UK HIU Test Regime

Technical Specification
June 2016

UK HIU Test Regime Technical Specification

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Foreword

The development of heat networks in the UK is a key component of the UK's future energy strategy (DECC, 2013). In order to support the deployment of low carbon heat networks, DECC provided funding (via SBRI) designed to stimulate innovation that will help address cost and performance efficiency challenges related to heat networks.

As part of this SBRI Heat Networks Demonstration Initiative, Guru Systems was awarded funding to develop tools to analyse the energy efficiency of heat networks using machine-learning algorithms.

Within Phase 1 of the SBRI project it was identified that HIU performance has a major impact on overall system performance and that HIU performance is a function of the design of HIUs, how HIUs are commissioned and the performance of the space heating circuit. It was also identified that, although there are testing regimes appropriate to other European markets (most notably that developed by the Swedish District Heating Association), there is no testing regime in place that can adequately assess HIU performance given UK typical operating parameters. As such, it is difficult to assess and compare HIU performance on UK heat networks.

As part of Phase 2 of the SBRI project, Guru Systems was awarded funding from DECC in order to: (a) develop a technical specification for an HIU testing regime that is appropriate for typical UK heat networks; (b) test a number of the market leading HIUs; and (c) input the data from the testing into the energy management system that Guru is developing, in order to better identify opportunities for improving heat network performance.

FairHeat produced a first draft Technical Specification (Modified Swedish Test UK HIU Test Regime_V1), under contract to Guru Systems, as part of a Heat Networks Demonstration SBRI research project funded by DECC. Seven HIU's were tested by SP Technical Research Institute of Sweden under this first regime.

Following feedback from the industry from that first round of testing, FairHeat and Martin Crane of Carbon Alternatives have collaborated to develop a second version of the test regime (this document) for use in the UK market.

Use of Document

The intention is that this Technical Specification will be used on an ongoing basis for the testing of HIUs for the UK market. To that aim, the document is available to be used by any party wishing to test an HIU at a UKAS accredited test house or test house accredited under an equivalent national accreditation standard.

It is a requirement of use that the test house that carries out the testing publishes a report documenting the results on their website.

It is requested that the test house provides both the report and the full data from tests 1a-1c, 2a and 4 to FairHeat in order that FairHeat is able to carry out the Volume Weighted Return Temperature calculations as set out in Section 5.2. Both the report and the Volume Weighted Return Temperature calculations will be published on the FairHeat website where results and reports from previous tests can be found.

It is also requested that the testing data is provided to Guru Systems as input data for the energy management system that it has developed with assistance from DECC. The intention is that this will enable heat network operators to better identify opportunities for improving heat network performance by enabling divergence to expected HIU performance to be identified and/or identifying tested patterns of response.

A Steering Group of industry experts has been established in order to provide guidance on future iterations of the test and to provide a reference sounding board for sign-off on how to treat data in reporting. At the time of publishing, there were representatives on the Steering Group from:

- BESA
- Carbon Alternatives
- DECC
- Engie
- E.ON
- FairHeat
- SSE

Authors

This technical specification was prepared by Martin Crane, of Carbon Alternatives and Gareth Jones and Tom Naughton of FairHeat.

Acknowledgements

This Technical Specification was originally based substantively on the Technical Regulations F:103-7e, produced and published by the Swedish District Heating Association in conjunction with manufacturers and which are used in Sweden for certification of substations (HIUs) prior to connection to district heating systems (Heat Networks).

The Swedish District Heating Association is an organisation that is made up of a group of district heating specialists who work to promote the development of the district heating industry as a key component of an ecologically, financially and socially sustainable future energy landscape.

We would like to acknowledge that the preparation of this Technical Specification would not have been possible without the excellent work carried out by the Swedish District Heating Association and would like to thank the Association for making these regulations available in English and for providing permission for the utilisation of their work in preparing this Technical Specification.

The full Swedish District Heating Association standards can be found at http://www.svenskfjarrvarme.se/In-English/District-Heating-in-Sweden/ It should be noted that most of the 'Technical Requirements' are in Swedish only.

Disclaimer

While the Swedish District Heating Association's Technical Regulations, F:103-7e, have been produced with the purpose of certifying district heating substations as 'fit for purpose' prior to connection to district heating systems, the test regime set out within the technical specification (this document) is not for use for certification and in no way are the results to be interpreted as "certifying" or "not certifying" HIUs as being fit for connection to Heat Networks in the UK (or elsewhere).

Furthermore, it should be noted that while the technical specification is based on the Swedish District Heating Association's Technical Regulations, F:103-7e, the Swedish District Heating Association have not reviewed or approved this document and should not be construed as having endorsed this Technical Specification in any way.

