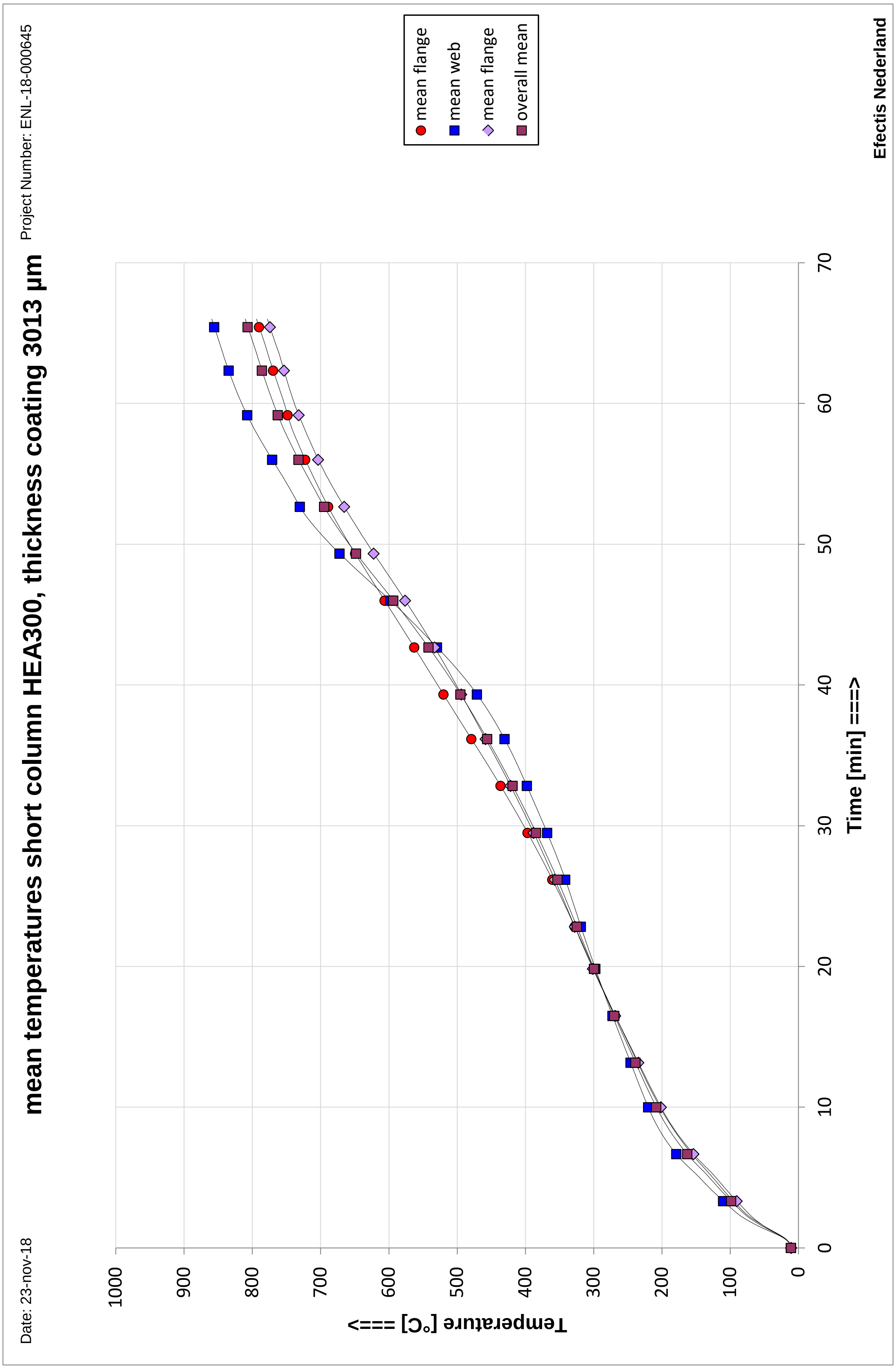


Figure B.28 Test 3: mean temperatures short column HEA 300, coating thickness 3013 µm

