SUSTAINABLE SOLUTIONS

JOA PROJECTS B.V.

Test report SpeedComfort

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Introduction

About SpeedComfort

SpeedComfort is a smart radiator ventilator that can be integrated with / attached to radiator panels and convectors. The device is suitable for standard panel radiators, type 20/21/22. With accessories it is also suitable for types 10, 11 and convectors. SpeedComfort claims that radiator capacity is increased, airflow boosted and circular heat is being created. This should result in increased power, more comfort (better heat profile), faster warm-up time and saving on energy consumption / CO2.

A SpeedComfort unit consists of a plastic casing with 3 axial fans. Depending of length of the radiator up to 20 SpeedComforts can be linked. The device(s) is activated by a heat sensor that is triggered by radiator temperature (32°C). During the cooling phase, SpeedComfort stops operating when radiator temperature reaches 25°C.

TNO Test Report

In 2016 SpeedComfort's performance was tested by TNO (www.tno.nl), a Dutch, independent testing agency. The report (TNO 2016 R11745, "Determination of the influence of the SpeedComfort fan system affixed on a plate radiator") draws conclusions on the effects of SpeedComfort, including increasing radiator capacity with around 20%.

JOA objectives and Test Program

In 2019 JOA Sustainable Solutions ("JOA" hereinafter) was asked to reperform the TNO tests and to perform additional tests with a wider scope. For this purpose a test-room and an extensive test-program was created. Main objective: evaluate and quantify SpeedComfort's claim (hypothesis) on **increasing comfort while reducing energy/CO2 consumption.** This claim[1] has been bifurcated into the following hypotheses:

I. Comfort

1. SpeedComfort increases capacity of existing radiators (increased power)
2. SpeedComfort brings heat more quickly into the room (faster warm-up time)
3. SpeedComfort creates better air circulation (better heat distribution)

II. Savings

4. Lower energy consumption due to improved room temperature (lower thermostat level)
5. Lower energy consumption due to boiler/central heating system[2] efficiency

The test-setup at JOA had the following specifications:

a. Insulated test-room consisting of 2 radiators, one on each end of the room
b. A grid of 83 sensors, logging samples every 30 seconds
c. A series of test: 28 batches
d. Test-data: 700 hours, 7.5 million data-points.

1 The terms 'Hypothesis' and 'claim' are interchangeably used in this report.

2 Boiler and Central Heating System (CV) are interchangeable terms in this report

In addition, a customer survey was sent out on behalf of SpeedComfort to 7.687 users, representing a population of 28.000 households. With a response rate of 23% this field-data is representative for the entire population with a desired confidence level of 99% and a 'margin of error' of 3%. With the survey responses coming from a non-controlled environment[3] this field data has primarily been used as support-evidence.

Note that JOA was asked by the client to write this report with non-technical readers in mind so that SpeedComfort is able to publish these results for a wider audience.

Disclaimer: all technical and measurement data provided in this report is based on the specified full-scale test room, built for testing purposes only. The conclusions provided cannot be translated to individual cases without involving detailed specialist interpretation and analyses.

Overall conclusion

The report shows that JOA was able to draw clear conclusions on all claims. A summary is found in the following table. The underlying evidence, definitions, methodology, test-specifications, calculations, formulas and details/data-sets are described in this report.

Summary: SpeedComfort claims

Claim / Hypothesis	**Justified**	**Test Results and metrics** *(SpeedComfort abbreviated to 'SC')*
1. Comfort: SpeedComfort increases capacity of existing radiators	✔	Depending on water temperature settings, 14.3% to 19.4% additional heat is extracted by SpeedComfort. **See §3.1**
2. Comfort: SpeedComfort brings heat more quickly into the room (faster warm-up time)	✔	Warm-up time (with 2°C) is 41% to 49% faster with SpeedComfort. **See §3.2**
3. Comfort: SpeedComfort creates better air circulation / heat distribution)	✔	• With SpeedComfort, convection is assisted, improving heat stratification by 1.2°C at 64°C boiler setting (> 1.2°C at 70°C) . **See §3.3**
4. Saving: Lower energy consumption due to boiler efficiency	✔	• Standard Boiler settings (70°C supply water) can be lowered to 64°C (2% energy saving) without capacity loss due to SpeedComfort. Either lowering from higher standards (80°C) or lowering below 64°C result in significant energy savings. **See §4.1** • Customer survey results show that 2/3 of SpeedComfort users lower boiler settings after installing SC, the majority to 60°C.
5. Saving: Faster warm-up time with less energy consumption	✔	• Savings due to faster, more efficient warm-up time result in 0.7% to 2,9% energy reduction, depending on boiler settings and number of average heating times per day. **See §4.2**
6. Saving: Lower energy consumption due to improved room temperature (lower thermostat settings)	✔	• **Paragraph §4.3** shows various scenarios for energy savings. • The overall savings range from 5% to 21% depending on the situation and action of the user. • Overall average saving estimated at 11,2%

[3] *Examples: level of insulation, room dimension, temperature setting, type of radiator/boiler, etc.*

Comments and recommendations

We recommend SpeedComfort to carry out follow-up research, mostly to determine the (side) effects of personal circumstances. We recommend to install test-panels and to send out a follow-up survey with more detailed questions.

Research topics that might be interesting to investigate are:

1) Warm-up time: In the tests warm-up time was based on 2°C (ΔT). It seems plausible that in practice this could often be higher (warming up a room by 3°C, i.e. 17-20, 18-21, etc.), having a higher impact on both comfort and savings.
2) External conditions: testing with factors of weather (outside temperature, sunshine/clouds) and insulation level (draft, heat loss, etc.) included.
3) Test room modifications. Equip the test-room with objects representing furniture. Mass absorbs heat, impacting warm-up and cool-down time and also heat distribution throughout the room. With the current heat stratification results, more warmth could be held by these objects, potentially influencing performance.
4) Radiator types. Test different type of radiators.
5) Stress-tests. Optimum of power versus noise level and number of required SpeedComforts per area.

1. DEFINITIONS

Hypothesis: SpeedComfort provides more comfort while saving on CO2 and energy cost

To assess "Comfort", this term needs to be defined to making it measurable/quantifiable.

Thermal Comfort

Most people will feel comfortable at room temperature (20 to 22 °C / 68 to 72 °F), although this may vary greatly between individuals and depending on factors such as activity level, clothing, and humidity. In accordance with the ASHRAE standard 55-56, thermal comfort for a person can be defined as "*a certain state of mind; someone who is satisfied with the thermal conditions*". See: "Enclosure: Defining Thermal Comfort" for a background on this definition.

Based on the hypotheses/claims by SpeedComfort in relation to the factors defining comfort, JOA defined comfort as a person's state of mind influenced by:

1. Temperature of the room in general (temperature)
2. Warming up a room from an uncomfortable to a comfortable state (time)
3. Having the right temperature at the right location (temperature distribution)
4. Radiant temperature (water temperature)

Main focus of the test is based on the above environmental drivers. To collect supporting evidence on personal, more subjective drivers, a customer survey (questionnaire) has been included in the test-program.

2. TEST SETUP

2.1 Test Room

All tests are executed in a dedicated test room with controllable ambient temperature. The dimensions of the (partially insulated) test room are 7.15m x 3.85m x 2.7m. in the test room schematic image in the next paragraph, the following boundary characteristics are present in the test room:

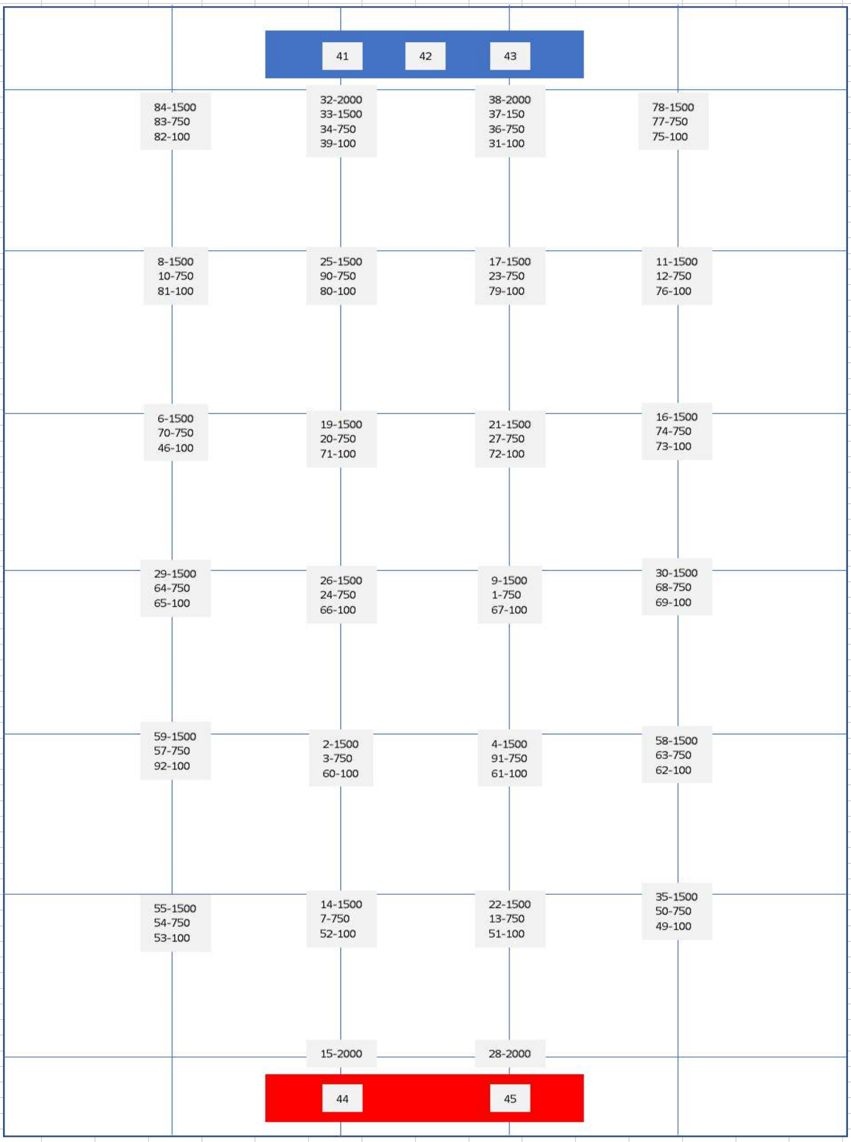
- Floor: concrete with floor heating turned off
- Ceiling: 60% concrete, 40% thick Styrofoam insulated (wooden panel)
- Left wall: fully insulated with thick Styrofoam
- Walls: insulated panels
- Front observation wall: glass; area other side is an office room conditioned at 20°C

