ETH zürich

Data Driven Building Retrofit

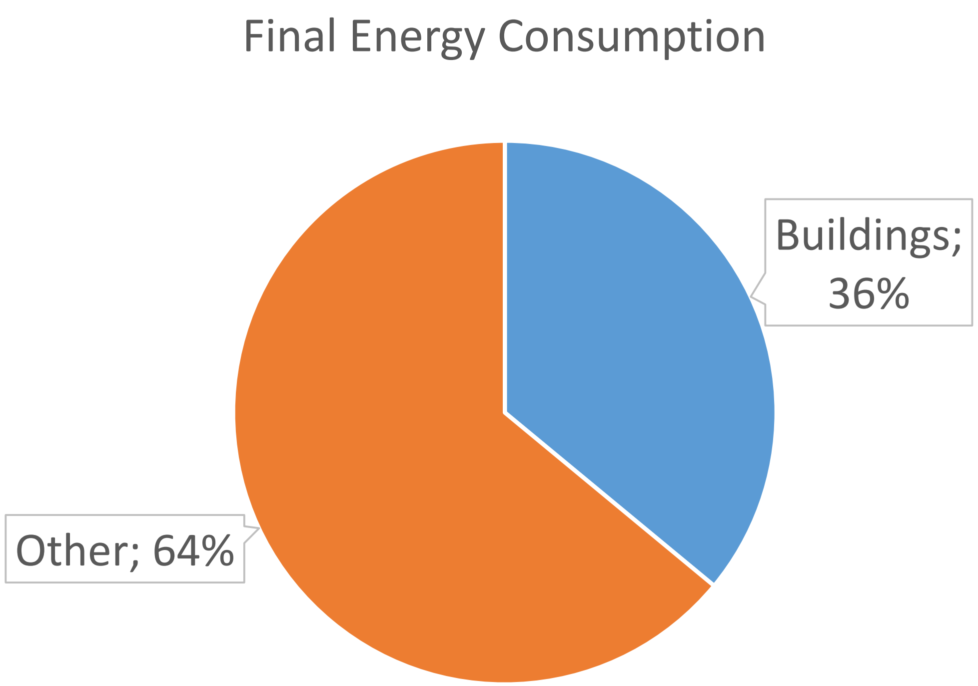
Mario Frei

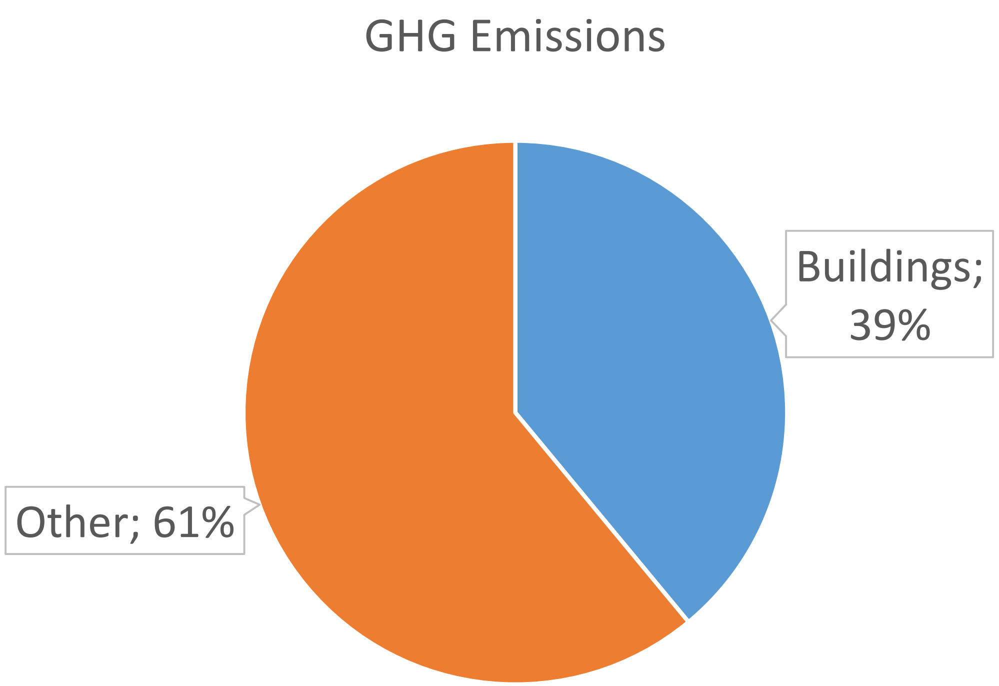
A / S Architecture and Building Systems
Prof. Dr. Arno Schlueter
Institute of Technology in Architecture (ITA)
ETH Zurich

Mission

Improve the energy performance of existing buildings

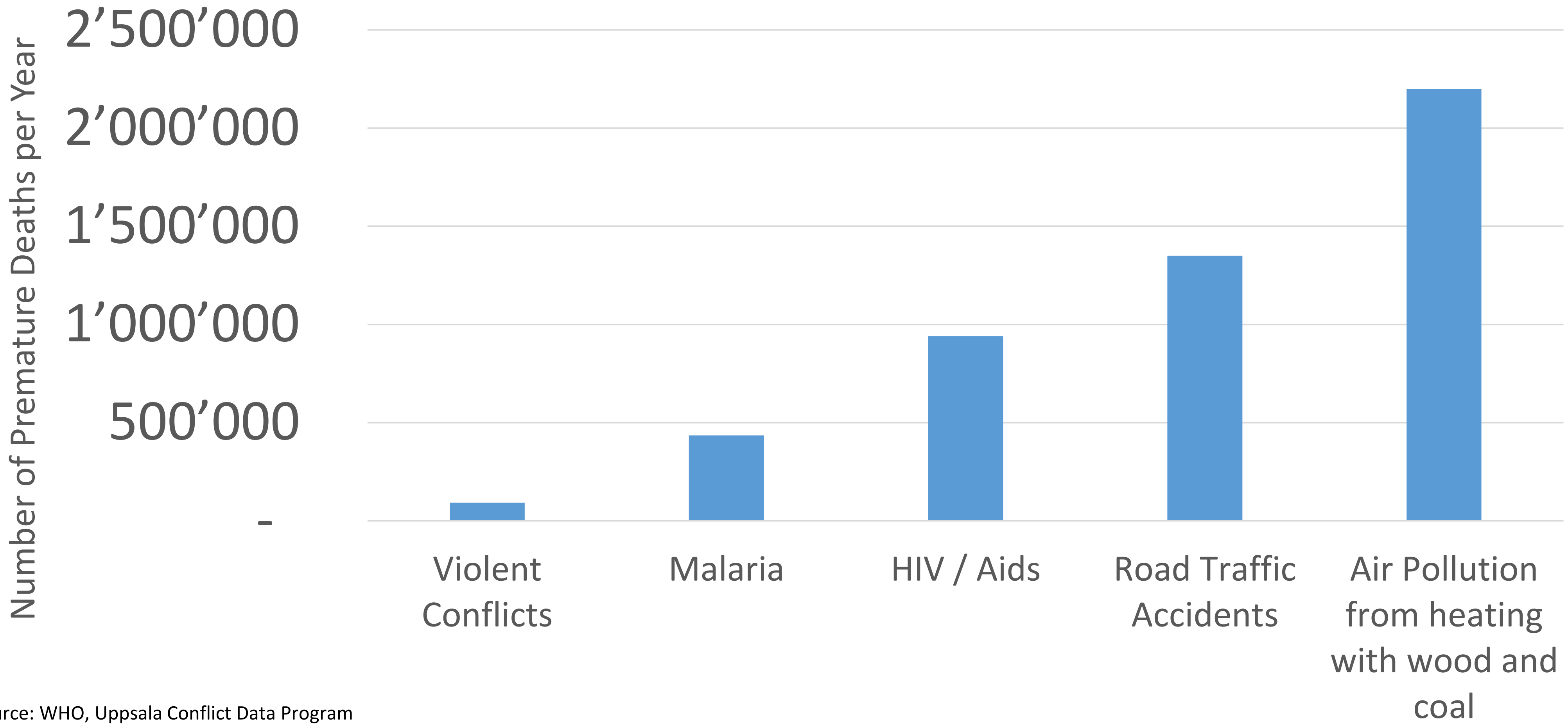
Building Energy Consumption & Emissions





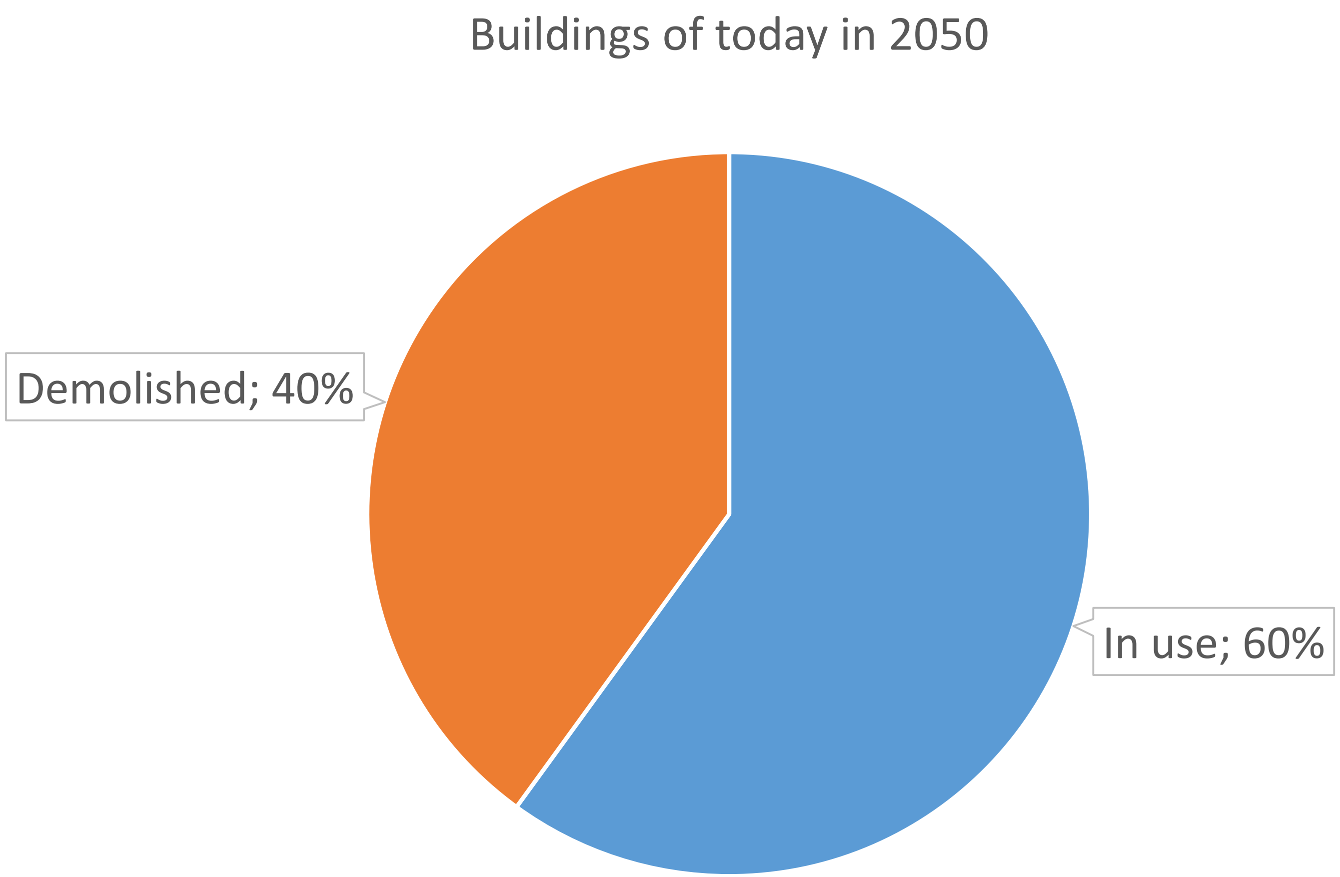
Source: IEA; 2018 Global Status Report, p. 12, 2018.