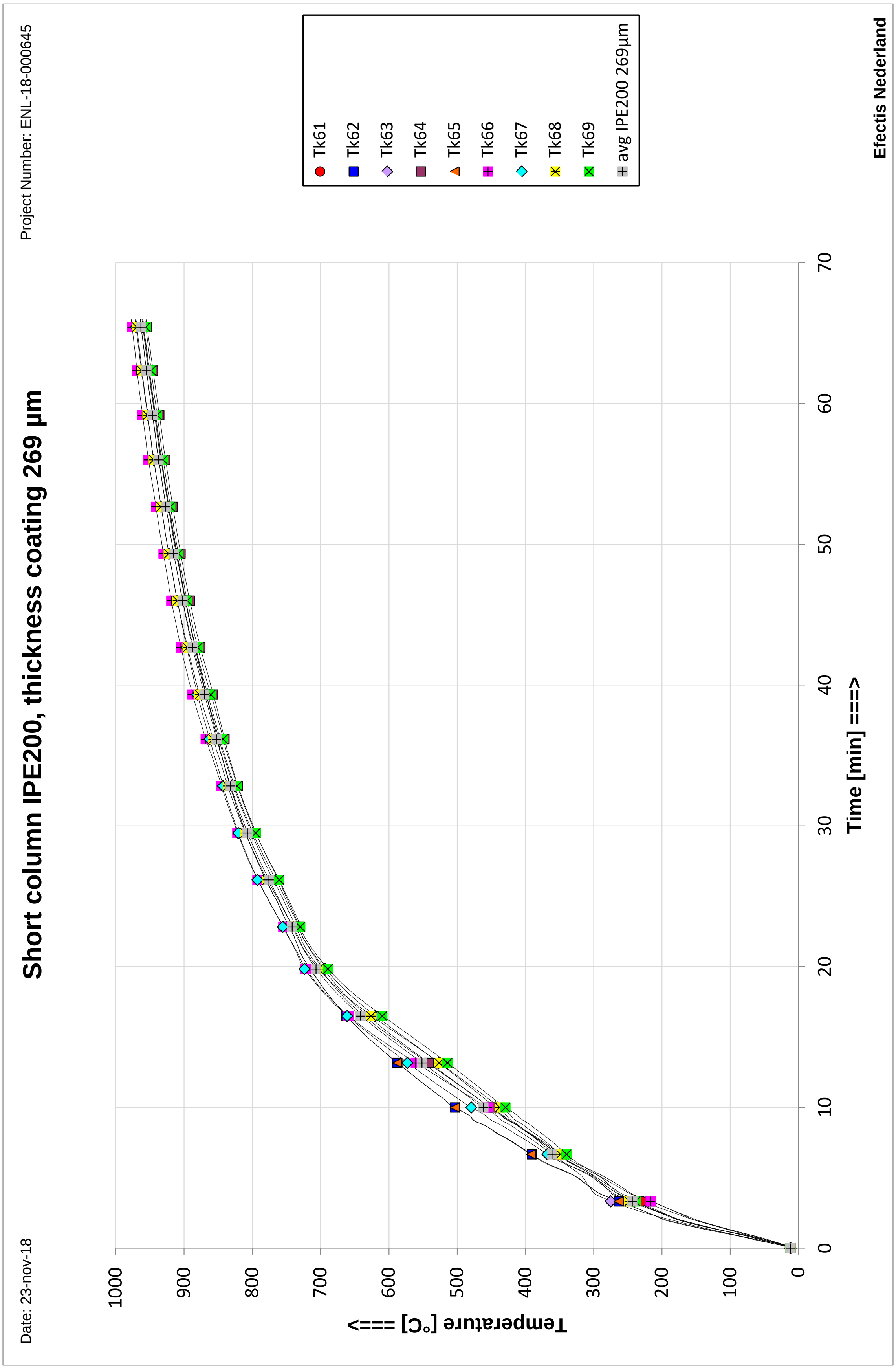


Figure B.28 Test 3: Unloaded short column IPE 200, coating thickness 269 µm