2.2. Grid & Sensors

The test room has a grid of strings with sensors, 83 in total. The grid is 7 sensors deep/long x 4 sensors wide and 3 to 4 sensors high. The temperature & Rh sensors log data each 30 seconds. See next image.

e: 20-2-2019

Lengte afstand	Breedte	Hoogte
400	800	1500
400	800	750
400	800	100
400	1600	2000
400	1600	1500
400	1600	750
400	1600	100
400	2400	2000
400	2400	1500
400	2400	750
400	2400	100
400	3200	1500
400	3200	750
400	3200	100
1460	800	1500
1460	800	750
1460	800	100
1460	1600	1500
1460	1600	750
1460	1600	100
1460	2400	1500
1460	2400	750
1460	2400	100
1460	3200	1500
1460	3200	750
1460	3200	100
2520	800	1500
2520	800	750
2520	800	100
2520	1600	1500
2520	1600	750
2520	1600	100
2520	2400	1500
2520	2400	750
2520	2400	100
2520	3200	1500
2520	3200	750
2520	3200	100
3580	800	1500
3580	800	750
3580	800	100
3580	1600	1500
3580	1600	750
3580	1600	100
3580	2400	1500
3580	2400	750
3580	2400	100
3580	3200	1500
3580	3200	750
3580	3200	100
4640	800	1500
4640	800	750
4640	800	100
4640	1600	1500
4640	1600	750
4640	1600	100
4640	2400	1500
4640	2400	750
4640	2400	100
4640	3200	1500
4640	3200	750
4640	3200	100
5700	800	1500
5700	800	750
5700	800	100
5700	1600	1500
5700	1600	750
5700	1600	100
5700	2400	1500
5700	2400	750
5700	2400	100
5700	3200	1500
5700	3200	750
5700	3200	100
6760	1600	2000
6760	2400	2000
Geplakt op cooling radiator		
Geplakt op cooling radiator		
Geplakt op cooling radiator		
Geplakt op heater radiator		
Geplakt op heater radiator		

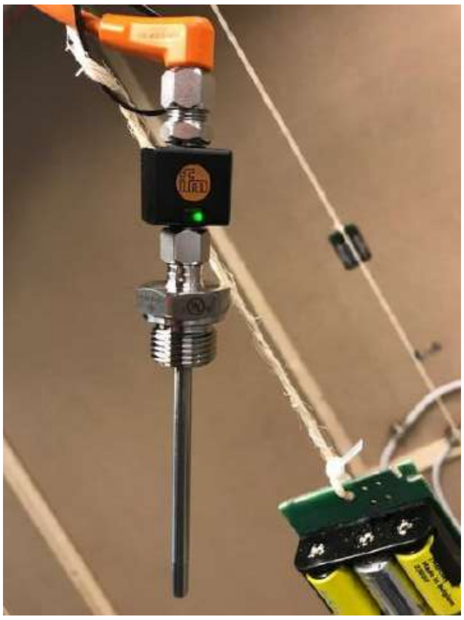


Air room temp/RH sensors

The test room contains a Type 22 radiator, equipped with 3 SpeedComforts. On the radiator panel, additional temperature sensors were attached for measuring metal plate/panel temperature →

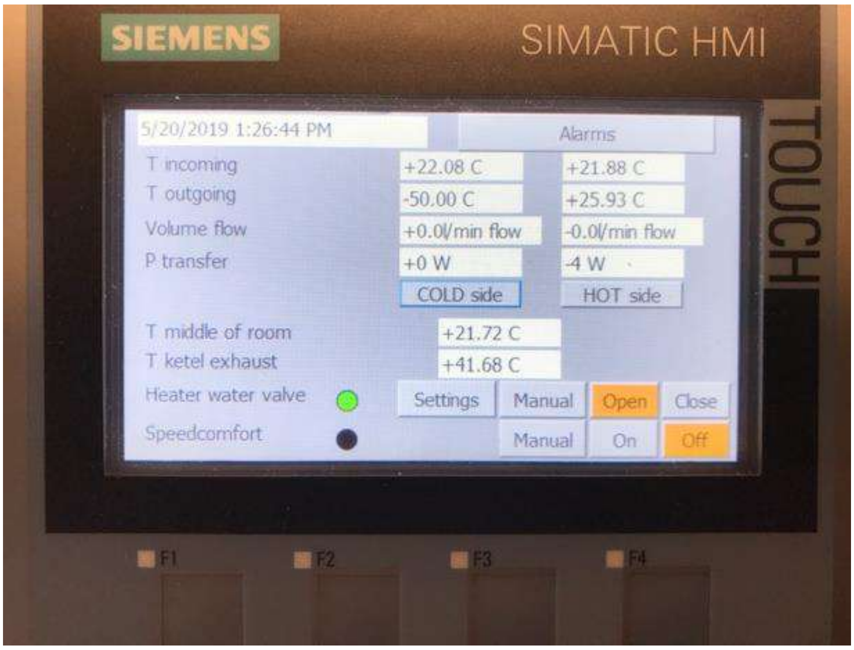
←Temperature sensors were installed in the piping of the incoming- (inflow) and outgoing heating-water (return flow) in order to accurately measure water temperature.

The outgoing heating water pipe also contained a waterflow-sensor. The incoming water-pipe contained an automatic on/off valve →



← In the centre of the test-room a temperature sensor was installed, acting as the room thermostat

↓The SpeedComforts and the automatic on/off valve were controlled by a Siemens PLC[4]:



All collected data from room air sensors, water flow measurement and on/off valve, SpeedComforts were logged.

NB. The Enclosures contain technical specifications of all test-equipment.

[4] **P**rogrammable **L**ogic **C**ontroller

2.3 Test Runs

In total a series of test, 28 in total[5], were performed with various boiler / supply water temperature settings. These varied from 50°C to 70°C. The amount of degrees for warming up the room was set at 2°C (ΔT).

A summary of the test sequence is given below[6]:

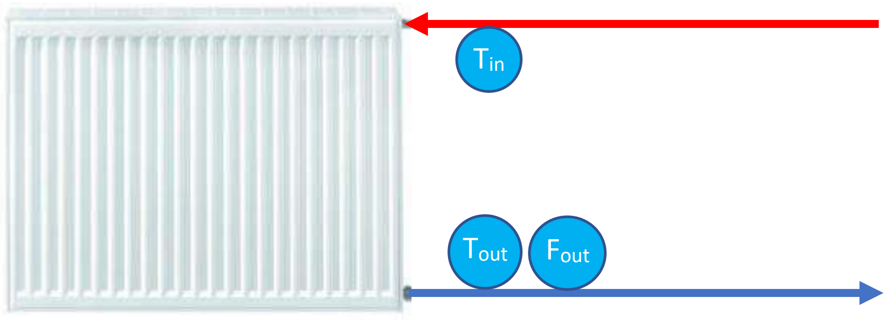
Test-run (#)	Test Date	Sensors Grid (#)	Sensors Power (#)	Data logs (Power)	Boiler Temp (STP, °C)	Testing Time (mins)	Testing Time (hrs)	(Data Points) (Logs)
1	15-mrt-19	83	6	986	50	493	8,22	87.754
2	20-mrt-19	83	6	991	50	495,5	8,26	88.199
3	22-mrt-19	83	6	817	60	408,5	6,81	72.713
4	25-mrt-19	83	6	661	60	330,5	5,51	58.829
5	26-mrt-19	83	6	621	70	310,5	5,18	55.269
6	27-mrt-19	83	6	590	70	295	4,92	52.510
7	29-mrt-19	83	6	540	65	270	4,50	48.060
8	2-apr-19	83	6	540	70	270	4,50	48.060
9	3-apr-19	83	6	603	70	301,5	5,03	53.667
10	5-apr-19	83	6	601	65	300,5	5,01	53.489
11	9-apr-19	83	6	598	70	299	4,98	53.222
12	10-apr-19	83	6	598	65	299	4,98	53.222
13	11-apr-19	83	6	560	70	280	4,67	49.840
14	12-apr-19	83	6	560	70	280	4,67	49.840
15	13-apr-19	83	6	720	60	360	6,00	64.080
16	14-apr-19	83	6	2731	55	1365,5	22,76	243.059
17	16-apr-19	83	6	5246	55	2623	43,72	466.894
18	23-apr-19	83	8	18138	70	9069	151,15	1.650.558
19	26-apr-19	83	8	8726	60	4363	72,72	794.066
20	29-apr-19	83	8	8005	65	4002,5	66,71	728.455
21	9-mei-19	83	5	7917	65	3958,5	65,98	696.696
22	10-mei-19	83	6	1800	65	900	15,00	160.200
23	13-mei-19	84	7	9000	65	4500	75,00	819.000
24	19-mei-19	84	7	5172	65	2586	43,10	470.652
25	20-mei-19	84	7	2200	65	1100	18,33	200.200
26	21-mei-19	84	7	2025	65	1012,5	16,88	184.275
27	23-mei-19	84	7	1890	70	945	15,75	171.990
28	24-mei-19	84	6	423	70	211,5	3,53	38.070
					Totals	**41.630**	**694**	**7.512.869**
						(Minutes)	**(Hours)**	**(Data-Points)**

[5] From the 28 test-runs, 2 were interrupted and are therefore excluded from the test results.