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Abbreviations

P_1	Power, primary side	[kW]
P_2	Power, space heating system	[kW]
P_3	Power, domestic hot water	[kW]
t_{11}	Temperature, primary side supply connection	[^{o}C]
t_{12}	Temperature, primary side return connection	[^{o}C]
t_{21}	Temperature, space heating system return connection	[^{o}C]
t_{22}	Temperature, space heating system supply connection	[^{o}C]
t_{31}	Temperature, cold water supply	[^{o}C]
t_{32}	Temperature, domestic hot water output from HIU	[^{o}C]
q_1	Volume flow, primary side	[l/s]
q_2	Volume flow, space heating system	[l/s]
q_3	Volume flow, domestic hot water	[l/s]
Δp_1	Primary pressure drop across entire HIU unit	[MPa]
Δp_2	Pressure drop, space heating system across HIU	[MPa]
Δp_3	Pressure drop, domestic hot water across HIU	[MPa]

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1 Introduction

In Sweden, to connect to a district heating network, HIUs ("substations" in Swedish parlance) are required to fulfil the requirements set out in the latest edition of the Swedish District Heating Association's Technical Regulations F:101e, District Heating Substations - Design, Construction and Installation. Certification. In order to demonstrate compliance with these regulations, HIUs are tested in accordance with F:103-7e, Certification of District Heating Substations, and in accordance with SPCR 113, SP Technical Research Institute of Sweden's rules for certification of district heating substations.

While aspects of the Swedish regulations are appropriate for the UK, there are significant differences between the operational parameters of heat networks in Sweden and the UK (e.g. there is no requirement to test to 120˚C, as UK heat networks do not typically operate to these temperatures).

This document provides a technical specification for testing HIUs derived from the Swedish F:103-7e certification, but modified to better fit typical UK Heat Network operating parameters.

The purpose of this test regime is four-fold:

i) To enable the performance of different HIUs to be evaluated within the context of typical UK operating conditions, thereby enabling heat network developers to evaluate the performance of specific HIUs against design requirements.
ii) To generate operating data on the expected performance of specific HIUs given 'normal' operating parameters, to enable heat network operators to identify anomalous performance.
iii) To provide a framework for HIU manufacturers to evaluate the performance of their equipment within the UK context, thereby feeding into their continuous improvement development programmes.
iv) To provide data on the impact of different design and installation choices (e.g. Domestic hot water temperature) on HIU performance, thereby assisting designers of heat networks to optimise heat network performance.

HIUs that are tested according to the test regime specified in this document will not be 'certified' as they would be in Sweden. Rather, the intention is to provide test results that will enable performance evaluated within the UK context.

The main evaluation will be to estimate the annual volume weighted return temperature from the HIU, with this being a composite of estimations of the annual volume-weighted return temperatures for domestic hot water, space heating and standby.

In addition, the test regime will evidence compliance with other performance and reliability standards within the F:103-7e certification standard, such as speed of temperature stabilisation.

This test procedure is for HIUs that: (a) heat DHW on demand via a plate heat exchanger; (b) are 'indirect', in that there is a heat exchanger between the DH primary and the space heating system; and (b) have an active keep-warm function to maintain primary system flow temperatures. The test assumption is that the space heating system heat emitters are radiators.