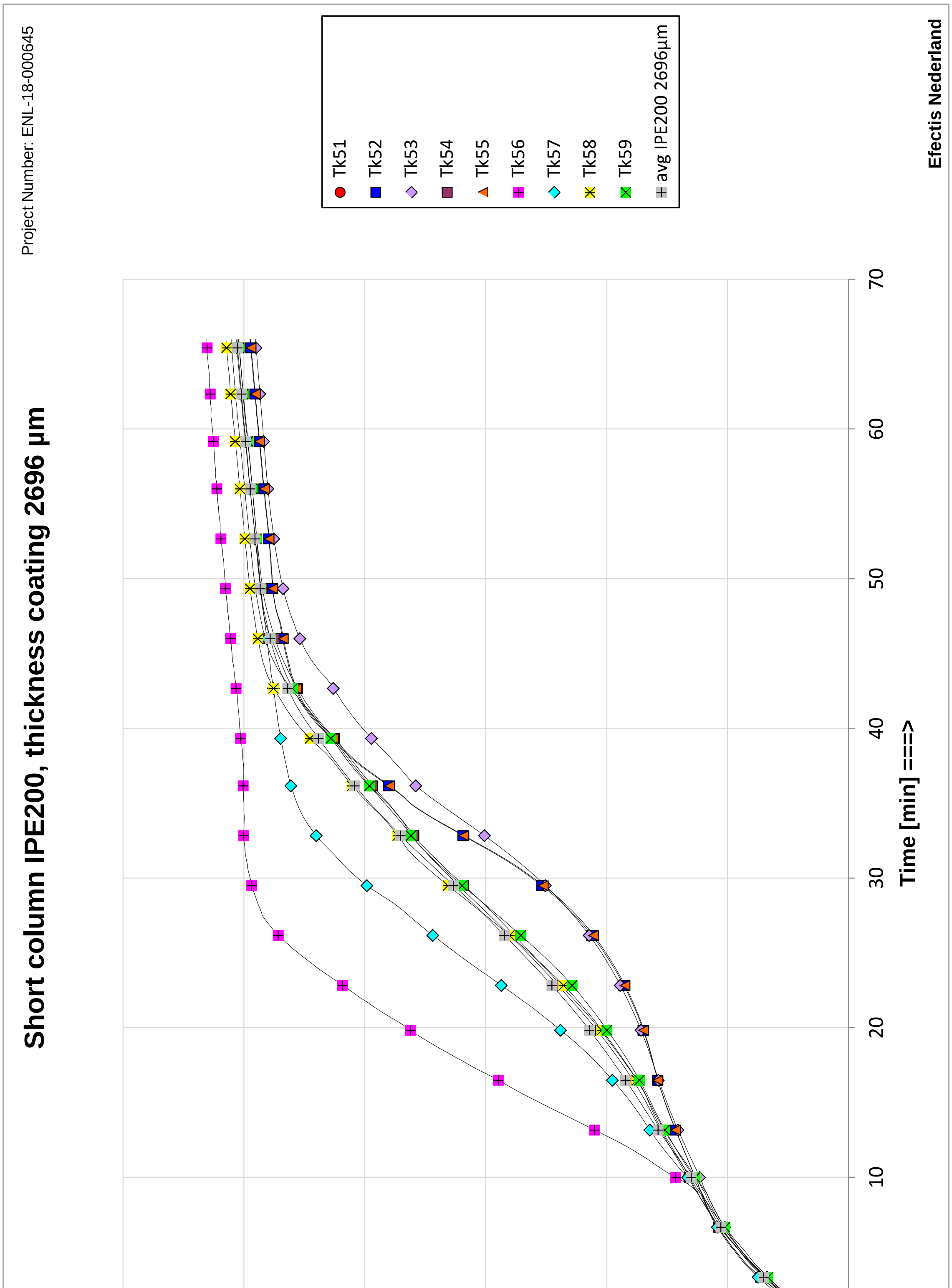


Figure B.29 Test 3: Unloaded short column IPE 200, coating thickness 2696 µm