[6] The term power refers to the sensors utilized for determining power consumption

2.4 Calculations

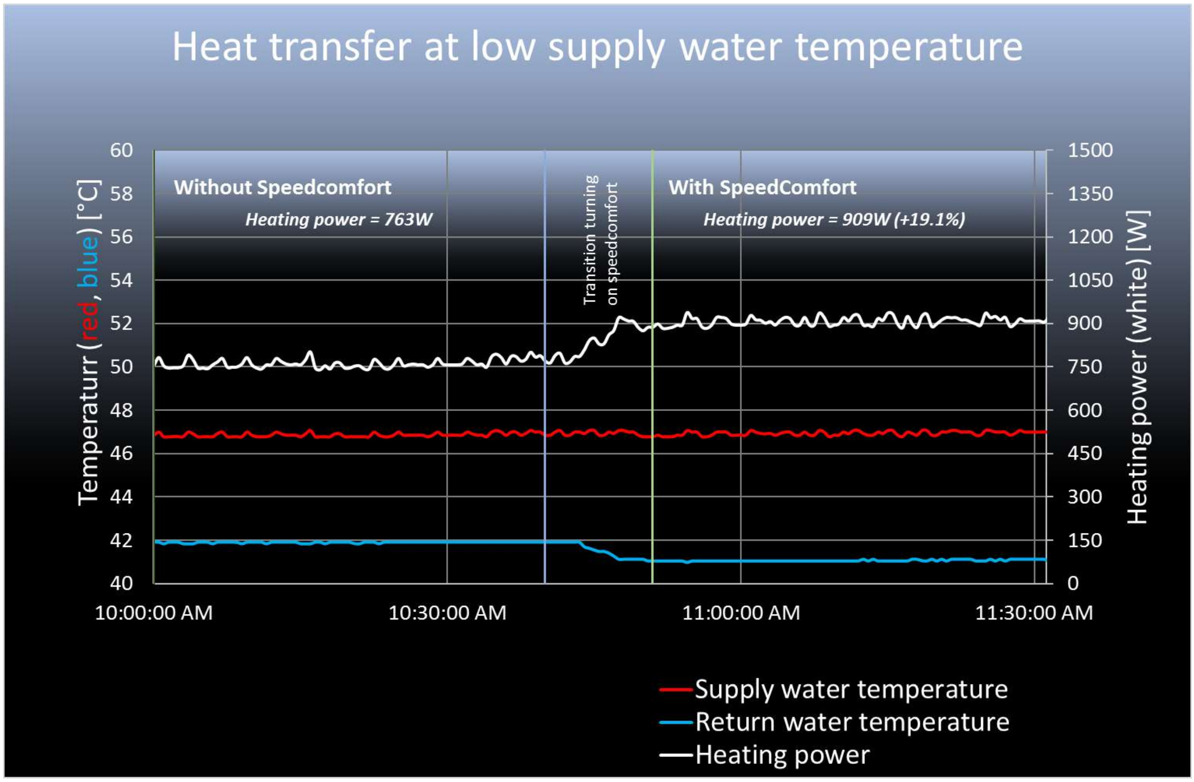
Power released by the heating panel to verify Hypothesis 1 has been calculated by measuring incoming water temperature (supply), outgoing water temperature (return) and mass flow.



With the measured quantities, power can be calculated with the following equation:

$$P = \dot{m}.C_v.(T_{in} - T_{out})$$

P = Power released by heating panel [W]
$\dot{m}$ = massflow though system [kg/s]
C_v = Heat capacity of water [4190 J/kg.K]
T_{in} = supply water temperature [°C]
T_{out} = return water temperature [°C]



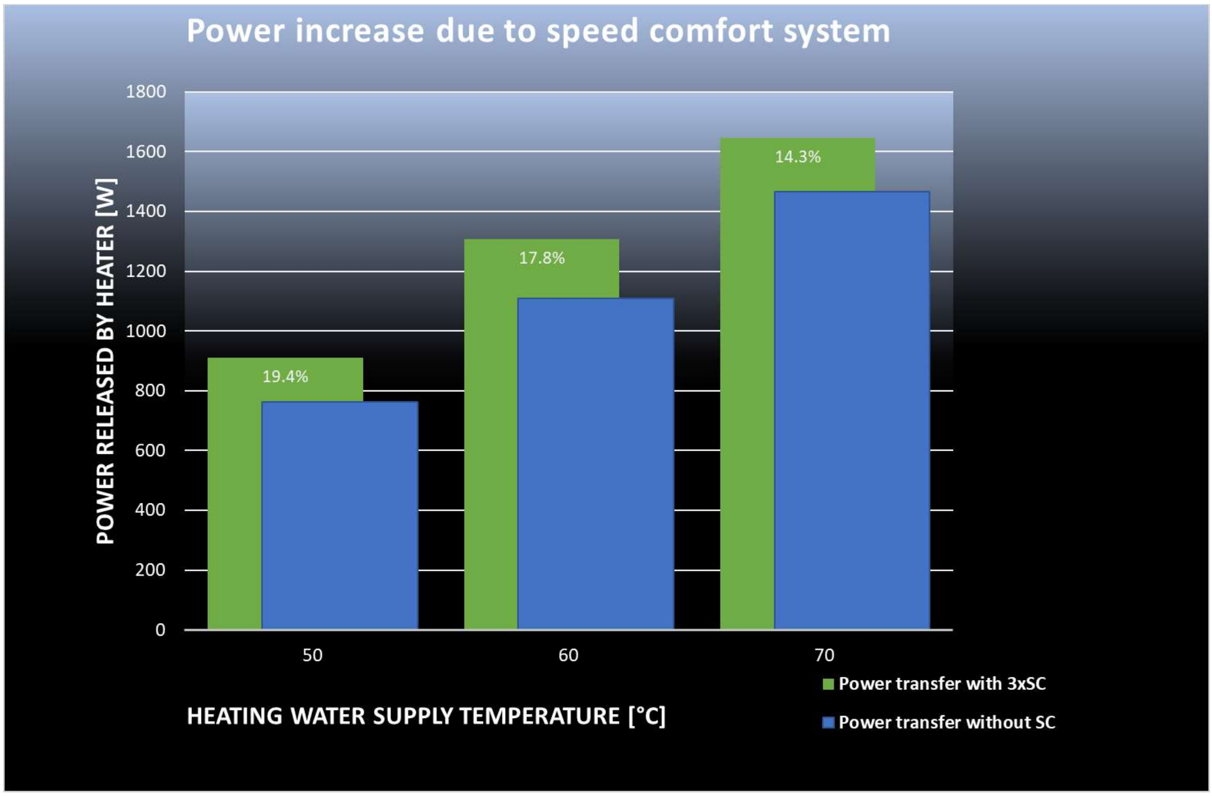
The increase in power transfer induced by SpeedComfort is a result of increased heat transfer from heating panel to air. This heat transfer is given by the following equation:

$$P = U.A.\Delta T$$

P = Power transfer from water to air, through the metal barrier of the heating panel [W]
U = Heat transfer coefficient [$W/m^2.K$]
A = Heat transfer surface area [m^2]
ΔT = Temperature difference between water and air [K]

By forcing the air alongside the heating panel, the heat transfer coefficient is enhanced. The heating panel is exposed to an averaged lower air temperature, resulting in a lower water return temperature, effectively extracting more thermal energy from the heating water.

At high water supply temperatures, the natural convection of air naturally increases the heat transfer coefficient. At lower temperatures, this natural convection effect is less and the SpeedComfort solution assists by forcing convection – having a relative larger effect on thermal power transfer.



When gas is burned with oxygen, carbon dioxide and water vapor is formed. Following the (near same equation as before), the energy transfer from exhaust air to water can be obtained:

$$P_{cooling} = \dot{m}.C_p.(T_{combustion} - T_{exhaust})$$

$P_{cooling}$ = Power released from combustion exhaust to heating water [W]
$\dot{m}$ = massflow exhaust stream through air-water heat exchanger [kg/s]
C_v = Heat capacity of exhaust air at constant pressure [1030 J/kg.K]
$T_{combustion}$ = temperature after combustion [~1500 °C]
$T_{exhaust}$ = exhaust temperature after heat exchanger [°C]

The equation shows a linear relationship between exhaust temperature and power transfer from combustion to water, but this linearity is *only valid above the dewpoint* of the gas.

The dewpoint of the exhaust stream when exact amount of air is provided for complete burning is around 59°C. With an excess air of 15%, the dewpoint will be reduced to 56°C (hence why finetuning gas/air mixture is relevant for boiler performance). When the exhaust gas temperature is reduced below dewpoint, condensation of water vapor will occur, releasing power satisfying the following equation:

$$P_{condenation} = \dot{m}_{condensation}.C_w$$

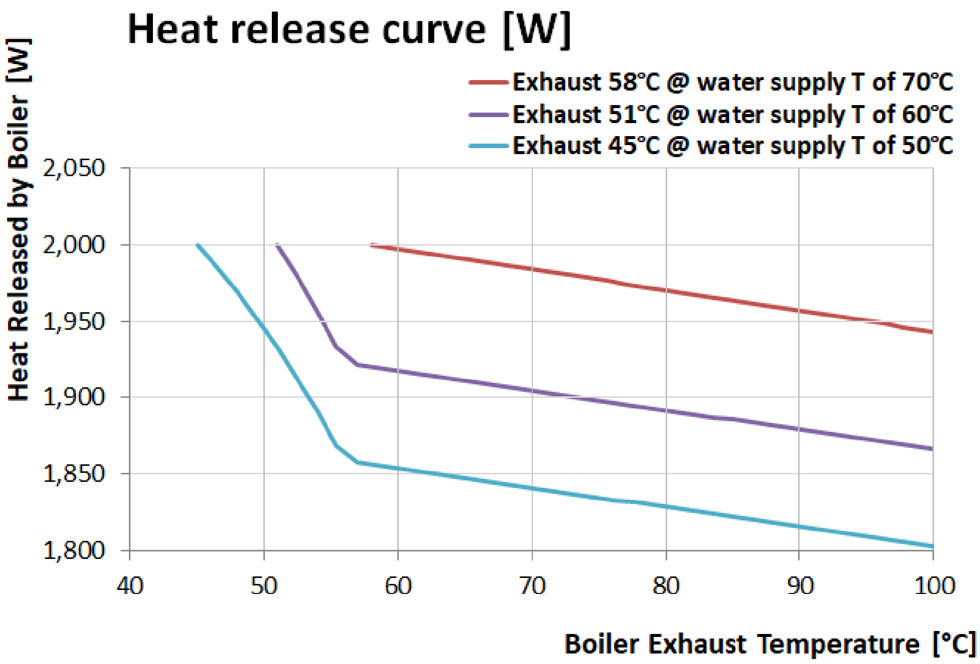
$P_{condenation}$ = Power released from condensation [W]
$\dot{m}_{condensation}$ = Water vapor condensation rate [kg/s]
C_w = enthalpy of vaporization [2250000 J/kg]