Air pollution



Source: WHO, Uppsala Conflict Data Program

Building Stock



Source: International Energy Agency and Organization for Economic Co-operation and Development, *Transition to sustainable buildings strategies and opportunities to 2050*. Paris: OECD/IEA, 2013.

Stakeholders

Owner

Occupants

Architect

Neighbors

Building

Bank / Investor

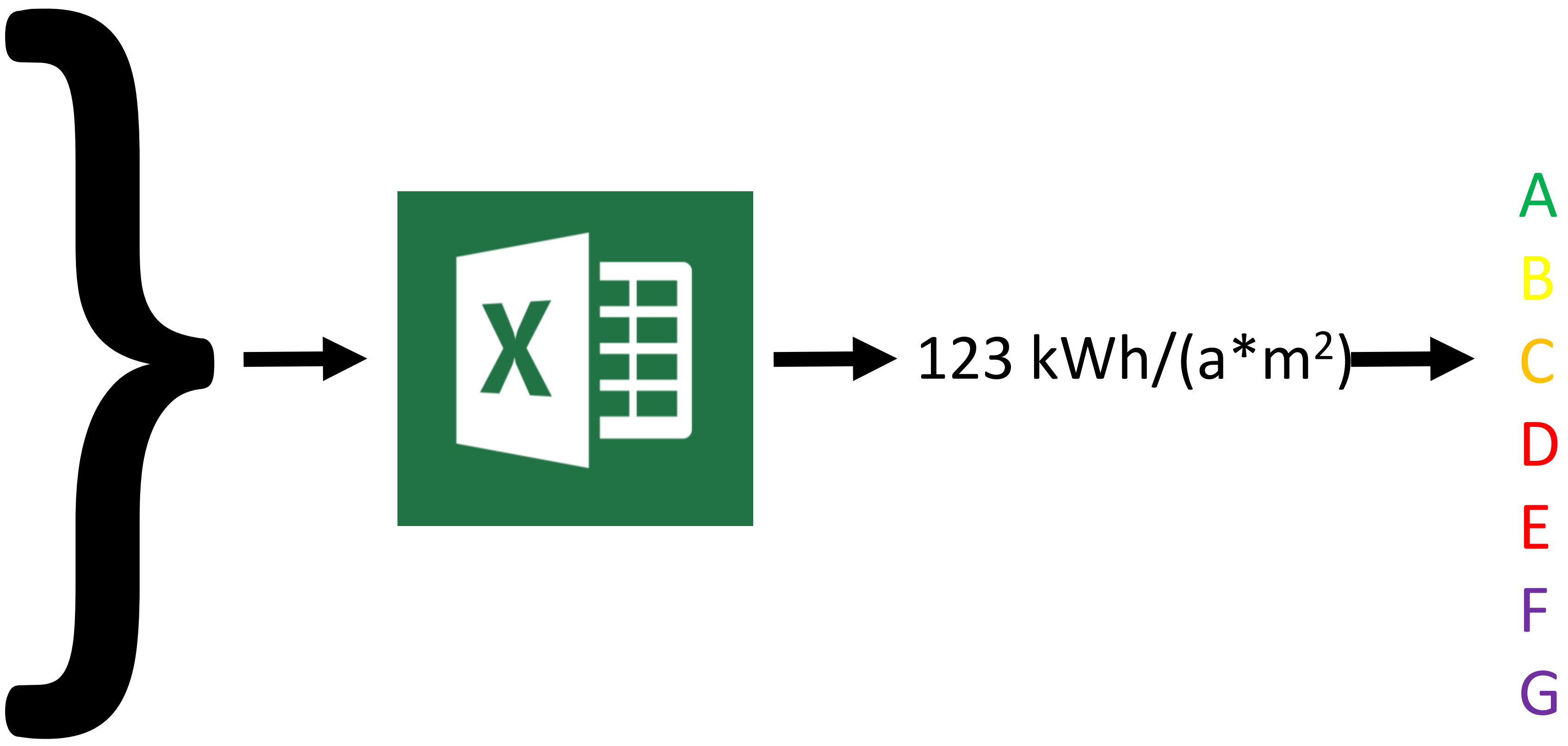
Engineers

Government

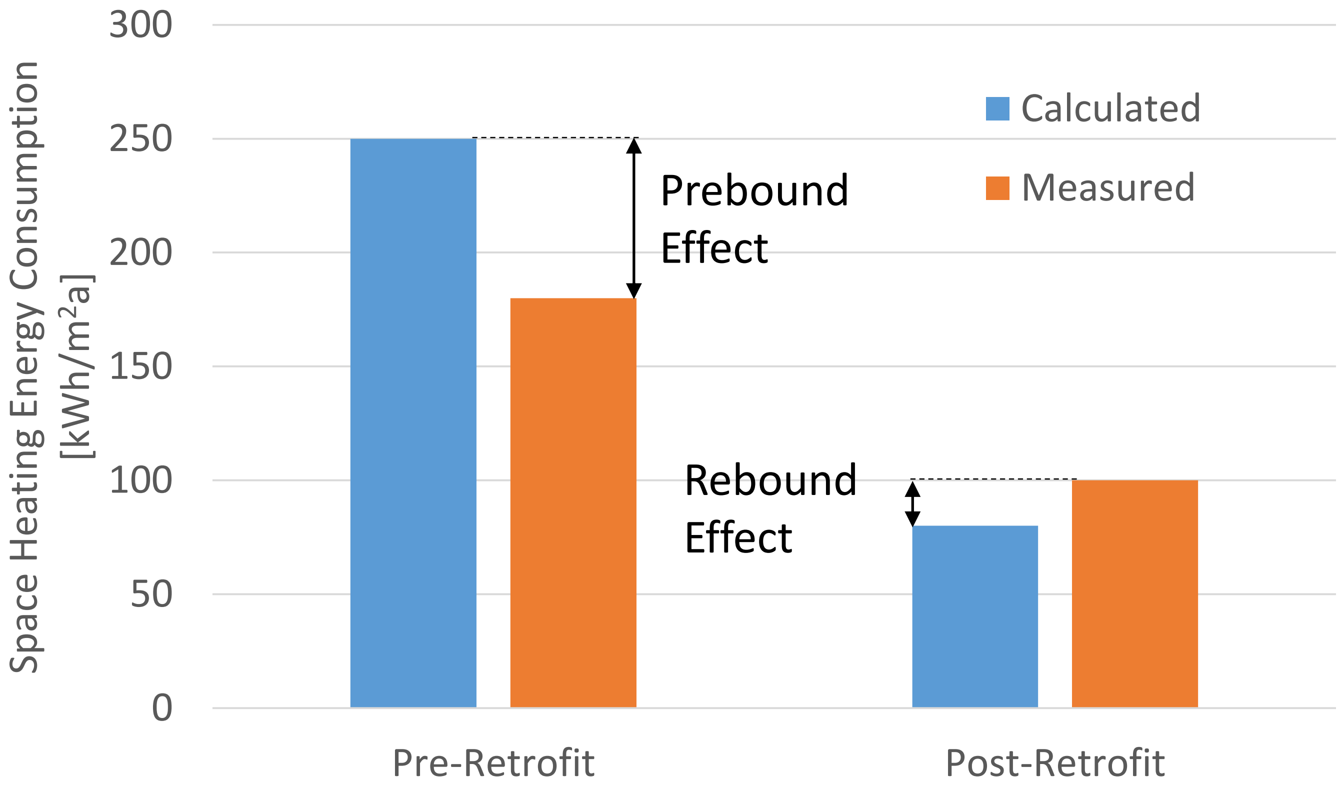
Construction workers

Building Energy Assessment

- Climate
- U-value
- g-value
- Orientation
- Schedules
- Systems
- User behaviour
- ....