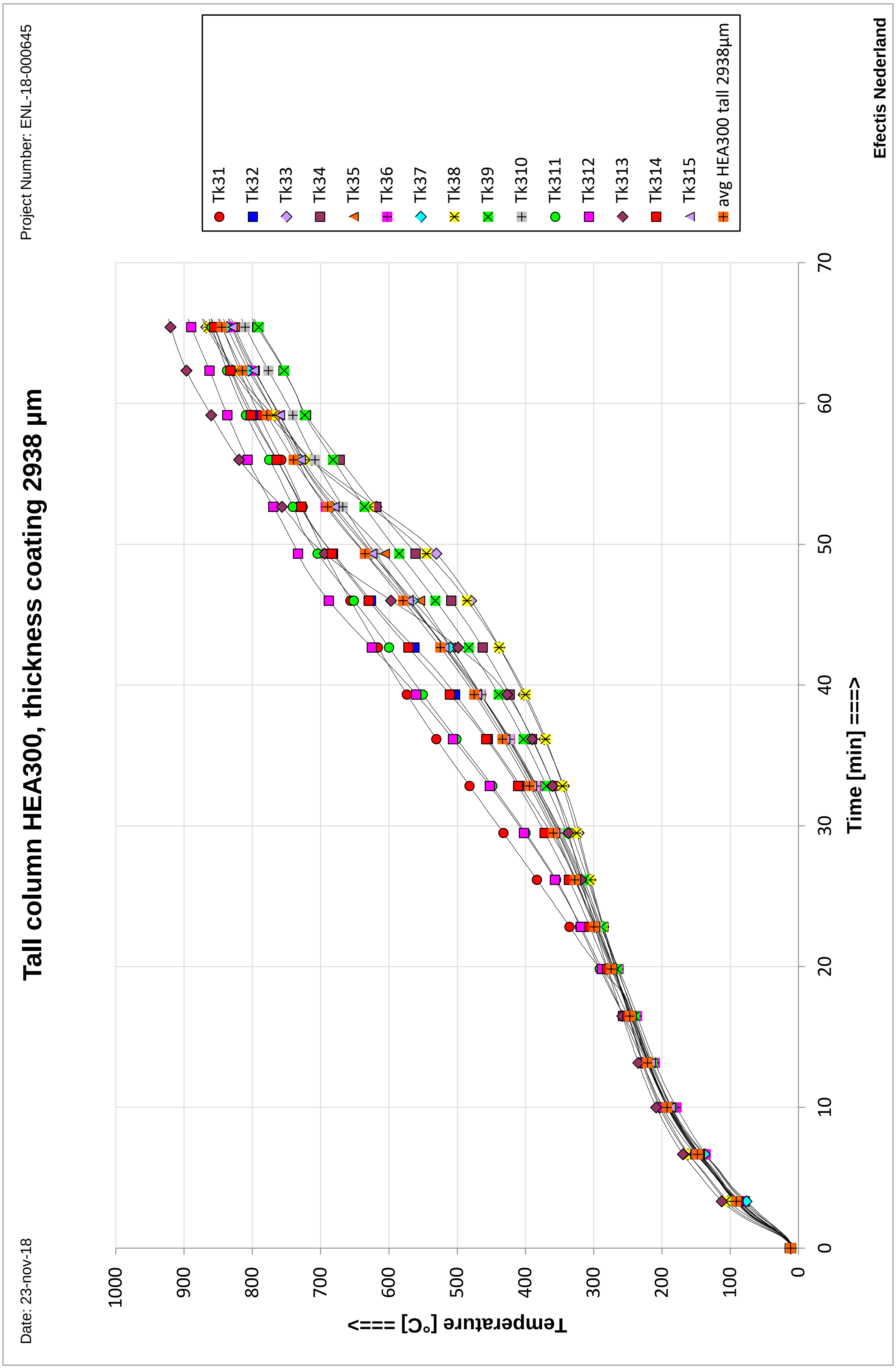


Figure B.30 Test 3: Unloaded tall column HEA 300, coating thickness 2938 µm