The low exhaust gas temperature can be obtained by

1. Reducing supply water temperature setpoint (less necessity to heat)
2. Reducing return water temperature (exposing exhaust gas to lower temperatures)

The amount of heating power released in a boiler only linear when cooling down to the exhaust dewpoint. Below the exhaust dew point, the released power is no longer linear to the temperature due to condensation, but can be modelled.
For the modelling, the required heating power is assumed to be 2000W. By changing the boiler exhaust temperature, the consumed gas also changes, to have a steady consumed power.

The modelling shows that lowering supply water temperature, the boiler will operate more efficient: less gas consumption for the same power output. It must be noted that reducing water supply temperature also will reduce the amount of power released to the house (smaller temperature difference). SpeedComfort increases the power output.



By proper utilization of the SpeedComfort units, gas consumption for heating can be reduced by around 2% by turning the supply water temperature down, without taking any other saving measures.

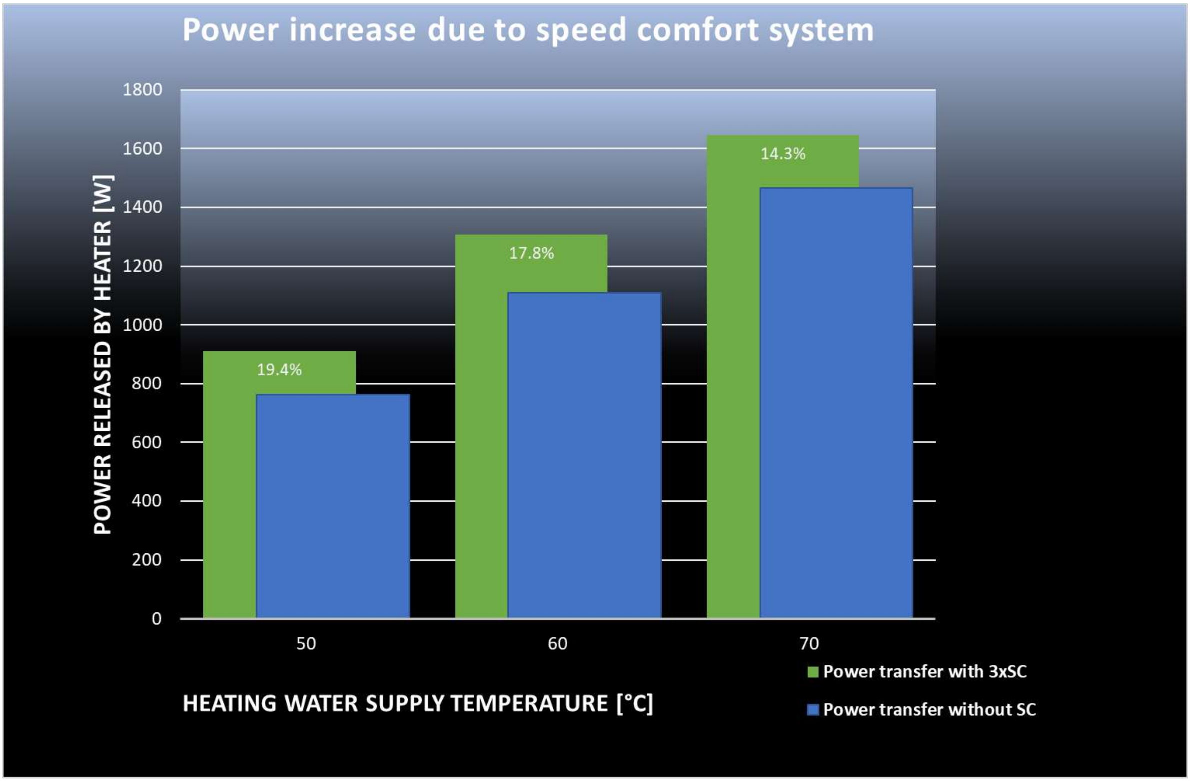
3. Test Results

3.1 Increasing thermal output

A range of tests were executed at several heating water supply temperatures. They indicate that a lower heating water supply gives the highest increase of thermal radiator output (natural convection is lower at lower heating water temperatures):

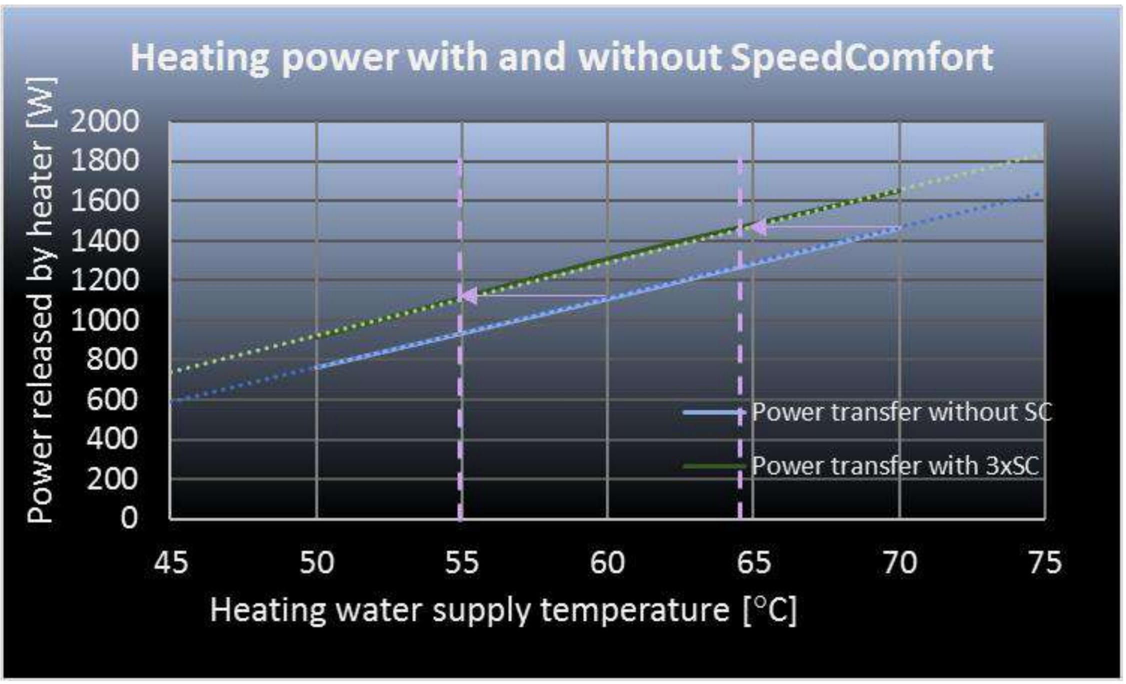
Setpoint water [°C]	**70** (100%)	**60**	**50**
Power transfer without SC[7] (Watt)	1465 (100%)	1109 (-24,3%)	763 (-47,9%)
Power transfer with 3xSC (W)	1647	1307 (-10,8%)	911 (-37,8%)
% power transfer (W)	14.3%	17.8%	19.4%

Depending on boiler water temperature settings, additional power transfer / heat extraction from the radiators with SpeedComfort varies between 14.3% and 19.4%. The blue bars in the graph show the power transfer without SpeedComfort compared to the situation with SpeedComfort (green bars):



[7] SC: SpeedComfort

The data also shows that SpeedComfort increases the heat transfer coefficient, enabling more thermal output of the radiator. This is visible in the following chart:

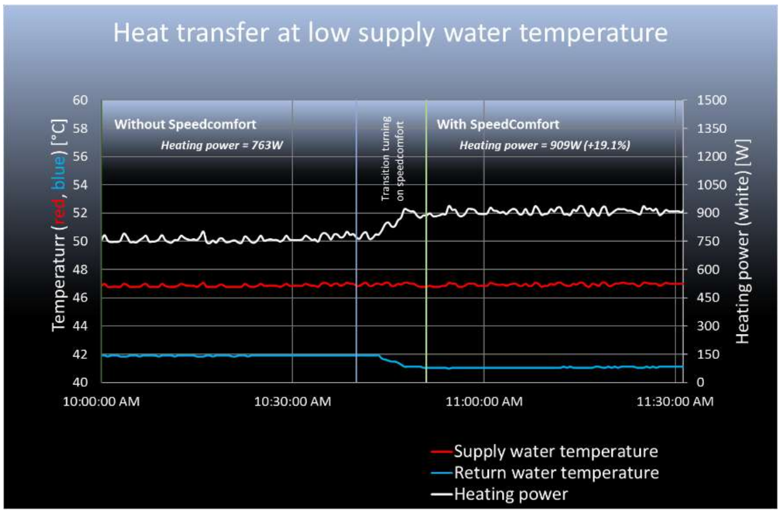


Conclusion

Claim 1: "SpeedComfort increases capacity of existing radiators (increased power)" is supported by the data: depending on water temperature settings, between 14.3% and 19.4% additional heat is extracted from the radiator when using SpeedComfort.