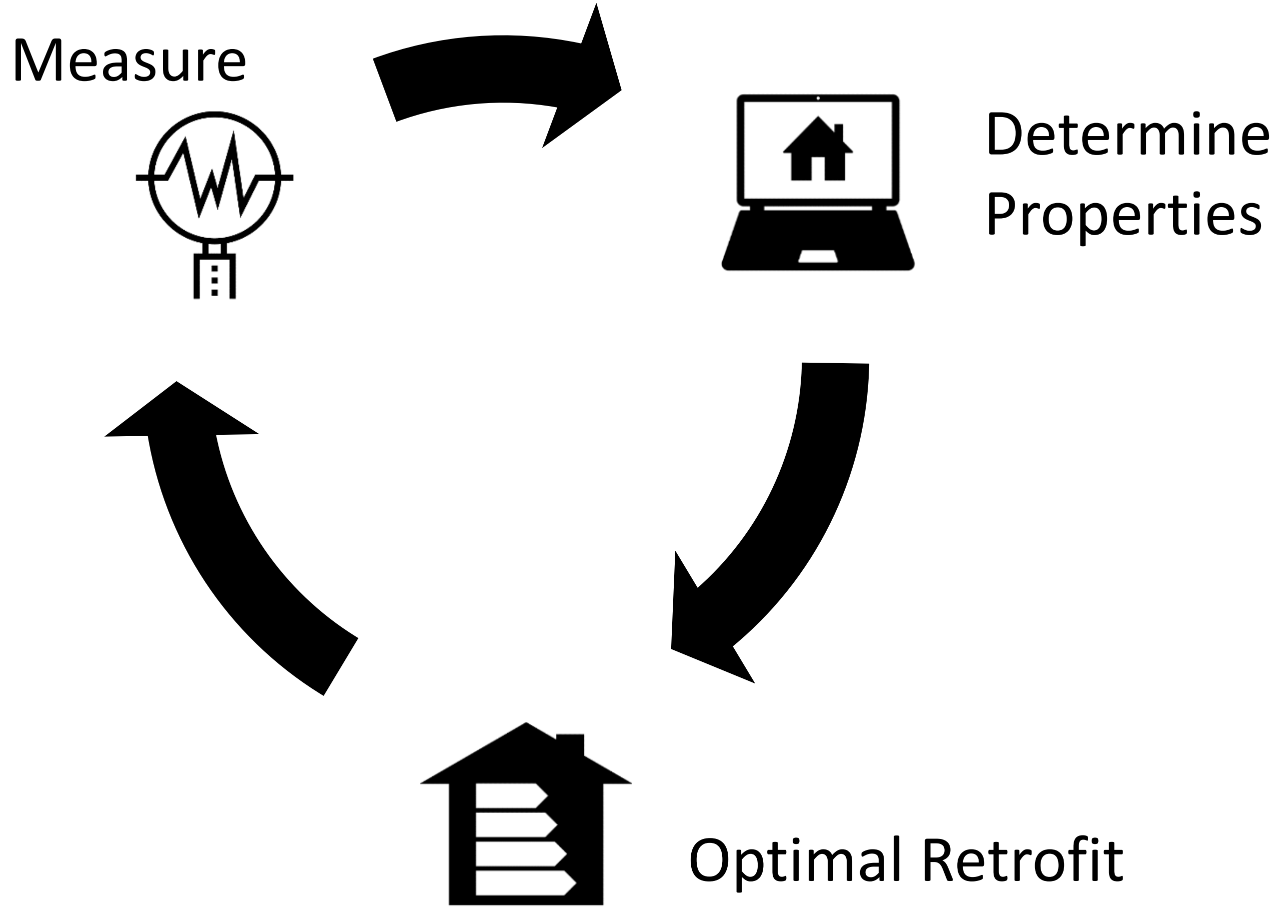


Performance Gap

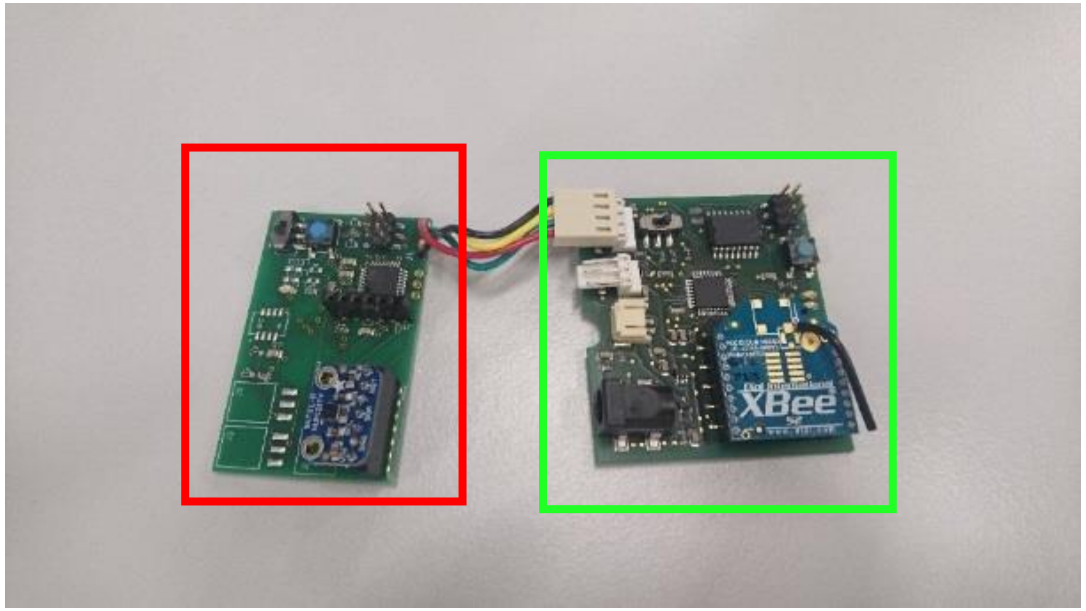


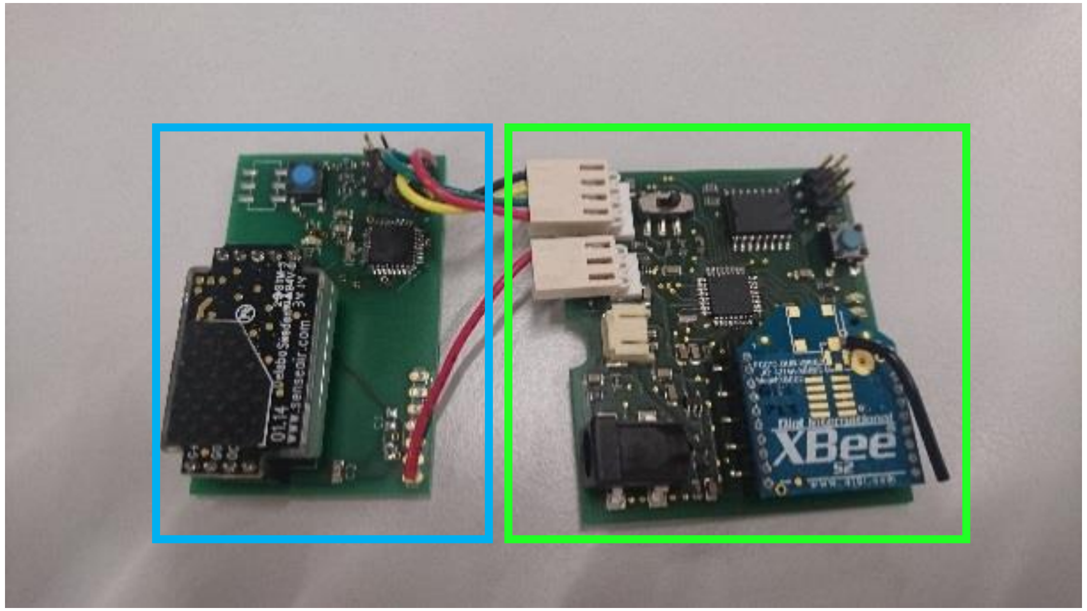
Adapted from: Minna Sunikka-Blank and Ray Galvin. Introducing the prebound effect: the gap between performance and actual energy consumption. Building Research & Information, 40(3):260–273, 2012.

New Framework



Open Source Wireless Sensor Network





https://github.com/architecture-building-systems/Wireless-Sensor-Network

Measured Modalities

- Air temperature & relative humidity
- Temperatures: supply/return, indoor/ outdoor
- Heat flux
- Windows opening duration
- Electricity consumption
- Oil flow
- CO_2 concentration

Wireless Sensor Network

Web-Interface

Is it up right now?

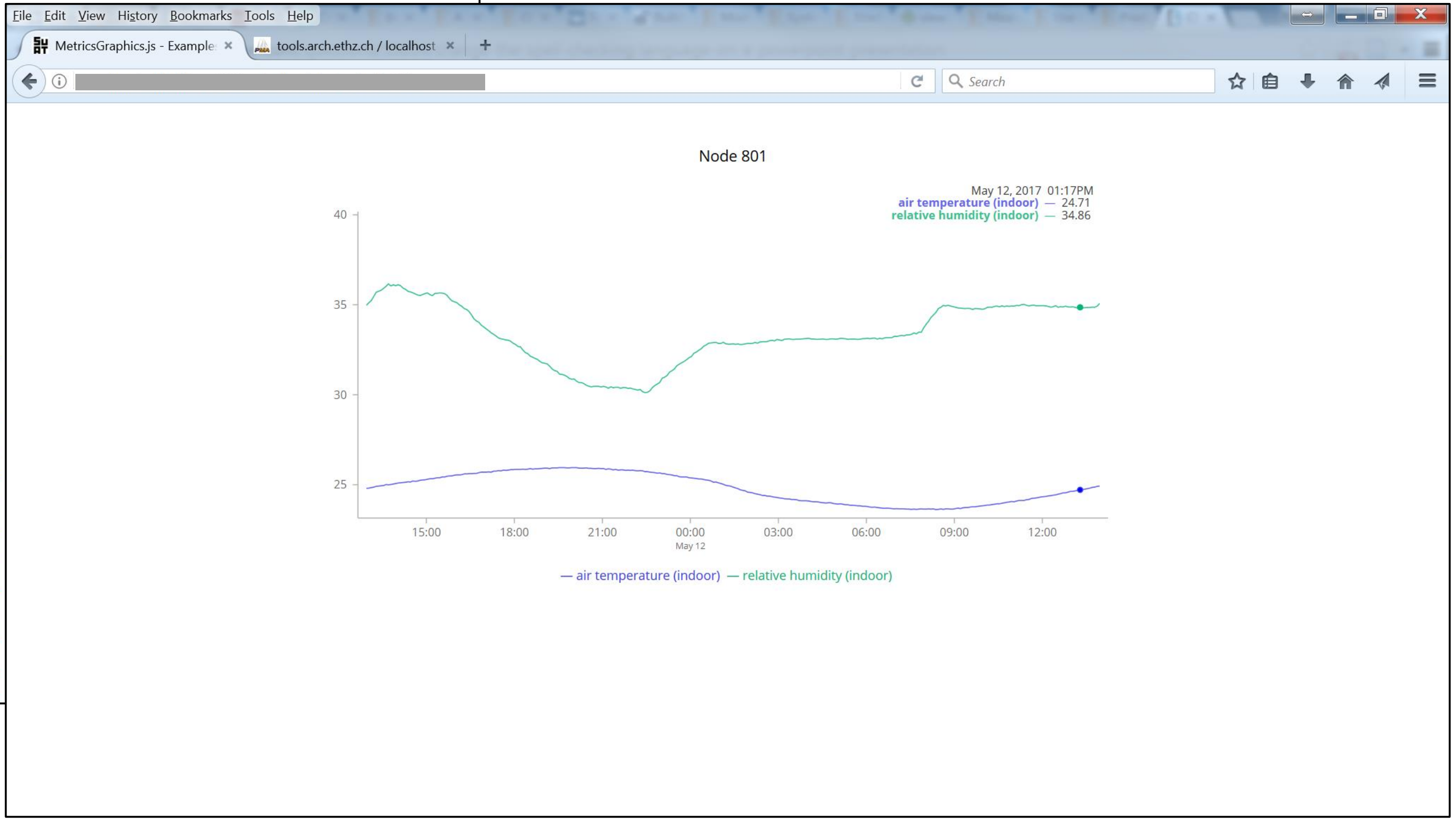
12.05.2017 13:56:45

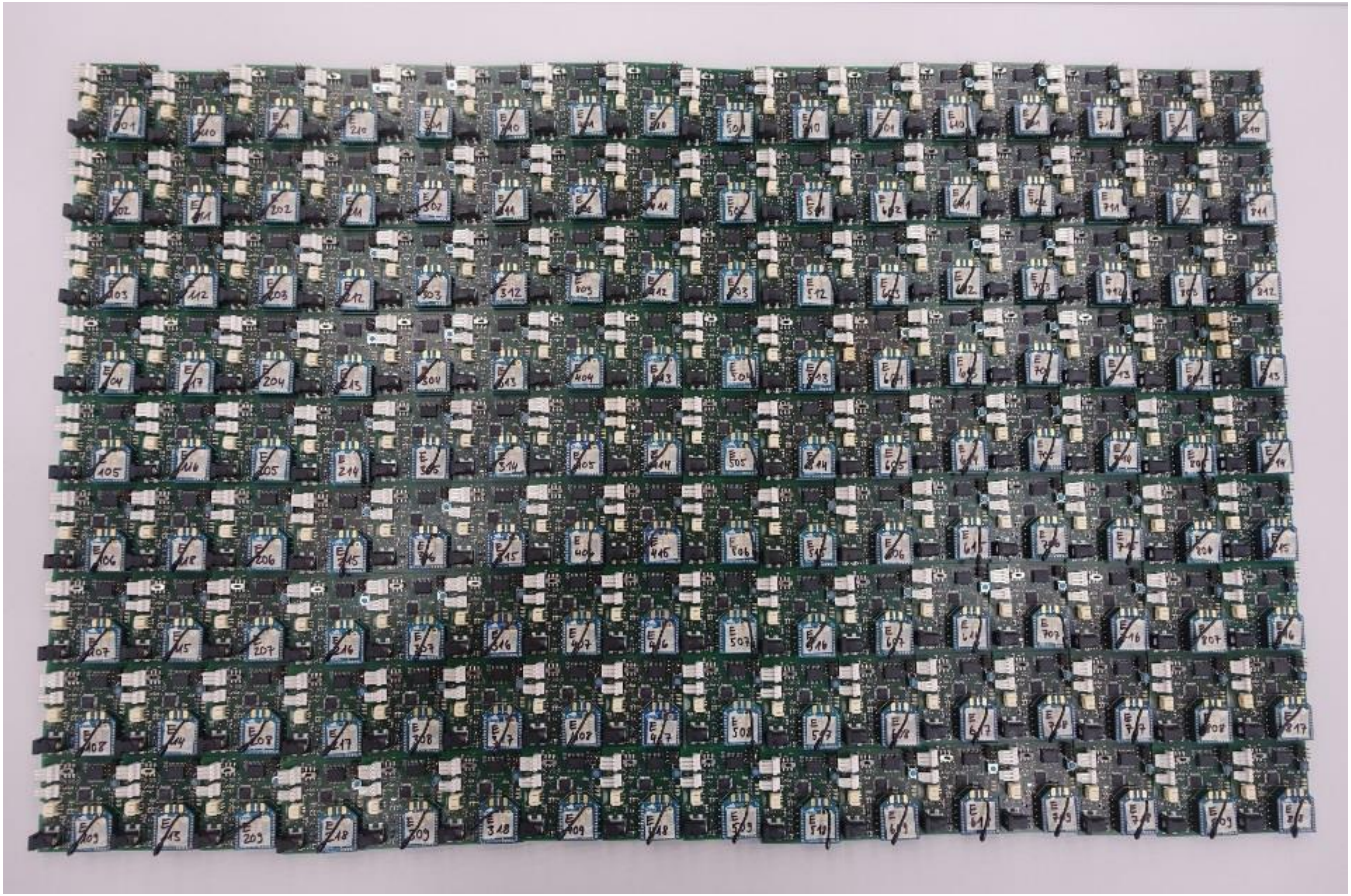
Gateways

Gateway ID	Minutes since last entry	Status
1	0	OK
2	0	OK
3	1	OK
4	0	OK
5	0	OK
6	0	OK
7	0	OK
8	0	OK