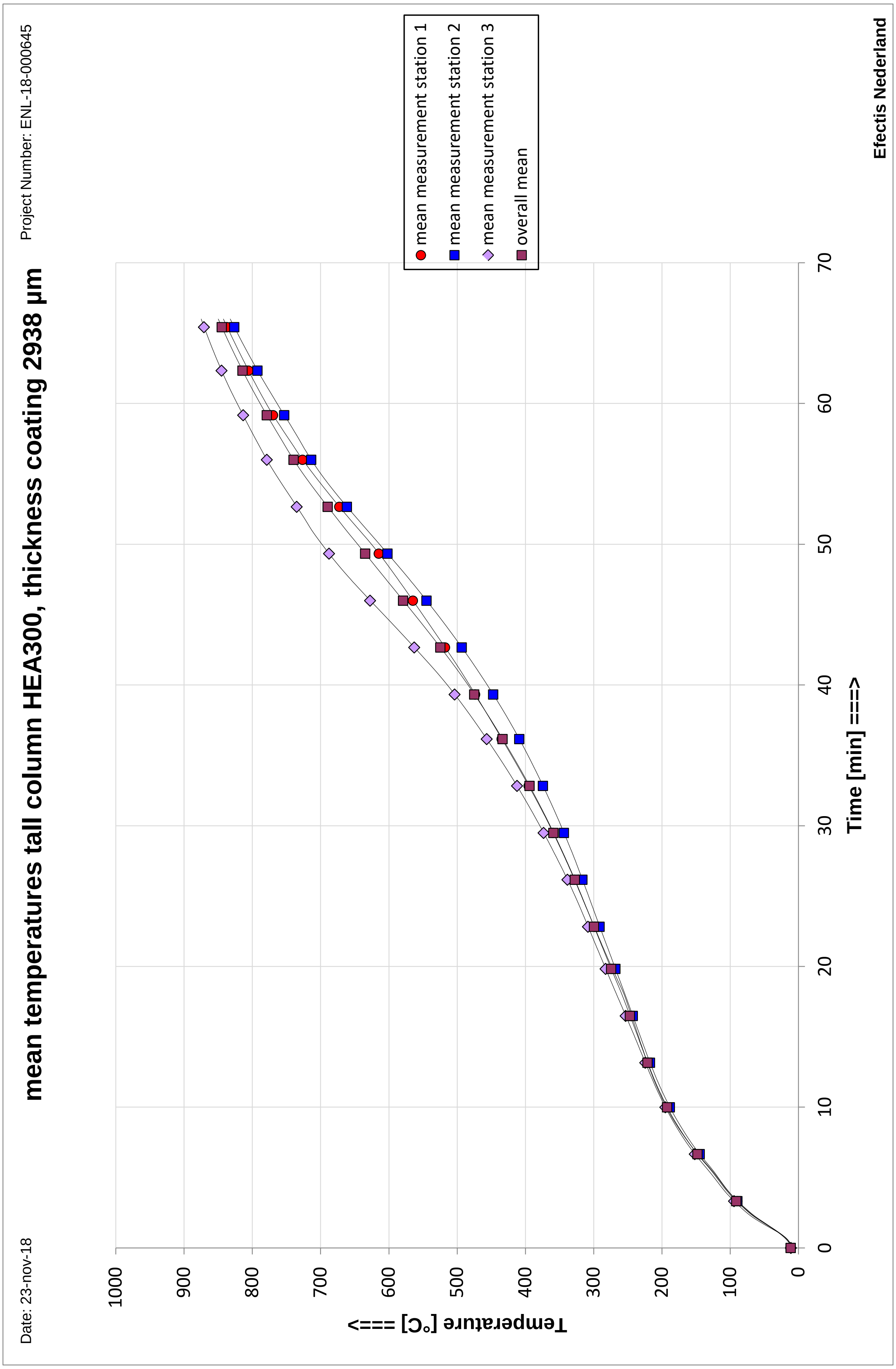


Figure B.31 Test 3: mean temperatures unloaded tall column, coating thickness 2938 µm