Note: Heat pump application

This graph shows the effects on heating (radiator) power with lower water supply temperatures. With the increased capacity of existing radiators, SpeedComfort could contribute to low temperature heat pump applications in the existing building environment.



3.2 Acceleration heat transfer in room

A sequence of 28 test runs were performed to measure time in relation to temperature (warming up the room by / ΔT 2°C) and required energy (Wh) for standard boiler settings (70°C supply water). An intermediate marker was set at 1.3°C.

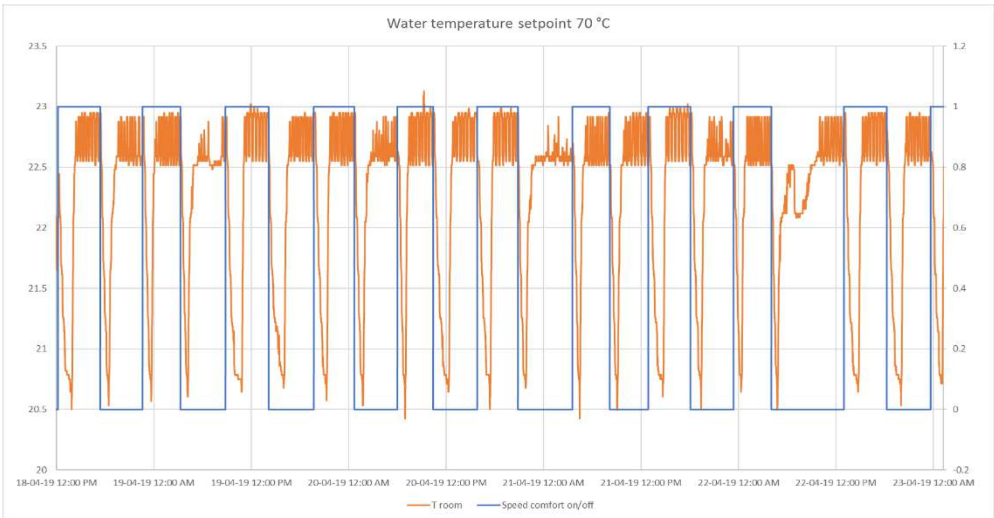
The ON/OFF column shows whether test were performed with (ON) or without (OFF) SpeedComfort. Note that the red-marked tests were excluded from the final test results due to an interruption of the test-run (resulting into anomalies in energy usage data).

The table shows the comparable averages of warm-up time and energy usage.

Test-results batch 1 (water temperature @ 70°C)

Dataset #	SpeedComfort ON/OFF	Water temperature	Start temperature	Start time heating	Time to heat room with 1.3°C	Used radiator power (W) with 1.3°C	Total required energy (Wh)	Time to heat room with 2°C	Used radiator power (W) with 2°C	Total required energy (Wh)	Average Temp Flue Gas
1	ON	70	20,7	13:52:00	00:13:00	3788	820,67	00:31:00	2542,70	1314	54,7
2	OFF	70	20,7	18:24:00	00:22:00	2553	936,15	01:12:30	1801,51	2162	55,2
3	ON	70	20,7	23:39:30	00:12:00	3816	763,26	00:36:00	2352,95	1412	
4	OFF	70	20,7	04:09:00	00:16:30	2749	756,07	01:40:30	1740,59	2901	
5	ON	70	20,7	10:47:00	00:12:00	3900	780,02	00:21:30	2822,07	1011	
6	OFF	70	20,7	15:59:00	00:15:30	3122	806,42	00:42:30	2063,43	1462	
7	ON	70	20,7	21:14:30	00:12:30	3787	788,98	00:28:00	2647,97	1236	
8	OFF	70	20,7	01:43:00	00:17:30	2743	800,08	01:35:00	1684,38	2667	
9	ON	70	20,7	06:55:00	00:13:30	3560	801,03	00:29:00	2587,96	1251	
10	OFF	70	20,7	12:16:30	00:14:00	3385	789,91	00:33:00	2227,59	1225	
11	ON	70	20,7	17:22:30	00:13:00	3666	794,20	00:27:30	2665,43	1222	
12	OFF	70	20,7	21:47:00	00:17:00	2791	790,77	02:45:30	1589,39	4371	
13	ON	70	20,7	04:25:00	00:13:00	3664	793,86	00:44:00	2172,38	1593	
14	OFF	70	20,7	09:03:00	00:17:30	2699	787,10	00:50:00	1872,88	1561	
15	ON	70	20,7	14:41:00	00:12:00	3850	770,04	00:24:30	2815,22	1150	
16	OFF	70	20,7	19:22:00	00:16:00	2870	765,45	01:01:30	1834,38	1880	
17	ON	70	20,7	00:19:00	00:15:00	3268	817,06	00:43:00	2278,37	1633	
18	OFF	70	20,7	04:46:00	00:23:30	2336	915,11	05:13:00	1483,15	7737	
19	ON	70	20,7	14:43:00	00:14:00	3550	828,37	00:32:00	2477,58	1321	
20	OFF	70	20,7	19:59:30	00:15:00	3099	774,74	00:39:30	2073,62	1365	

Below is a graphical representation of this test-batch:

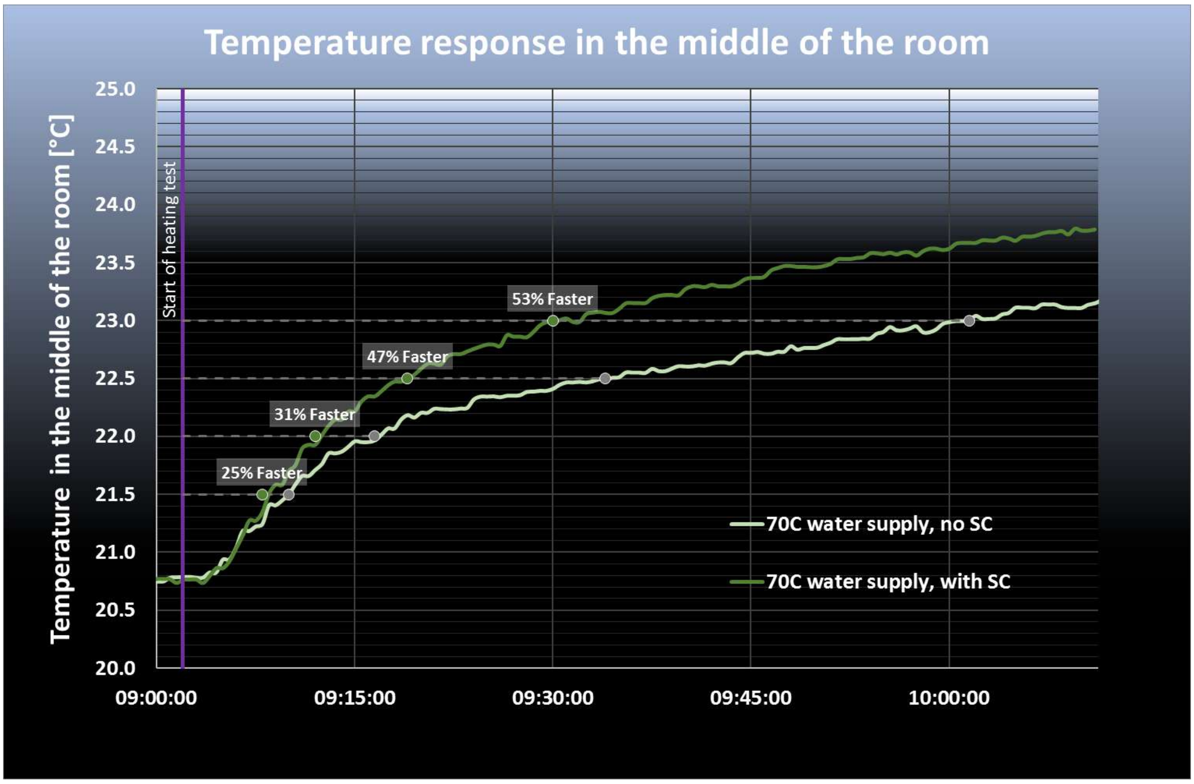


The consolidated data looks as following:

	SpeedComfort ON/OFF	Water temperature	Start temperature	Start time heating	Time to heat room with 1.3°C	Used radiator power (W) with 1.3°C	Total required energy (Wh)	Time to heat room with 2°C	Used radiator power (W) with 2°C	Total required energy (Wh)	Average Temp Flue Gas
Average values	ON	70	20,7		00:13:00	3685	796	00:31:39	2536	1314	54,7
Average values	OFF	70	20,7		00:16:45	2903	802	01:01:49	1912	1903	55,2
					22%		**1%**	**49%**		**31%**	

When warming up the area by 2°C with SpeedComfort the room is 49% faster at desired temperature level compared to not using SpeedComfort. While doing so, 31% less energy is consumed.