Nodes

Node ID	Sensor type	Minutes since last entry	Status
801	SHT31	4,48	OK
802	SHT31	0,57	OK
803	SHT31	4,13	OK
804	Window	0,23	OK
805	Window	0,13	OK
806	Window	0,32	OK
807	S8 - CO2	1,55	OK
808	2xDS18B20	1,45	OK
809	2xDS18B20	1,35	OK
810	2xDS18B20	1,17	OK
811	2xDS18B20	3,57	OK
812	2xDS18B20	4,58	OK
813	2xDS18B20	4,38	OK
814	Heat flux	3,87	OK
815	Heat flux	2,18	OK
816	Heat flux	3,10	OK
817	-	165'100,17	Offline
818	-	114'852,90	Offline

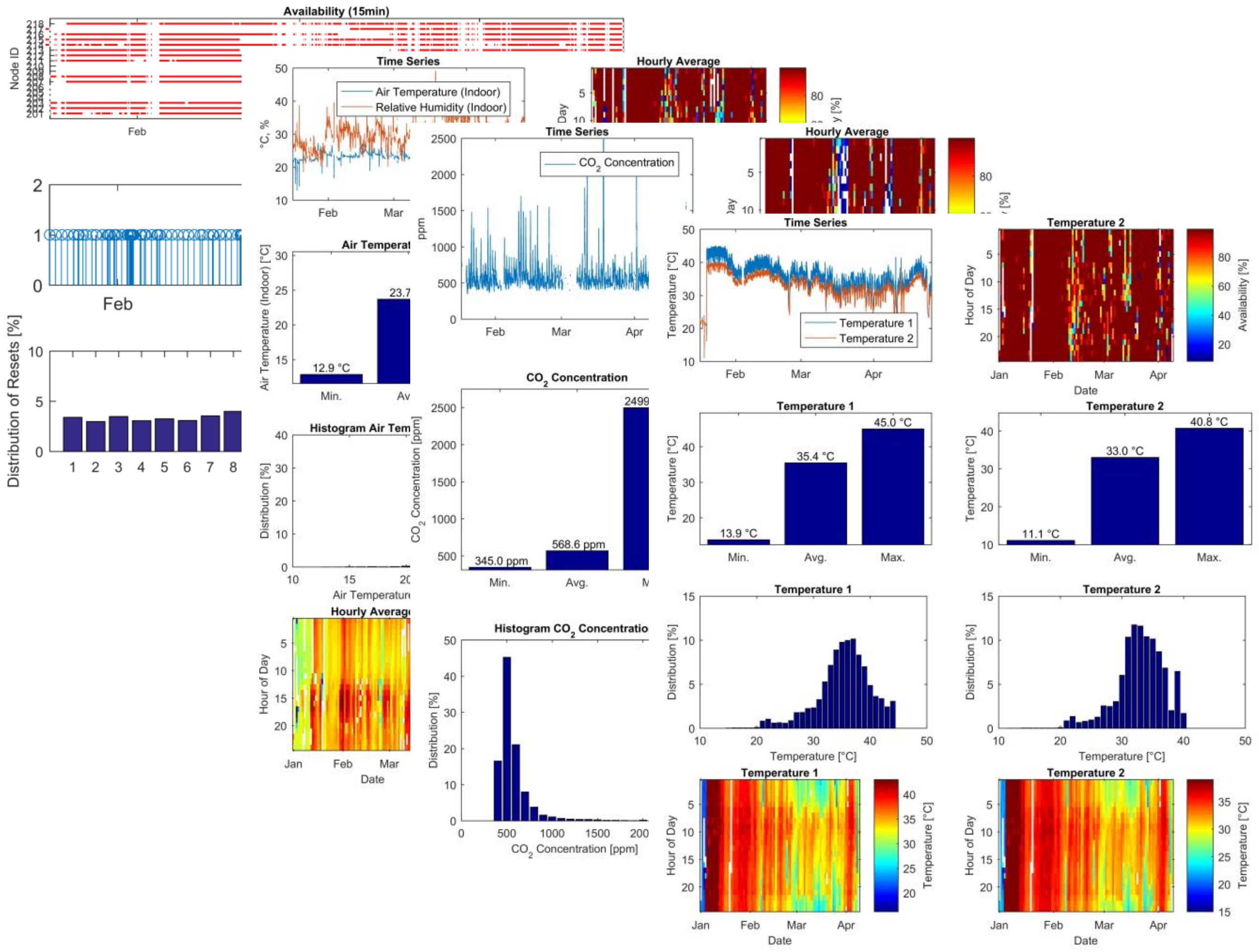




Case Study 1

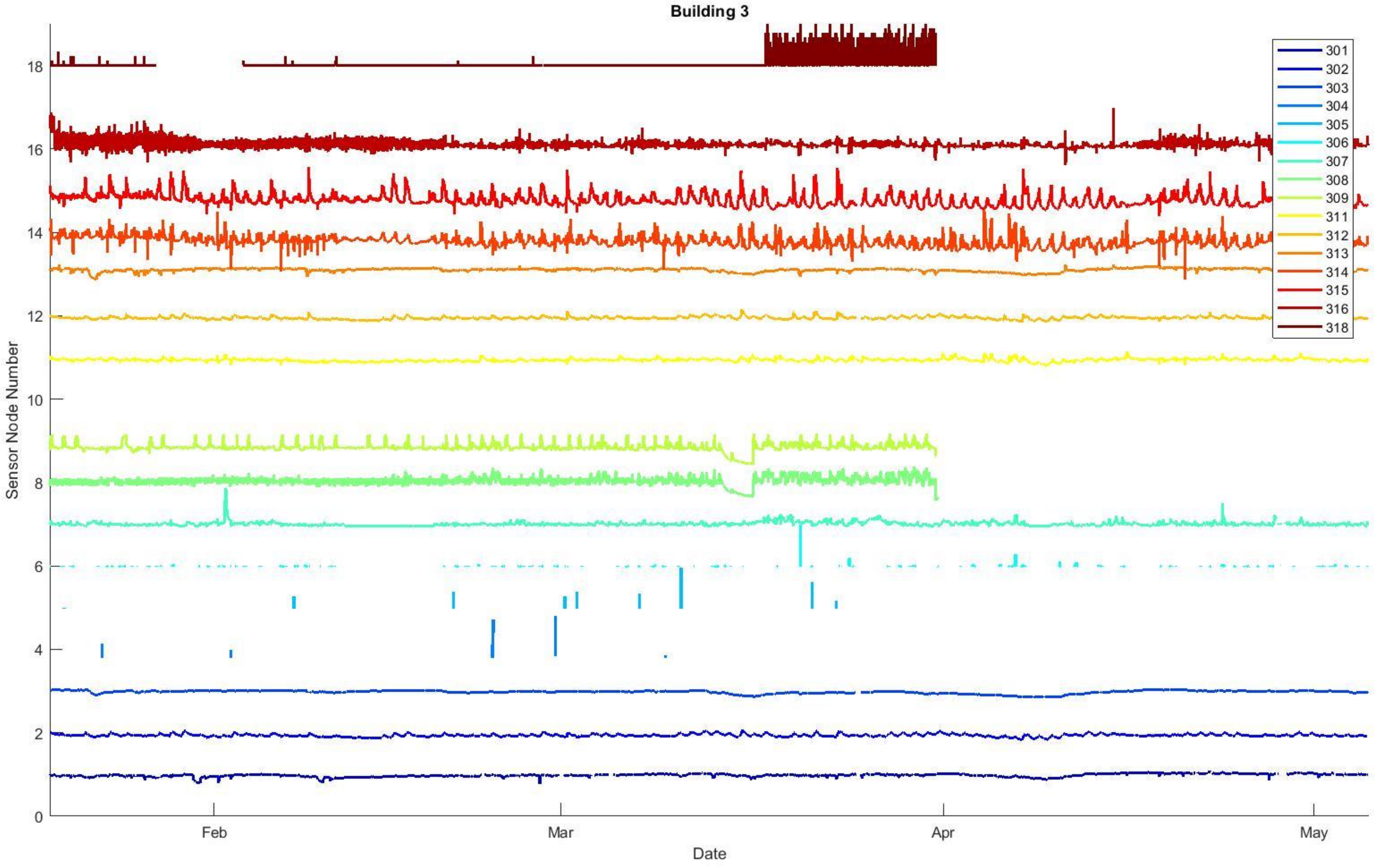
Source: Drechsler Energieberatung

Automated Reports



2 Zusammenfassung Messresultate

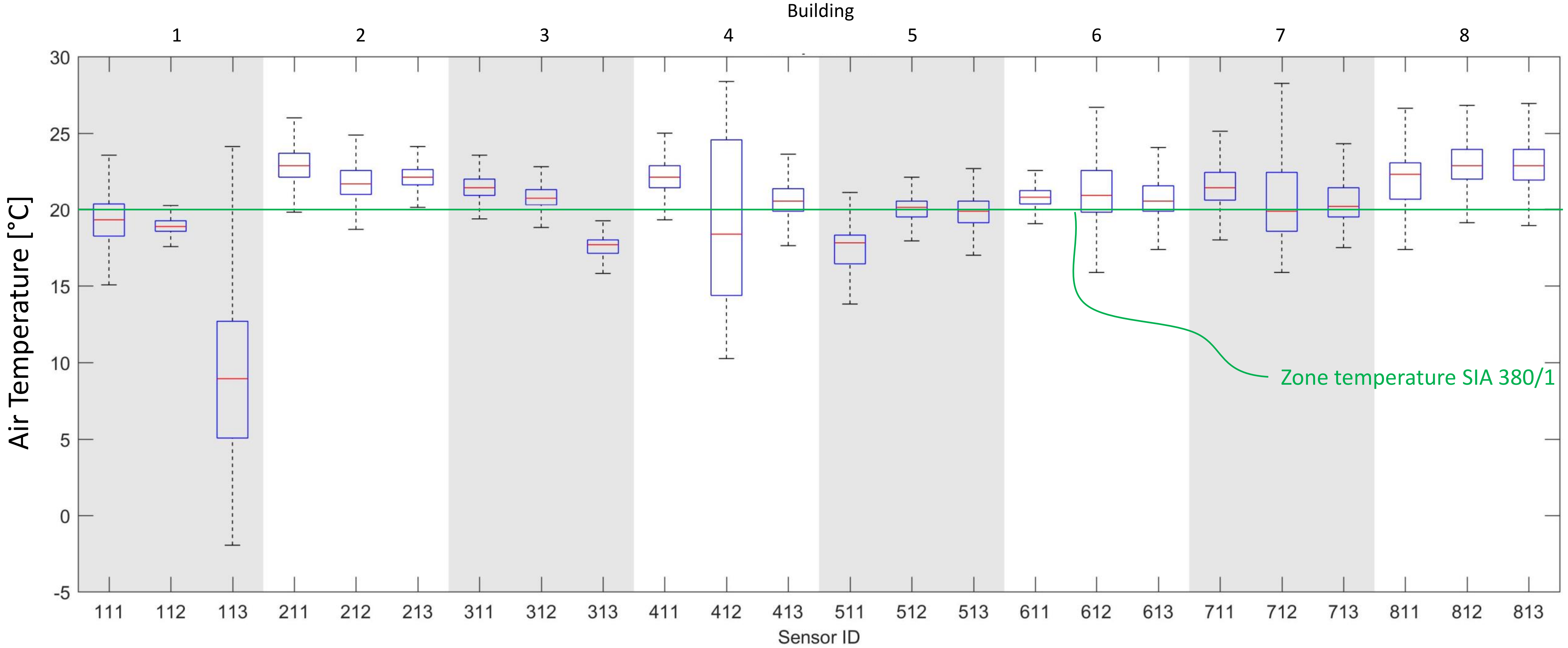
Messperiode:	Datum:	19.01.2017 - 11.05.2017
	Dauer:	111 Tage
	Anzahl Datenpunkte:	521'034
U-Werte:	Fenster, Wohnzimmer, EG:	2.61 W/(m²·K)
	Wand, Wohnzimmer, EG:	0.71 W/(m²·K)
	Wand, Garderobe, UG:	0.76 W/(m²·K)
CO_2-Konzentration:	Minimum:	387 ppm
	Maximum:	1'659 ppm
	Durchschnitt:	560 ppm
Energieverbrauch:	Strom:	20.7 kWh / Tag
	Heizöl:	25 Liter/Tag
Aussentemperatur:	Minimum:	-9.6 °C
	Maximum:	18.9 °C
	Durchschnitt:	4 °C
Innentemperatur:	Minimum:	20.3 °C
	Maximum:	26.5 °C
	Durchschnitt:	23.3 °C
Luftfeuchtigkeit	Minimum:	18.6 %
	Maximum:	41.3 %
	Durchschnitt:	29.4 %


Building 3
Sensor Node Number
Date
Feb
Mar
Apr
May
0
2
4
6
8
10
12
14
16
18
301
302
303
304
305
306
307
308
309
311
312
313
314
315
316
318

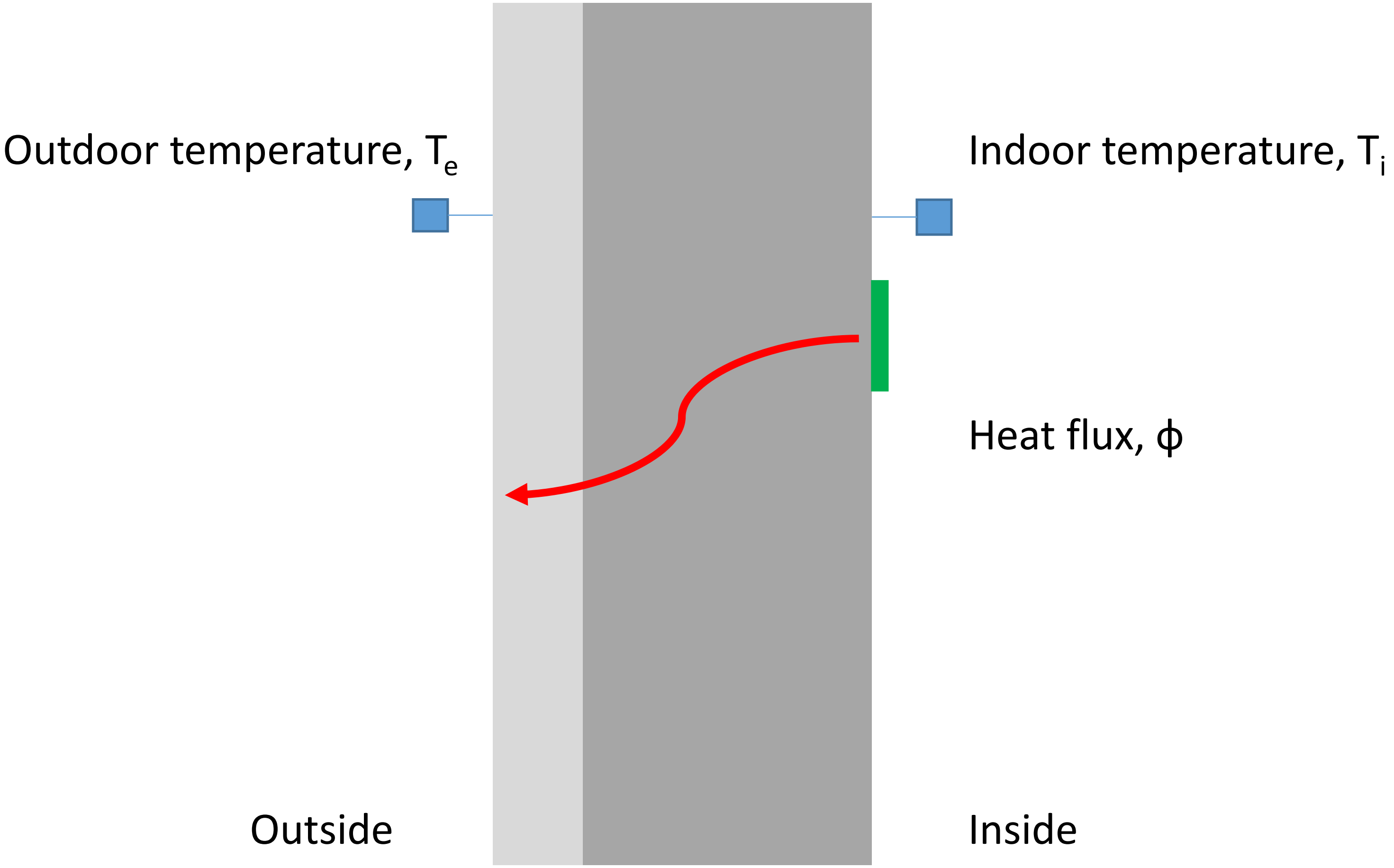
Challenges

- Gateway modem
- Unplugged devices
- Sensors falling off
- Very different heating system setups
- Automation
- Communication and scheduling