APPENDIX C: LOAD CALCULATION

AERATED CONCRETE	
total length (m)	4.5
thickness (m)	0.15
width (m)	0.6
volume (m³)	0.405
density (kg/m³)	671
total weight (kg)	271.755
load (kN/m¹)	0.604
CERAMIC BLANKET	
total length (m)	4.5
thickness (m)	0.025
width (m)	0.18
volume (m³)	0.020
density (kg/m³)	125
total weight (kg)	2.531
load (kN/m¹)	0.006
BEAM IPE 400	
weight (kg.m)	66.3
weight (kN/m¹)	0.663
PROTECTION OF THE BEAM	
total length (m)	4.5
total width (m)	1.323
thickness (m)	0.003
volume (m³)	0.018
density (kg/m³)	1000
total weight (kg)	17.858
load (kN/m¹)	0.040
Moment = (1.8 * applied load (kN) + 1/8 * Q x L²	
Q = load aerated concrete (kN/m¹) + load ceramic blanket (kN/m¹) + load IPE400 (kN/m¹) + load protection (kN/m¹)	
Q (kN/m¹)	1.312
hydraulic jack load (kN)	101
surface of the piston of the hydraulic jack (mm²)	6981
pressure (n/mm²)	14.468
hydraulic jack load (bar) at 500 KN jack	144.678
hydraulic jack load (volt) at 500 kN jack and 1000 bar transducer	1.447
hydraulic jack load (volt) at 500 kN jack and 250 bar transducer	5.787
Moment = (0.9 * D50))+(1.8 * D50))+ (1/8 x D46)*4.5²	
Moment (kN/m)	185.122
Moment M (N/mm)	185121529
resistance moment W (mm³)	1307147
Stress (N/mm²) = M/W	141.623
is approx. 60% of a S235 beam	

Figure C.1 Load calculation Test 1

AERATED CONCRETE	
total length (m)	4.5
thickness (m)	0.15
width (m)	0.6
volume (m^3)	0.405
density (kg/m^3)	671
total weight (kg)	271.755
load (kN/m^1)	0.604
CERAMIC BLANKET	
total length (m)	4.5
thickness (m)	0.025
width (m)	0.18
volume (m^3)	0.020
density (kg/m^3)	125
total weight (kg)	2.531
load (kN/m^1)	0.006
BEAM IPE 400	
weight (kg.m)	66.3
weight (kN/m^1)	0.663
PROTECTION OF THE BEAM	
total length (m)	4.5
total width (m)	1.323
thickness (m)	0.03
volume (m^3)	0.179
density (kg/m^3)	1000
total weight (kg)	178.578
load (kN/m^1)	0.397
Moment = (1.8 * applied load (kN) + 1/8 * Q x L^2	
Q = load aerated concrete (kN/m^1) + load ceramic blanket (kN/m^1) + load IPE400 (kN/m^1) + load protection (kN/m^1)	
Q (kN/m^1)	1.669
hydraulic jack load (kN)	100
surface of the piston of the hydraulic jack (mm^2)	6981
pressure (n/mm^2)	14.325
hydraulic jack load (bar) at 500 KN jack	143.246
hydraulic jack load (volt) at 500 kN jack and 1000 bar transducer	1.432
hydraulic jack load (volt) at 500 kN jack and 250 bar transducer	5.730
Moment = (0.9 * D50))+(1.8 * D50))+ (1/8 x D46)*4.5^2	
Moment (kN/m)	184.226
Moment M (N/mm)	184225580.2
resistance moment W (mm^3)	1307147
Stress (N/mm^2) = M/W	140.937
is approx. 60% of a S235 beam	

Figure C.2 Load calculation Test 2

APPENDIX D: PHOTOS

Photo D.1 Intumescent coating

Photo D.2 Primer

Photo D.3 Application of the coating on the short columns

Photo D.4 Test 1: Loaded beam with minimum protection thickness before the test

Photo D.5 Test 1: Reference beam with minimum protection thickness before the test

Photo D.6 Test 1: Loaded beam with minimum protection thickness after the test

Photo D.7 Test 1: Reference beam with minimum protection thickness after the test

Photo D.8 Test 2: Loaded beam with maximum protection thickness before the test

Photo D.9 Test 2: Reference beam with maximum protection thickness before the test

Photo D.10 Test 2: Some of the unloaded columns before the test

Photo D.11 Test 2: Loaded beam with maximum protection thickness after the test (1)

Photo D.12 Test 2: Loaded beam with maximum protection thickness after the test (2)

Photo D.13 Test 2: Reference beam with maximum protection thickness after the test

Photo D.14 Test 2: Some of the unloaded columns after the test

Photo D.15 Test 3: Unloaded columns and tall column before the test

Photo D.16 Some of the unloaded columns after the test (1)

Photo D.17 Some of the unloaded columns after the test (2)

Photo D.18 Tall column after the test