When warming up the room with 1.3°C this it is 22% faster (almost using the same amount of energy; 1% difference). This shows the relationship between warm-up time, required energy and ΔT: the higher ΔT, the relative shorter warm-up time and relative lower energy requirement. The following graph demonstrates this:

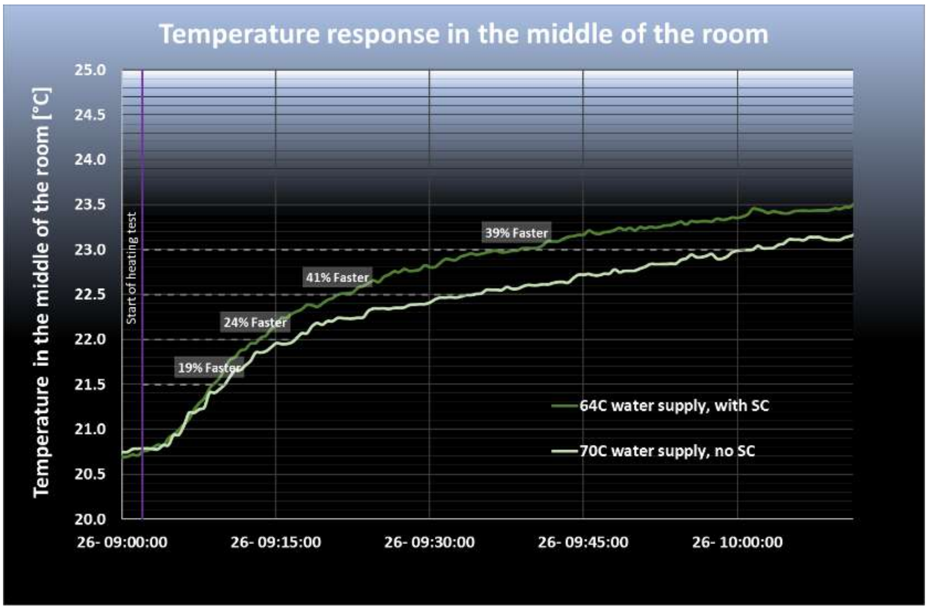


A second series of tests was held at a lower boiler supply water temperature (65°C). Overall this showed the reinforcement of the warm-up time and energy effects. The results are in the <u>Enclosure: Heat Extraction – Test @ 65°C</u>

Energy recovery (boiler efficiency)
A result of extracting more heat from the radiator by applying the SpeedComfort is the colder return-flow to the boiler system. Energy recovery by central boiler systems is determined by condensation (water vapor in the flue gas). Lower flue gas temperatures result in increased condensations. In order to reclaim energy, flue gas temperature must to be under 56.1°C . Increasing the difference (ΔT) between this threshold and the actual flue gas temperature results in a greater reclamation of energy. With flue gas temperature directly impacted by boiler water temperature (return flow), the supply water temperature of the boiler makes the boiler system more efficient. The supply water temperature can be optimized to create enough comfort at maximized boiler efficiency. The specific household situation will determine how far boiler supply water temperature can be lowered: how far can the heating (over)capacity be reduced, without underpowering the boiler output, still being capable to heat room.

Comparison by power load
With SpeedComfort creating more power (see 3.1) another test was set-up to measure convection without the additional power created by SpeedComfort. This can be seen as a 'break-even point' of similar heating power at 70°C water supply temperature without SpeedComfort in comparison to 64°C water supply temperature with SpeedComfort.

These test-results also show a faster heat-up time. The same effect occurs when the heating is off; heat transfer will continue longer with the use of SpeedComfort than without SpeedComfort. With the comparable radiator heating capacity (heating power load) it must be concluded that these effects are a result of forced convection.



Conclusion

The hypothesis "SpeedComfort brings heat more quickly into the room" is substantiated; Heating-up the room is proven to be faster due to the forced convection. Also, less energy consumption is achieved with a ΔT >= 2°C. When using SpeedComfort at standard boiler settings (70°C), warm-up time is 49% faster with an energy consumption of -31%.

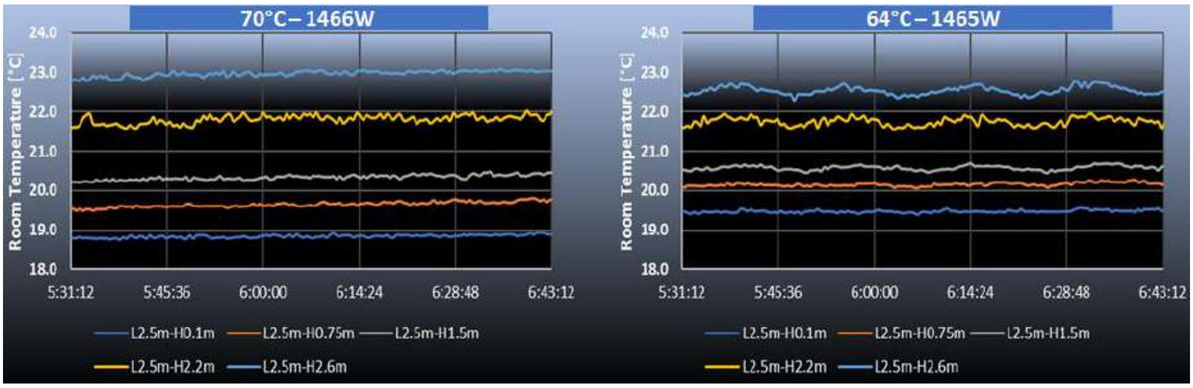
Reperforming the test with lower boiler water supply temperature shows a similar pattern (at 65°C: 41% faster, -21% Wh).

3.3 Heat Distribution

Claim: *"SpeedComfort creates better air circulation (better heat distribution)"*

When forcing convection, it is expected that a better mixture of the room air is created, meaning heat from the ceiling is brought down. This is also referred to as (temperature) stratification improvement. With the sensor-grid, temperatures were logged at three heights and in total at 83 locations in the room, making it relatively straightforward to monitor the heat patterns (over time) to collect evidence of this potential effect.

The following charts shows the heat distribution with- and without SpeedComfort. For comparison ('apples to apples') identical heating power levels were applied (≈1465W):



Temperature difference floor (0.1m) and ceiling (2.6m) @ 70°C heating water supply without SpeedComfort	Temperature difference floor (0.1m) and ceiling (2.6m) @ 64°C heating water supply with SpeedComfort	Stratification improvement with SpeedComfort (at identical heating power)
4.2°C	3.0°C	27%

The graphs show that a **stratification difference of 1.2°C** (4.2 -/- 3.0) is created by assisted convection: temperatures at ceiling level come down, whereas those at the bottom of the room ('feet level') reach higher levels. This indicates a better warmth distribution on those locations where people will notice it (0.1m < 2.0m). Apart from the actual increase in temperature in the living zone, it will also add to the personal factors/drivers of thermal comfort ('warmer feet').

In this test (boiler at 64°C) it is justified to reduce thermostat setting by 0.5°C to 1°C still achieving the same temperatures in the comfort zone. Note that the test room had no draft and/or other forms of heat loss.

Conclusion

This test supports Claim 3: "SpeedComfort creates better air circulation resulting in better (vertical) heat distribution". Assisted convection leads to a 1.2°C improved temperature stratification between 0.1m and 2.6m , with the highest impact in the 'living zone'(note that for boilers with supply water temperature of 70°C this effect will be larger).

Customer Survey Results

To test the 1.2°C stratification improvement in the field, and the behaviour of people influenced by these personal comfort factors, the customer survey included two related questions:

“Which effects were directly noticeable after installing/using SpeedComfort?”

Answer Choices	Responses	
1) More comfort (better heat distribution)	71.7%	1,220
2) Faster warm-up time	60.4%	1,027
3) Energy Saving	17.2%	293
4) Solve specific issue (draft, heat blockage, rad capacity)	9.7%	165
Total Respondents: 1,701 (skipped: 100)		

Response shows that 71.7% of SpeedComfort users experience more personal comfort due to a better heat distribution.

A follow-up question asked whether people felt warmer and whether they had lowered their temperature (thermostat) as a result of this:

“Did you lower thermostat/temperature level due to SpeedComfort?”

Answer Choices	Responses	
Yes, 0.5°C lower	14.0%	250
Yes, 1°C lower	16.2%	291
Yes, 1.5°C lower	3.2%	58
Yes, 2°C lower	2.1%	37
No, I don’t notice a difference	50.4%	903
Other	14.1%	253
Total Respondents: 1,792 (skipped: 9)		

The answers show that 35.5% of the SpeedComfort users lowered their temperature (thermostat) settings: 14% with 0.5°C and 21.5% with 1°C or more.

The ‘Other’ answer-categeory included a comment box which confirmed increased temperature levels:

1) People felt warmer but their thermostat automatically managed the room temperature
2) People felt warmer but enjoyed the comfort and chose not to lower temperature.

The “No” category (50.4%) was not split into sub-categories so underlying reasons remain unknown. However, based on the ‘Other’ category we assume that a significant part of this group did not notice any difference because their (smart) thermostat automatically managed room temperature (faster cut-off).

4. SAVINGS

In this chapter the impact of SpeedComfort on reduced energy consumption is reviewed. The term “savings” relates to lower energy consumption, CO2 emissions- and cost.

Hypothesis: SpeedComfort reduces energy consumption:

1. due to improved boiler efficiency
2. due to reduced warm-up time
3. due to improved room temperature distribution

4.1 Reducing supply water temperature

Modern boiler systems have a maximum supply water temperature of 80°C, older boiler systems max. 90°C. Standard boiler setting often range between 80°C and 70°C.

The efficiency of the boiler is influenced by the condensation effect from the return-flow water temperature. The larger the delta between the return-flow temperature and the dewpoint (56.1°C), the higher effect of energy reclamation. This delta is mostly influenced by the supply water temperature (boiler setting) and the heat extraction from the radiators.

In paragraph 3.2 we saw that when offsetting the increased heat transfer due to SpeedComfort, boiler supply water temperature at 70°C without SpeedComfort equals 64°C with SpeedComfort. This means, given the standard boiler temperature at 70°C, the supply water temperature can be lowered with at least 6°C, keeping the same heating power (in this test 1465W). Because of that, boiler efficiency increases, saving ca. 2% on gas consumption.

When further lowering supply water temperature, increasing the delta between the return-flow temperature and the flue gas, the following efficiencies can be indicated:

Natural gas supply [m3/h]	0.300	0.243	0.273	0.238	0.209
Total air supply (m3/h @15°C)	3.24	2.63	2.95	2.57	2.25
% excess air	15.0%	15.0%	15.0%	15.0%	15.0%
Dewpoint exhaust (°C)	56.1	56.1	56.1	56.1	56.1
Boiler exhaust (°C)	64.4	57.9	57.9	53.9	51.3
Heating water supply (°C)	80.0	70.0	70.0	64.0	60.0
Heating power (W) - same radiator	1,802	1,466	1,647	1,465	1,307
speed comfort	NO	NO	YES	YES	YES
gas saving with respect to 80C		19.0%	9.0%		30.5%
power reduction with respect to 80C		18.6%	8.6%		27.5%
gas saving with respect to 70C				2.0%	14.2%
power reduction with respect to 70C				0.1%	10.9%

The data shows that most impact is reached from boilers with settings of 80°C, since return-flow water temperature (mostly) do not reach the Dewpoint Exhaust temperature, thus having 0% energy reclamation.