Zone Temperature

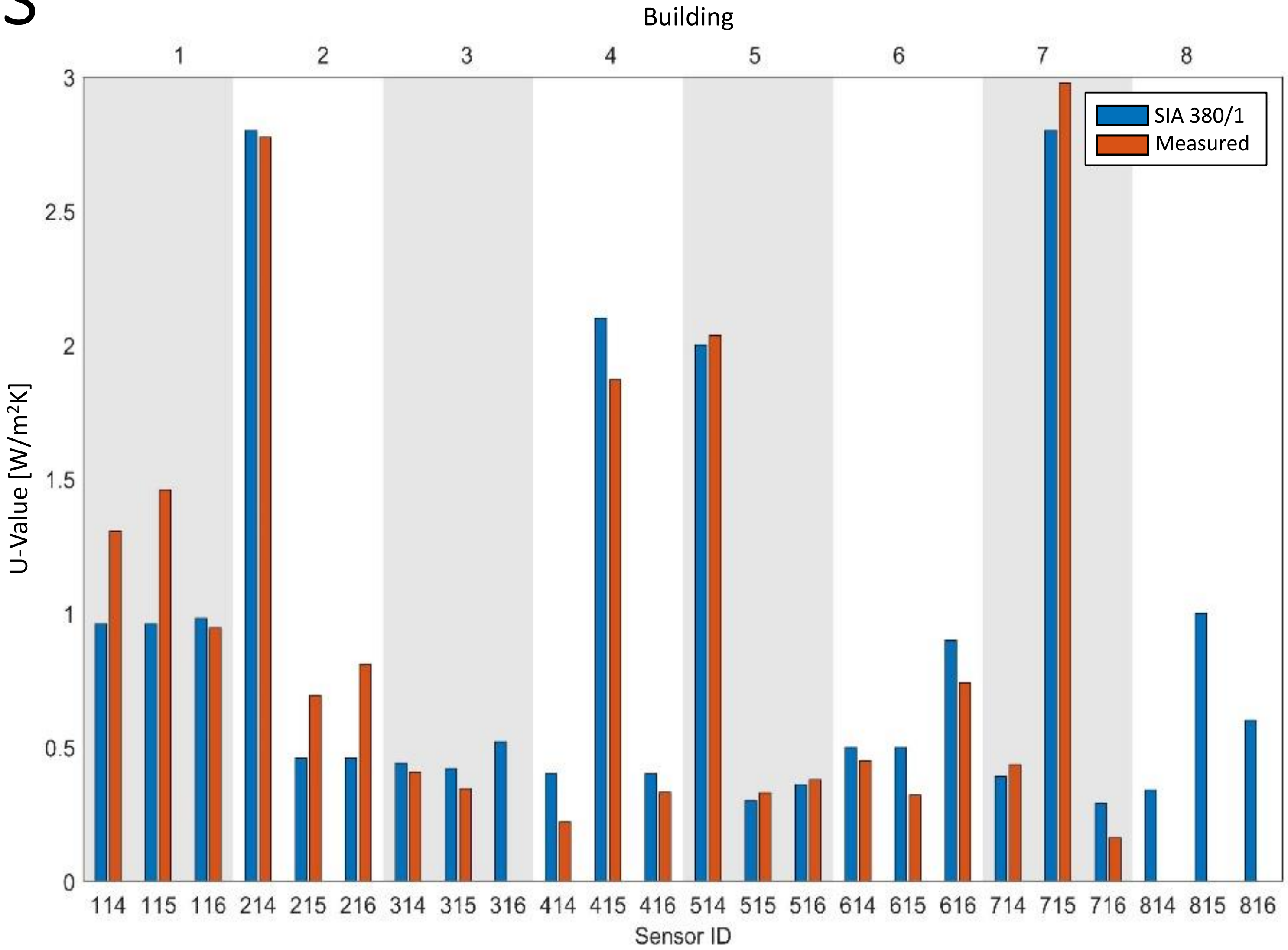


U-Value measurement

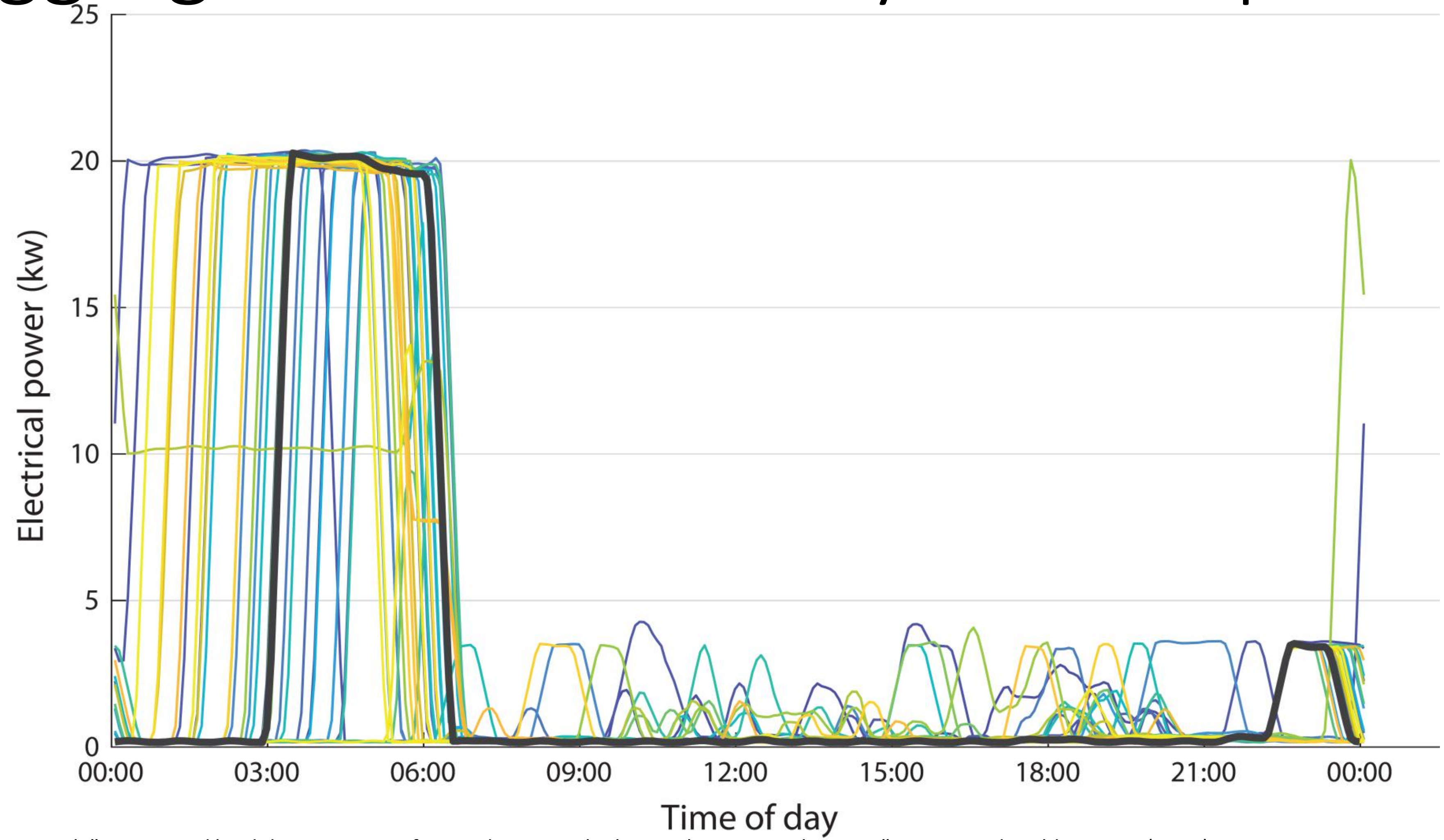


$$U = \frac{\sum \phi_i}{\sum T_{e,i} - T_{i,i}}$$

U-Values

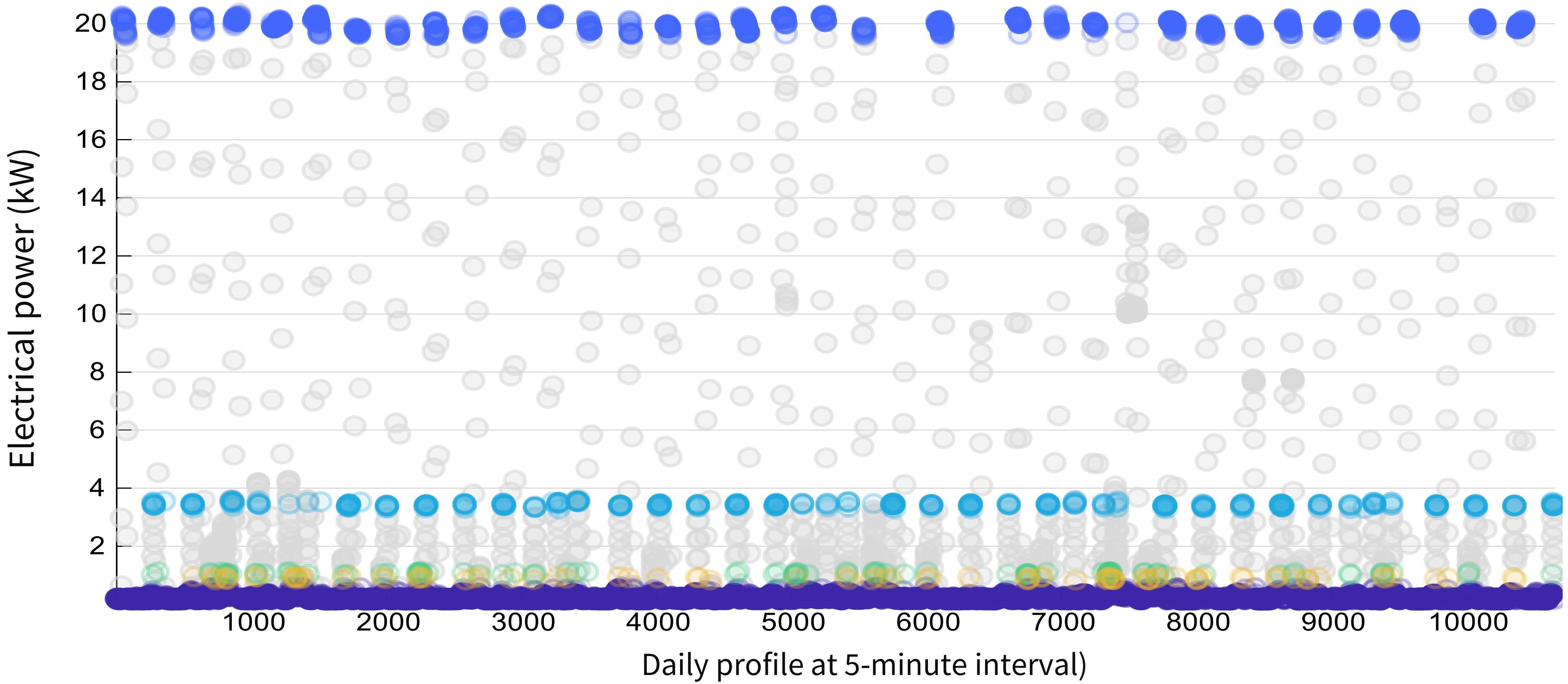

Building
1
2
3
4
5
6
7
8
SIA 380/1
Measured
U-Value [W/m²K]
0
0.5
1
1.5
2
2.5
3
114 115 116 214 215 216 314 315 316 414 415 416 514 515 516 614 615 616 714 715 716 814 815 816
Sensor ID

Disaggregation of electricity consumption