Note that lowering boiler settings also means that the capacity of the boiler system is lowered (less heating power), so a household needs to be able to handle this. It is therefore recommended to find the optimum between required energy (capacity needed to heat the rooms to a certain temperature) and the capacity of the boiler[8]. This is also dependent of insulation level, heat loss of piping, dimensions of the building, etc. Most households are able to lower their boiler from 80°C to 70°C and from 70°C to 64°C. When lowering settings from 70°C to 60°C the effect of energy reduction is significant, but it also creates a heating power reduction of 10.9%.

Boiler Water Temperature without SpeedComfort	With SpeedComfort, Lowered to	Power reduction (W)	Energy reduction
80°C / 1800W	70°C	-8.6%	9%
70°C / 1465W	64°C	n/a	2%
70°C / 1465W	60°C	-10.9%	14.2%

Field Research: customer feedback

The customer survey included a specific question on lowering Supply Water Temperature:
"Did you lower boiler water temperature level due to SpeedComfort?"

Answer Choices	Responses	
No, my situation is not suitable for that	14.2%	237
No, my boiler already was at 60°C or less	20.5%	341
Yes, I lowered it to 70°C	8.5%	141
Yes, I lowered it to 65°C	12.3%	204
Yes, I lowered it to 60°C or less	29.3%	487
I don't know / Did not know this was possible	15.1%	254
Total Respondents: 1,701 (skipped: 100)		

More than 50% of the respondents lowered boiler settings after using SpeedComfort. Around 20% of the respondents already did this prior SpeedComfort use, indicating that their comfort level allows for further reduction given the increased thermal output with SpeedComfort.

When excluding this 20% group, close to 63% of remaining correpondents (1.323) lowered their settings. An upward potential lies in the group whom anwered "didn't know / did not know it was possible". Only 14.2% was clear that their personal situation did not allow for lowering boiler settings (reasons unknown).

The largest group responded that they were able to lower their supply water to 60°C or less. With standard boiler settings at 70°C or 80°C, it can be assumed that temperature was at least 10°C.

[8] End temperature/max capacity should be sufficient in relation to setpoint temperature, preferably with a safety margin. Otherwise the boiler will keep on heating the room, never reaching the setpoint.

4.2 Warm-up time efficiency

As showed in chapter 3.2, warm-up time is shortened with less energy consumption (Wh) when using SpeedComfort. To determine the related energy saving, a comparison has been made between energy consumption with- and without SpeedComfort related to average household consumption.

Average energy consumption varies per country and household. Also, ΔT and supply water temperature are variables, so the following benchmark information was used to calculate these effects:

Variable	Metric	Comment
# Heating days/season (<18°C) -- Sept 1st to April 30th)	239	i.e. 2018 for Netherlands this was 239
# Heatings per day	1x to 2x	Most common: twice a day
ΔT	2°C	Most households: 18°C -> 20°C
Average Gas for heating of total energy consumption	64.1%[9]	See EU / Eurostat average
Average Gas usage per household	1500m3	NL: 1470 / UK 8-17k / DE: 17k

Chapter 4.1 showed that over 60% of the SpeedComfort users lowered their boiler supply water to 65°C or less[10]. Using this as a base, the following calculation can be made:

Savings: warm-up time efficiency

Estimated heating days 2018: 239	Heatings Min	Median	Heatings Max
Heat-up times/day	1x	1,5x	2x
Heat-up times/winter (heating) season	239	359	478
Energy Cons. w/o SC @ 65°C (1120Wh)	267.680	401.520	535.360
Energy Cons. With SC @ 65°C (848Wh)	202.672	304.008	405.344
Saving @ 65°C	65.008	97.512	130.016
Savings (m3)	7	10	13
Saving in relation to gas usage for space heating	**0,7%**	**1,0%**	**1,3%**

Note that for those with a standard Boiler Supply Water Temperature (70°C), warm-up efficiency savings increase: **1.5% to 2.9%.** See enclosure: "Warm-up time efficiency: calculation of Savings". For boiler settings at 60°C, warm-up time efficiency will be reduced to 0,7 to 1,3%). Hence, for any boiler setting, warm-up time efficiency increases when using a higher ΔT (i.e. warming up the room with 3°C).

[9] NL & DE close to 70-75% (www.vastelastenbond.nl, www.destatis.de), UK around 2/3 (i.e. OVO Energy)
[10] This group is likely higher considering the 'don't know' responses

Conclusion

The contribution of a faster warm-up time using less energy contributes to an overall reduction of energy consumption. The significance of this reduction depends on the specifics of the households. For boilers set at 60-65°C we assume a range of energy savings between 0.7% and 1.3%. For boilers set at 70°C or more, this increases to 1.5% to 2.9%

4.3 Energy saving due to temperature stratification

Chapter 3.3 concluded a 1.2°C reduction of heat stratification with 64°C boiler supply water temperature. For boilers at 70°C this is significantly higher. General benchmarks[11] show that each 1°C is equivalent to 7% energy.

With the increase heat profile at 10cm-200cm height in the test-environment as a result of the assisted convection, thermostat setpoint level was reached sooner. In the test-room the air room temperature sensor (thermostat) was placed at a height of 1.5m. On this level the temperature difference reached 0.5°C to 1.0 °C, resulting in a 3.5% to 7% energy saving.

However, with the highest impact of the heat stratification on the level below 1.5m (‘feet’ and ‘body’ heights) thermal comfort will play a significant role in reducing thermostat level. For this effect, the customer survey provides insights (also see 3.3).

- Almost 72% of the respondents experience more comfort and better heat distribution.
- More than 35% of respondents (manually) lowered thermostat level due to SpeedComfort with 0.5°C to 2+°C.
- The ‘other’category (14%) included a comments on enjoying higher temperatures (but keeping thermostat level similar) and/or mentioning that their (smart) thermostat automatically adjusted temperature. Based on this insight, it may be assumed that for a portion of the largest group (“not noticing any difference”; 50%) this might also be the case. This needs further investigation.

Finally, an analysis was made on the correlation between boiler (supply water) temperature and heat stratification. Will people both save on boiler efficiency and on improved heat profile benefits? It was expected that lower boiler settings (less power) would result in a decreased numbers of respondents lowering their thermostat. This correlation was not found though: the chart below shows a combination of two customer survey questions (Q6 and Q7). It shows the number of users that lowered their boiler (supply water) temperature and also their ability to lower thermostat level due to the improved heat stratification.

[11] Source: www.consumentenbond.nl , www.milieucentraal.nl

Thermostat Reduction → ↓Boiler Reduction	0.5°C	1.0°C	1.5°C	2.0°C or more	No difference	Other
70°C	22.5%	14.1%	3.5%	1.4%	47.2%	11.3%
65°C	16.8%	16.8%	2.9%	4.3%	47.1%	12%
60°C or less	13.9%	21%	3.7%	2.5%	45.8%	13.1%

Although the number of respondents with lower boiler settings gradually declines in the 0.5°C category, the opposite shows in the 1.0°C category. Also, the other numbers do not show a distinct correlation. Apparently, savings depend on individual situations (i.e. personal circumstances like thermal comfort and/or technical circumstances such as insulation level, capacity of boiler system, etc.).

Balancing the technical approach of the test-environment and the customer feedback from the survey we keep a range for savings due to heat stratification of 3.5% to 7%.

4.4 Total Energy savings indication

Based on customer feedback, the recommended (most applied) scenario is to lower boiler supply water to 60°C and adjust room temperature with 0.5°C to 1°C (manually or automatically). This results in a 17,5% to 21% saving[12].

However, energy savings are determined by the combination of boiler efficiency, warm-up time efficiency, heat stratification and the level of insulation and personal factors influencing thermal comfort. To come to an estimation of energy savings when using SpeedComfort, the following customer-scenarios are given:

#	Situation	Saving (min – max)
I.	• Standard Boiler Supply Water Temperature: 70°C • Situation: User does not do anything (not lowering boiler settings) • Effects due to SpeedComfort: o Comfort: convection, 49% faster warm up time o 14.3% more power/capacity generated o Warm-up time savings: 1.5% to 2.9% o Stratification: min. 3.5% (0.5°C), likely 7% or more (1+°C)	5% to 9.9%
II.	• Standard Boiler Supply Water Temperature: 70°C • Situation: User lowers boiler settings to 64°C (offsetting heat transfer) • Effects/results: o Comfort: convection, 41% faster warm up time o Same power/capacity as 70°C without SpeedComfort o Boiler efficiency: 2% o Warm-up time savings: 0.5% to 1.2% o Stratification: min. 3.5% (0.5°C) to 7% (1.0°C)	6% to 10.2%

[12] 14% + 3.5% or 7% (this excludes minor warm-up efficiency savings)

III.	• Standard Boiler Supply Water Temperature: 70°C • Situation: <u>User lowers boiler settings to 60°C</u> (mostly applied according to customer survey) • Effects/results: o Comfort: convection, est. 1/3 faster warm up time o Warm-up time savings: 0.35% to 0.65% o Power/capacity: -/-10.8% (boiler capacity -24.3%, compensated by SpeedComfort with +17.8%) o Boiler efficiency: 14.2% o Stratification: 0% (0°C) to max. 7% (1.0°C)	14.4% to 21.9%
Note: energy savings in these scenarios are likely to be higher when standard boiler supply water is 80°C.		

The non-weighted average saving indication of all scenarios is **11,2% energy saving**.