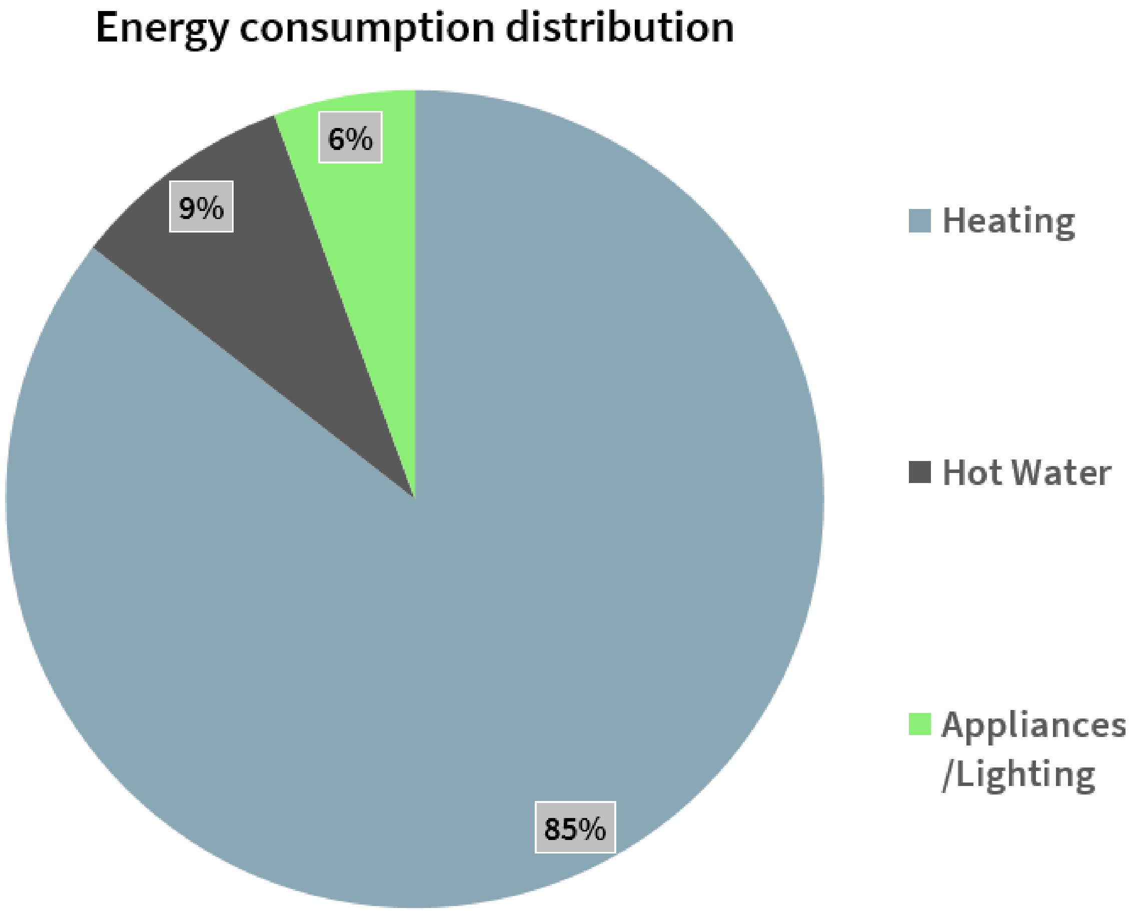
Source: Deb, Chirag, et al. "Automated load disaggregation for residences with electrical resistance heating." Energy and Buildings 182 (2019): 61-74.

Disaggregation of electricity consumption



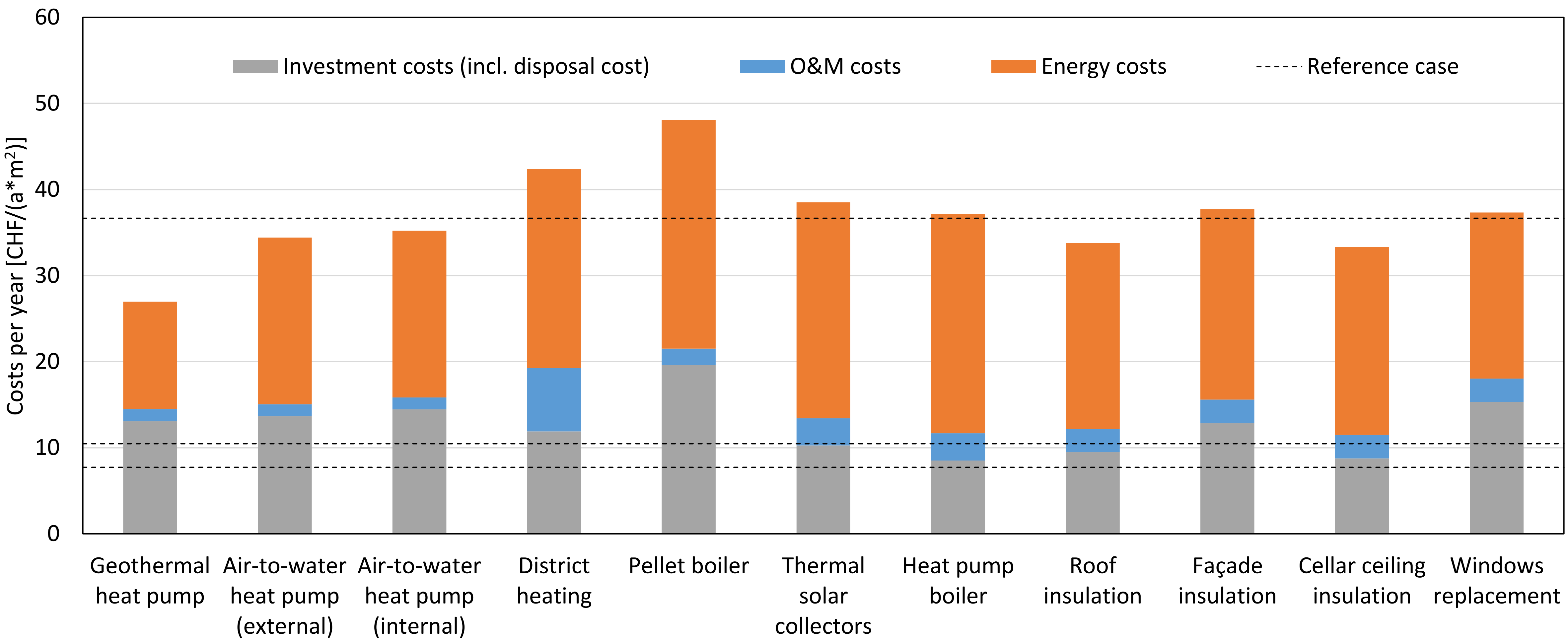
Source: Deb, Chirag, et al. "Automated load disaggregation for residences with electrical resistance heating." Energy and Buildings 182 (2019): 61-74.