COMMUNICATION & AUTHORIZATION

For additional information and/or questions, please contact:

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Yours faithfully,

Martin Tukker

JOA

General Manager

LIST OF ENCLOSURES

For details of this study, please refer to the following enclosures:

Enclosure: Equipment specification

Radiator: Type 22

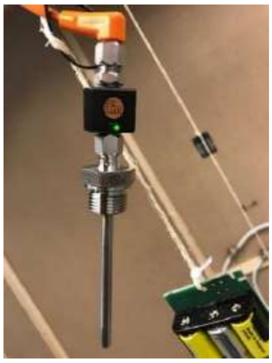
- Dimensions:
    - Length: 1.8m
    - Height: 40cm

SpeedComfort: 3x SpeedComfort Basic

- Year of construction: 2018
- Power consumption: 1.62 [W]
- CE approval: Yes

IFM temperature sensor TM4431 (utilized for both water and air)

- T Range: -40..+150C
- T accuracy: +-0.15K between -40C and 150C



IFM Flow sensor SM6000

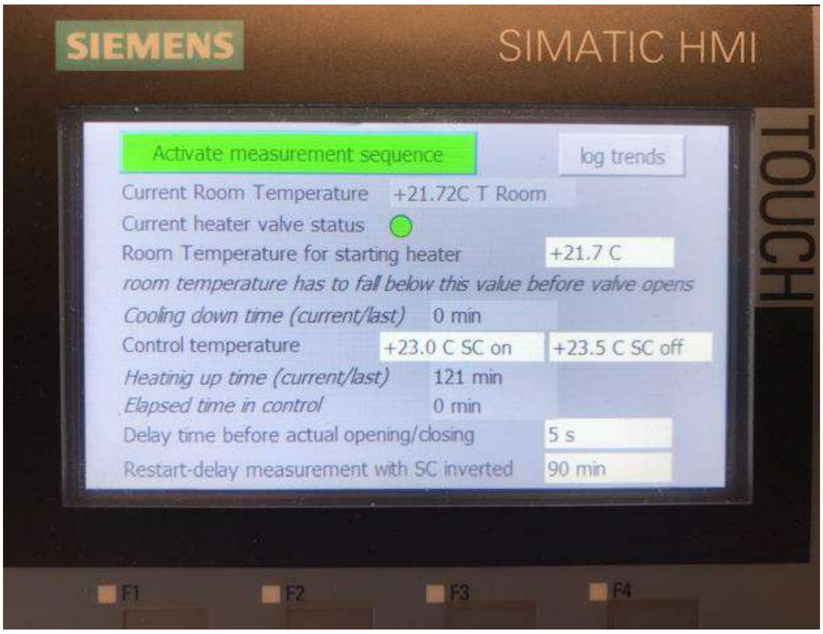
- F range: 0.1..25 liter/min
- F accuracy: +-0.2 liter/min

Room sensor type: SHTC3

- RH range: 0..100%
- RH accuracy: +-2% between 20% en 80% - outside range maximum accuracy of 4%
- T range: -40..+125C
- T accuracy: +-0.2C between 5C and 60C – outside range maximum accuracy of +-0.8C

Enclosure: Test program

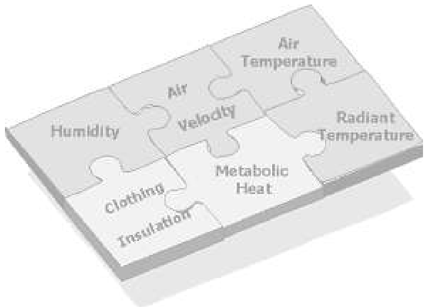
On the HMI several setpoints can be entered. Also different kind of test set-ups where programmed in the used Siemens 1200 PLC.



Enclosure: Defining Thermal Comfort

Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation of American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)[13].

A good breakdown of the drivers for this state of mind is given by The Health and Safety Executive (HSE) [14], a UK government agency responsible for encouragement, regulation and enforcement of workplace health, safety and welfare, and for research into occupational risks in Great Britain. According to HSE, the most commonly used indicator of thermal comfort is **air temperature** – it is easy to use and most people can relate to it. However, air temperature alone is not a valid or accurate indicator of thermal comfort or thermal stress. It should always be considered in relation to other environmental and personal factors. There are six factors affecting thermal comfort, both environmental and personal. These factors may be independent of each other, but together contribute to an employee's thermal comfort.



<u>Environmental factors:</u>
1. **Air temperature**: temperature of the air surrounding the body.
2. **Radiant temperature**: the heat that radiates from a warm object. Radiant heat may be present if there are heat sources in an environment. Radiant temperature has a greater influence than air temperature on how we lose or gain heat to the environment.
3. **Air velocity**. This describes the speed of air moving across the employee and may help cool them if the air is cooler than the environment.
   - *Air velocity was not taken into account for the tests. This was below the threshold to be noticeable for people and therefore has no impact on thermal comfort.*
4. **Humidity**. If water is heated and it evaporates to the surrounding environment, the resulting amount of water in the air will provide humidity. However: relative humidity between 40% and 70% does not have a major impact on thermal comfort
   - *Humidity was measured (RH value) by the sensors in the test room but fell in the 40%-70% range and did therefore not impact thermal comfort.*

<u>Personal factors</u>
5. **Clothing insulation**: Thermal comfort is very much dependent on the insulating effect of clothing on the wearer.
6. **Work rate/metabolic heat**: The more/less physical activities we do, the more/less heat we produce. Also, a person's physical characteristics should always be borne in mind when considering their thermal comfort, such as size and weight, age, fitness level and gender all have an impact on how they feel, even if other factors such as air temperature, humidity and air velocity are all constant.

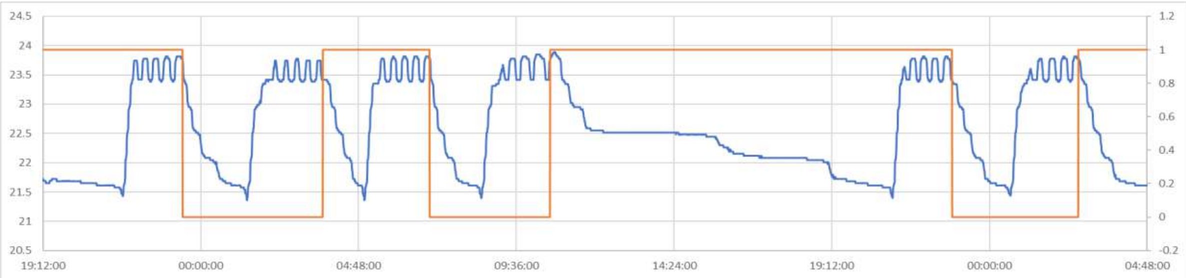
[13] STANDARD 55 – THERMAL ENVIRONMENTAL CONDITIONS FOR HUMAN OCCUPANCY
[14] www.hse.gov.uk

Enclosure: Heat Extraction – Test @ 65°C

Test-results batch 2 (water temperature @ 65°C)

Dataset #	SpeedComfort ON/OFF	Water temperature	Start temperature	Start time heating	Time to heat room with 1.3°C	Used radiator power (W) at 1.3°C	Total required energy (Wh)	Time to heat room with 2°C	Used radiator power (W) at 2°C	Total required energy (Wh)	Av. Temp Flue Gas (°C)
1	ON	65	21,5	21:35:00	00:13:00	2774	600,96	00:21:30	2151,84	771	51,5
2	OFF	65	21,5	01:21:30	00:16:30	2379	646,25	00:50:30	1544,24	1300	52,7
3	ON	65	21,5	04:56:30	00:13:00	2815	609,96	00:30:30	1981,50	1007	
4	OFF	65	21,5	08:29:30	00:15:30	2458	634,99	00:37:30	1659,72	1037	
5	ON	65	21,5	21:00:30	00:12:30	2985	621,97	00:21:00	2186,49	765	
6	OFF	65	21,5	00:36:00	00:14:00	2622	611,82	00:36:30	1680,33	1022	

	SpeedComfort ON/OFF	Water temperature	Start temperature	Start time heating	Time to heat room with 1.3°C	Used radiator power (W) at 1.3°C	Total required energy (Wh)	Time to heat room with 2°C	Used radiator power (W) at 2°C	Total required energy (Wh)
Average values	ON	65	21,5		00:12:50	2858	611	00:24:20	2107	848
Average values	OFF	65	21,5		00:15:20	2486	631	00:41:30	1628	1120
					16%		**3%**	**41%**		**24%**



The above test results show that the improved warm-up time is 16% at 1.3°C and 41% at 2°C. Energy consumption is slightly lower (-3%) at 1.3°C but significant at 2°C (-24%).

Warm-up time efficiency: calculation of Savings (70°C & 65°C)

Heating days (2018): 239	Heatings Min	Median	Heatings Max
Heat up times/day	**1**	**1,5**	**2**
Heat up times/winter (heating) season	239	359	478
Energy Cons. w/o SC @ 70°C (1903Wh)	454.817	682.226	909.634
Energy Cons. with SC @ 70°C (1314Wh)	314.046	471.069	628.092
Saving @ 70°C (Wh)	140.771	211.157	281.542
Saving m3	14	22	29
Saving in relation to gas usage for space heating	**1,5%**	**2,2%**	**2,9%**
Energy Cons. w/o SC @ 65°C (1120Wh)	267680	401.520	535.360
Energy Cons. With SC @ 65°C (848Wh)	202672	304.008	405.344
Saving @ 65°C	65.008	97.512	130.016
Saving m3	7	10	13
Saving in relation to gas usage for space heating	**0,7%**	**1,0%**	**1,3%**

Enclosure: Field Research – Customer Survey

- Total number of users/customers: approximately 28.000 households
- Survey: 7.687 users (≤ 2 years)
- Response rate: 23%
- Desired confidence level of 99%, margin of error 3%
- Tool: SurveyMonkey

Questions from the SurveyMonkey questionnaire that were used for this report/analysis (translated from Dutch):

- Which effects were noticeable after installing/using SpeedComfort?
- Were you able to reduce boiler water temperature settings after using SpeedComfort?
- Did you turn down your thermostat settings due to the use of SpeedComfort?
- What is the degree of insulation where the SpeedComforts are used?