Disaggregation of electricity consumption



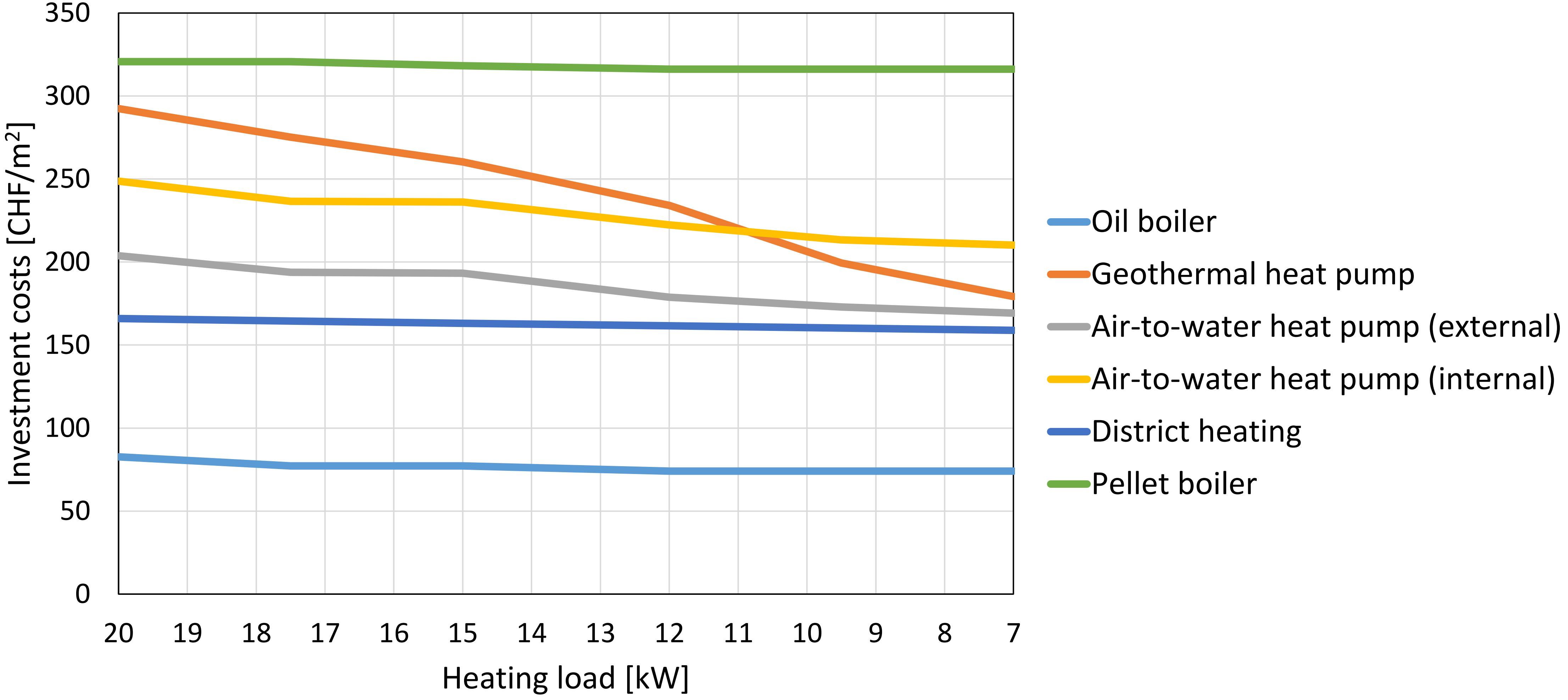
Source: Deb, Chirag, et al. "Automated load disaggregation for residences with electrical resistance heating." Energy and Buildings 182 (2019): 61-74.

Lifecycle Costs of Single Retrofit Measures



Source: Sigrist, Diego, Cost-Optimal Retrofit Analysis for Residential Buildings, Semester Project

Interrelation between Retrofit Measures



Source: Sigrist, Diego, Cost-Optimal Retrofit Analysis for Residential Buildings, Semester Project

Lifecycle Costs of Retrofit Strategies

$[CHF/(a*m^2_{ERA})]$	Oil boiler (RC)	Geothermal heat pump	Air-to-water heat pump (external)	Air-to-water heat pump (internal)	District heating	Pellet boiler	Thermal solar collectors	Heat pump boiler
No retrofit measures (RC)	37	27	34	35	42	48	39	37
Roof	34	26	32	33	40	45	36	34
Façade	38	30	36	37	43	49	40	38
Cellar ceiling	33	25	32	32	39	45	35	34
Windows	37	30	36	37	43	49	39	38
Roof, façade	35	29	34	35	41	47	37	36
Roof, cellar ceiling	31	25	30	31	36	42	33	31
Roof, windows	35	29	34	35	40	46	37	35
Façade, cellar ceiling	35	28	34	34	40	46	37	35
Façade, windows	39	33	38	39	43	50	40	39
Cellar ceiling, windows	34	29	33	34	39	46	36	35
Roof, façade, cellar ceiling	32	28	32	33	37	44	34	33
Roof, façade, windows	36	32	36	37	41	48	38	37
Roof, cellar ceiling, windows	32	28	32	33	37	43	34	32
Façade, cellar ceiling, windows	36	32	36	36	40	47	38	36
Roof, façade, cellar ceiling, windows	34	32	35	35	38	45	36	34

Source: Sigrist, Diego, Cost-Optimal Retrofit Analysis for Residential Buildings, Semester Project

Lifecycle Costs of Retrofit Strategies

[CHF/(a*m²$_{ERA}$)]	Oil boiler (RC)	Geothermal heat pump	Air-to-water heat pump (external)	Air-to-water heat pump (internal)	District heating	Pellet boiler	Thermal solar collectors	Heat pump boiler
No retrofit measures (RC)	37	27	34	35	42	48	39	37
Roof	34	26	32	33	40	45	36	34
Façade	38	30	36	37	43	49	40	38
Cellar ceiling	33	25	32	32	39	45	35	34
Windows	37	30	36	37	43	49	39	38
Roof, façade	35	29	34	35	41	47	37	36
Roof, cellar ceiling	31	25	30	31	36	42	33	31
Roof, windows	35	29	34	35	40	46	37	35
Façade, cellar ceiling	35	28	34	34	40	46	37	35
Façade, windows	39	33	38	39	43	50	40	39
Cellar ceiling, windows	34	29	33	34	39	46	36	35
Roof, façade, cellar ceiling	32	28	32	33	37	44	34	33
Roof, façade, windows	36	32	36	37	41	48	38	37
Roof, cellar ceiling, windows	32	28	32	33	37	43	34	32
Façade, cellar ceiling, windows	36	32	36	36	40	47	38	36
Roof, façade, cellar ceiling, windows	34	32	35	35	38	45	36	34

Source: Sigrist, Diego, Cost-Optimal Retrofit Analysis for Residential Buildings, Semester Project

Impact on Primary Energy Consumption

[kWh/(a*m²ERA)]	Oil boiler (RC)	Geothermal heat pump	Air-to-water heat pump (external)	Air-to-water heat pump (internal)	District heating	Pellet boiler	Thermal solar collectors	Heat pump boiler
No retrofit measures (RC)	325	178	276	276	223	398	311	319
Roof	268	143	223	223	184	328	254	262
Façade	274	147	229	229	189	336	261	268
Cellar ceiling	270	143	224	224	186	331	257	264
Windows	239	125	196	196	164	293	225	233
Roof, façade	218	114	178	178	150	267	204	212
Roof, cellar ceiling	214	111	173	173	147	262	200	208
Roof, windows	183	95	148	148	126	225	170	177
Façade, cellar ceiling	220	114	179	179	151	270	207	214
Façade, windows	190	98	153	153	130	232	176	183
Cellar ceiling, windows	186	95	149	149	128	228	172	180
Roof, façade, cellar ceiling	166	86	132	132	114	203	152	159
Roof, façade, windows	136	71	108	108	93	166	122	130
Roof, cellar ceiling, windows	132	69	104	104	91	162	118	126
Façade, cellar ceiling, windows	138	72	109	109	95	169	124	132
Roof, façade, cellar ceiling, windows	88	49	69	69	60	108	74	82

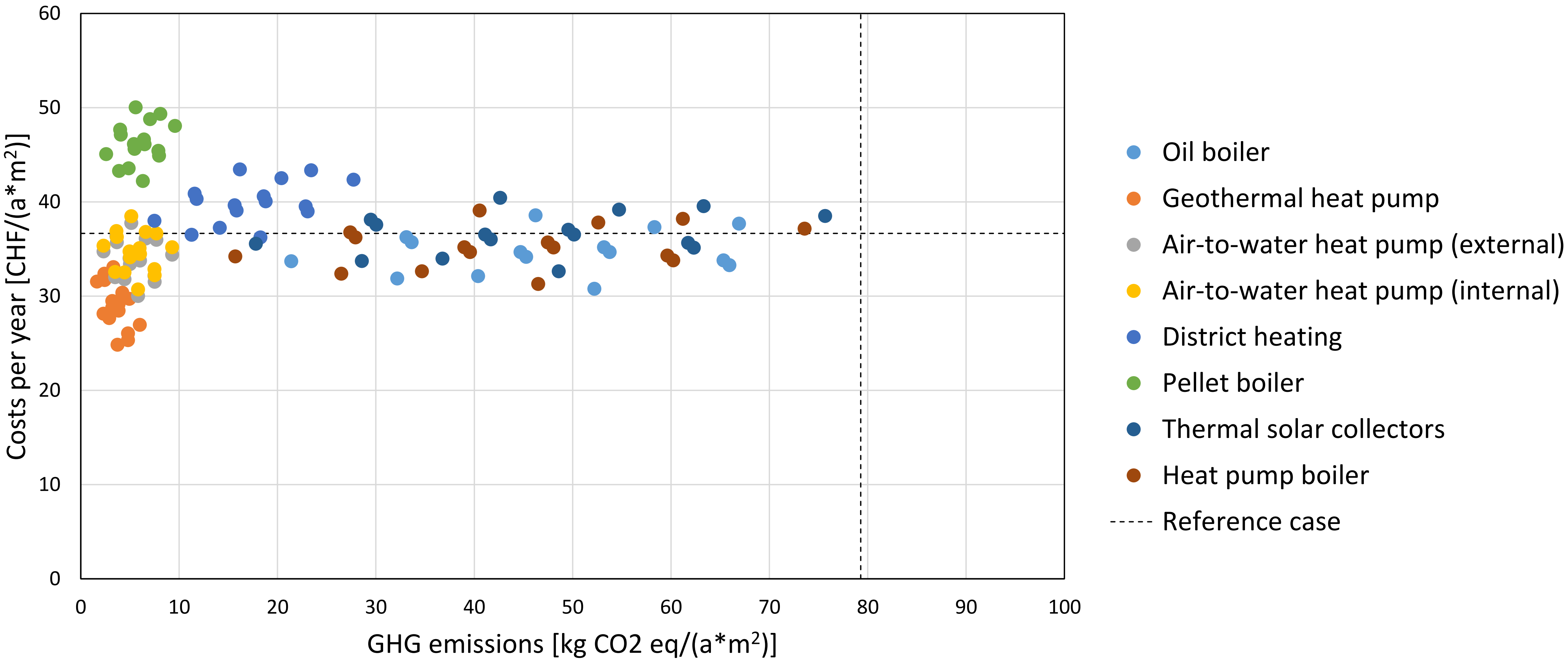
Source: Sigrist, Diego, Cost-Optimal Retrofit Analysis for Residential Buildings, Semester Project

Impact on GHG Emissions

[kg CO_2 eq/(a*m^2_{ERA})]	Oil boiler (RC)	Geothermal heat pump	Air-to-water heat pump (external)	Air-to-water heat pump (internal)	District heating	Pellet boiler	Thermal solar collectors	Heat pump boiler
No retrofit measures (RC)	79	6	9	9	28	10	76	74
Roof	65	5	7	7	23	8	62	60
Façade	67	5	8	8	23	8	63	61
Cellar ceiling	66	5	8	8	23	8	62	60
Windows	58	4	7	7	20	7	55	53
Roof, façade	53	4	6	6	19	6	50	47
Roof, cellar ceiling	52	4	6	6	18	6	49	46
Roof, windows	45	3	5	5	16	5	41	39
Façade, cellar ceiling	54	4	6	6	19	6	50	48
Façade, windows	46	3	5	5	16	6	43	41
Cellar ceiling, windows	45	3	5	5	16	5	42	40
Roof, façade, cellar ceiling	40	3	4	4	14	5	37	35
Roof, façade, windows	33	2	4	4	12	4	29	27
Roof, cellar ceiling, windows	32	2	3	3	11	4	29	26
Façade, cellar ceiling, windows	34	2	4	4	12	4	30	28
Roof, façade, cellar ceiling, windows	21	2	2	2	7	3	18	16

Source: Sigrist, Diego, Cost-Optimal Retrofit Analysis for Residential Buildings, Semester Project

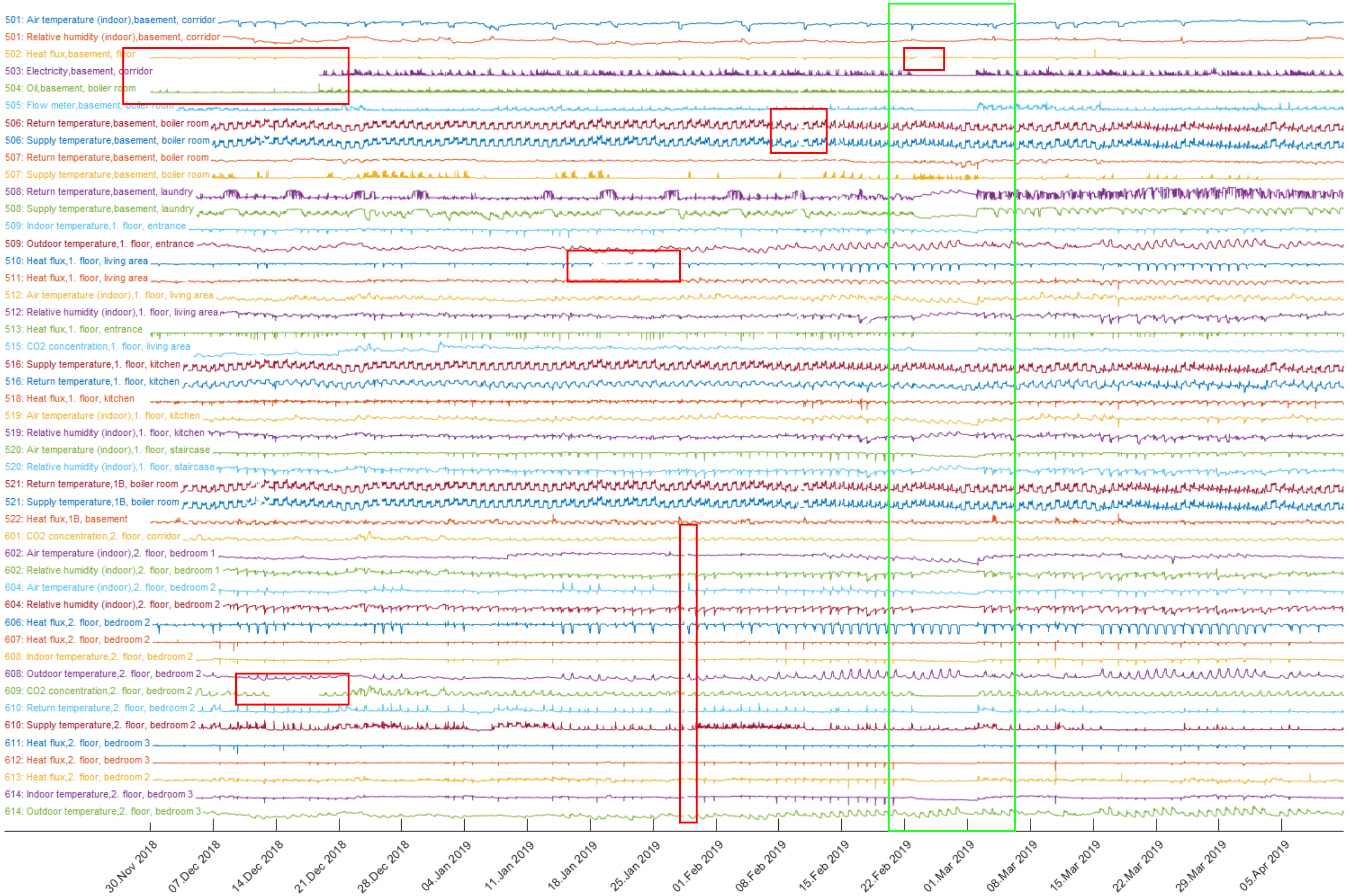
Impact on GHG Emissions and Cost



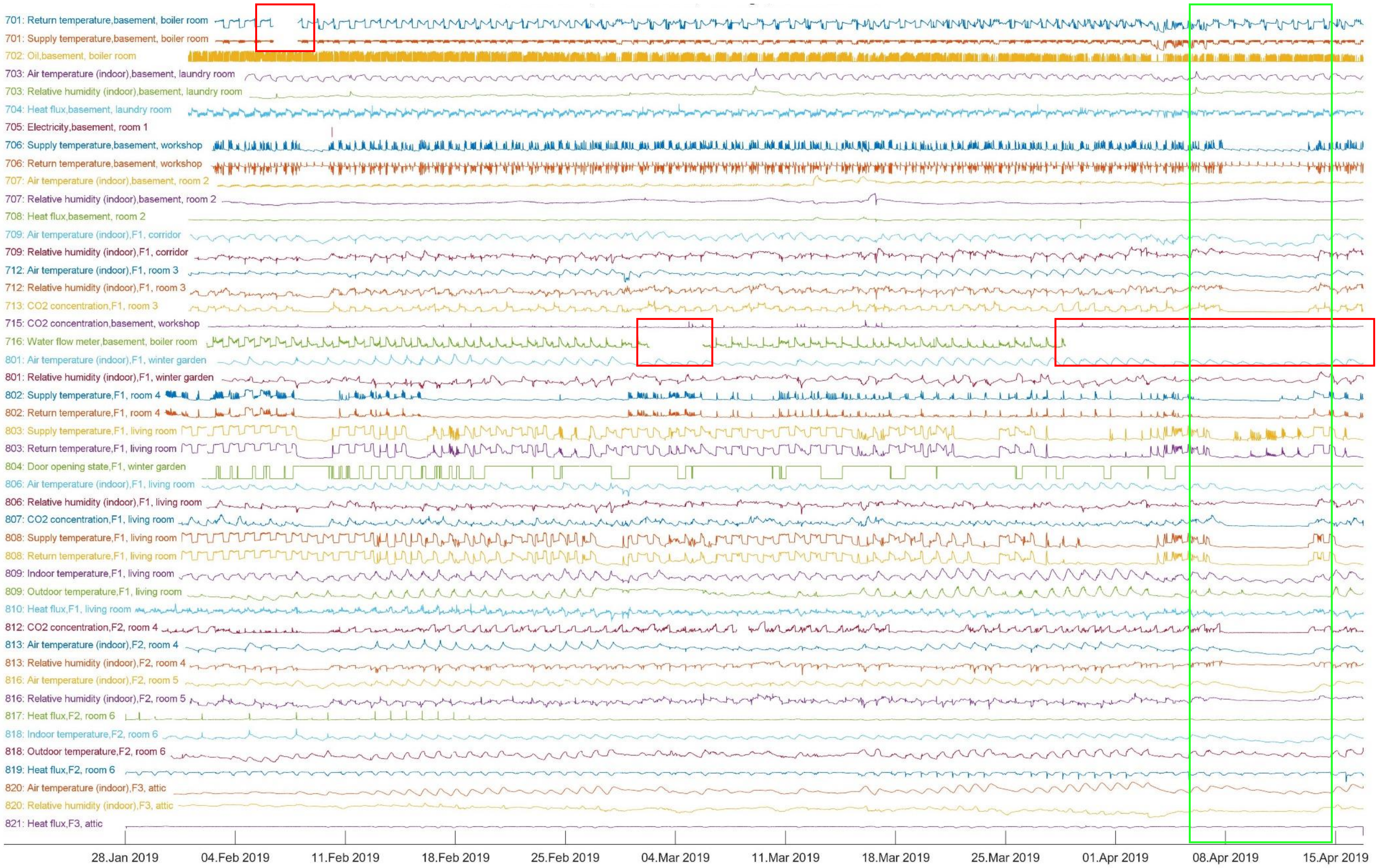
Source: Sigrist, Diego, Cost-Optimal Retrofit Analysis for Residential Buildings, Semester Project

Case Study 2

Building 1 – Overview normalized Data



Building 2 – Overview normalized Data



Conclusion

- Good measurements are difficult
- Measurements do not eleminate uncertainty
- Assessing whole house energy consumption is challenging and important
- WSN works and we collected a lot of experience
- Communication with partners is challenging

Dissemination

- Frei, Mario, Zoltán Nagy, and Arno Schlueter. "Towards data-driven building retrofit." *Proceedings of International Conference CISBAT 2015 Future Buildings and Districts Sustainability from Nano to Urban Scale*. No. CONF. LESO-PB, EPFL, 2015.
- Frei, Mario, et al. "An easily-deployable wireless sensor network for building energy performance assessment." *Energy Procedia* 122 (2017): 523-528.
- Deb, Chirag, et al. "Automated load disaggregation for residences with electrical resistance heating." *Energy and Buildings* 182 (2019): 61-74.
- Sigrist, Diego, Cost-Optimal Retrofit Analysis for Residential Buildings, Semester Project