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2 Test Facilities

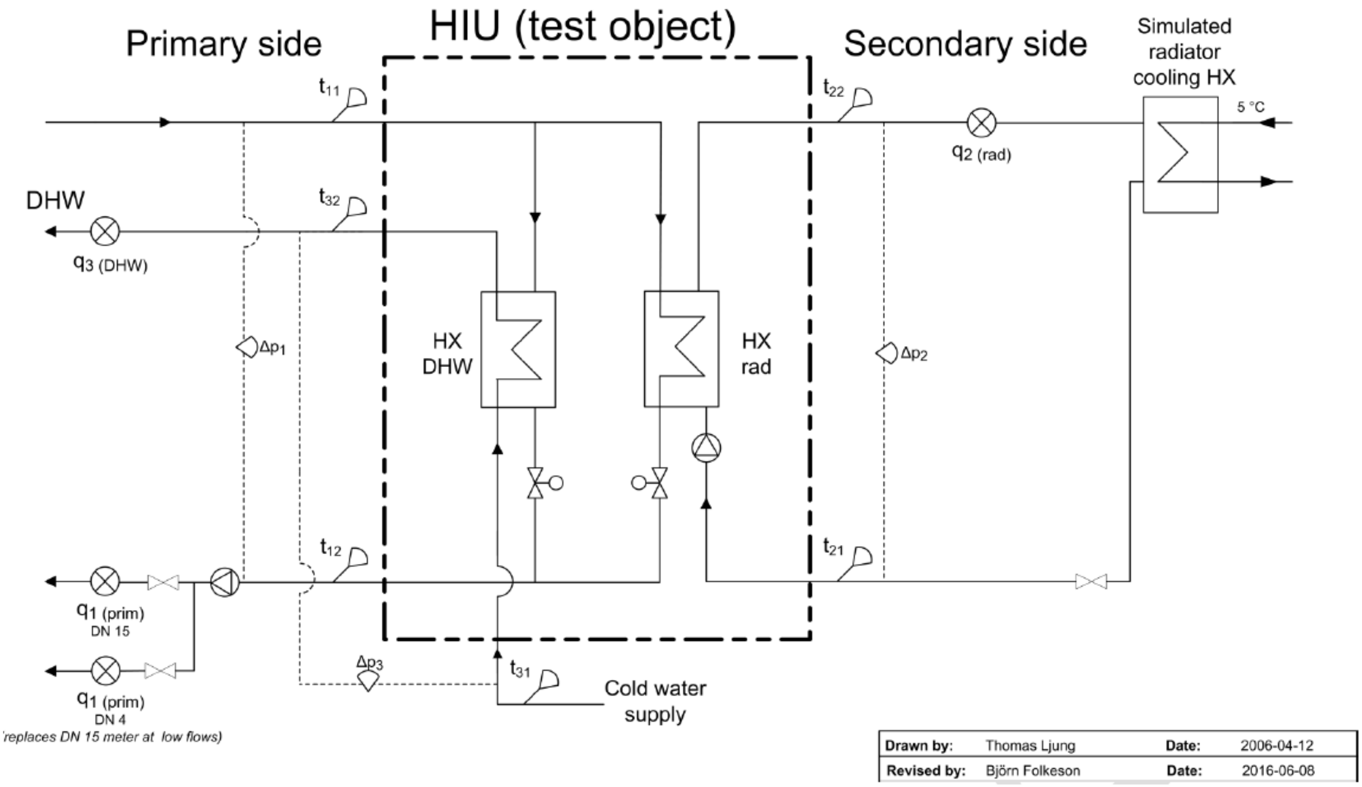
2.1 Test House

Tests are to be carried out by a UKAS accredited test house or test house accredited under an equivalent national accreditation standard.

At the time of publication, the only test house equipped to conduct these tests is SP Technical Research Institute of Sweden ("SP"), based in Borås, Sweden. At SP the tests are conducted on the test rig used to certify HIUs under the Swedish Test. FairHeat has paid for modifications to be made to the test rig to enable it to be used to carry out the tests set out in this technical specification.

2.2 Test rig arrangement and uncertainty of measurement

The test rig configuration shall be as per the following schematic:



The test report shall include a schematic diagram of the test rig that has been used for testing.

The maximum permissible total uncertainties of measurement for the sensors, installation and system voltmeters in the test rig are:

Differential pressure	*1 kPa*
Temperature	*± 0.1°C*
Volume flow	*± 1.5 %*

The time constant of the temperature sensor for t32 shall not exceed 1.5 seconds.

Temperature sensors, volume flow meters and pressure drop sensors shall normally be calibrated at least once a year. Instrumentation shall be tested before each set of tests.

2.3 Test rig configuration and preparation

The HIU is to be tested in the same position (i.e. vertically, horizontally) as when it is installed in a building.

The HIU's pipes and pressure vessel shall be filled and pressurised during the tests.

The test rig's instrumentation shall record the HIU's static and dynamic functions and performance at various loads.

The cold water supply to the HIU on test rig shall be at 10˚C and at 1.5 bar.

The measured pressure drop across the HIU is to include the heat meter flow sensor. In the case that a heat meter has not been fitted, a 25 kPa restrictor will be fitted to simulate a typical heat meter.

The HIU control equipment shall have the same settings for all operating conditions to be tested with the exception of Test 1f and the changes to the DHW setting.

The secondary system shall be pressurised to 1.5 bar for all tests.

The total volume of the primary flow pipework should be 10 litres.

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3 HIU Equipment

HIU suppliers should take care to ensure that the HIU supplied for testing is of the exact specification as the HIU model to be sold to the UK market. Test results are only valid for the specification of the equipment supplied.

As such, suppliers should be cautious about fitting optional components to the supplied equipment, particularly if they add significantly to the cost, as those evaluating performance for specification purposes will have to assume that the model supplied is the "standard" model for cost comparison purposes.

In the case that there are minor modifications to the specification of the HIU over time (e.g. change in size of pressure vessel) then the details will need to be submitted to the test house for an assessment of whether or not this would have a material impact on the performance of the unit. In the case that the test house deems that the modifications would not have a material impact on performance then the test house will issue a certificate stating that the test results are also applicable to the new model, with technical details stated. In the case that the test house deems that the changes *would* have a material impact, then the supplier will need to supply the new model for retesting in order to utilise the test results. This is analogous to the Swedish certification process.

Note for heat network developers / designers:
Care should be taken in ensuring that the test results reviewed are applicable for the model being evaluated. Results should *not* be applied across models (e.g. from the same manufacturer) as changes in key components can have a significant impact on performance.

3.1 HIU Rating

HIUs to be tested should conform to the following rating, as a minimum:

- Max temperature: 95˚C
- Maximum pressure 10 bar

3.2 Equipment

The HIUs shall be equipped as follows: <u>Primary side</u>

- Strainer
- Space heating heat exchanger
- Domestic hot water heat exchanger for instantaneous domestic hot water (DHW) delivery
- Control equipment for the space heating system
- Control equipment for the domestic hot water system
- Necessary drain and vent valves and connections

<u>Space heating side</u>

- Circulation pump
- Strainer
- A device that will easily allow the space heating circuit to be turned on and off for the tests (e.g. room thermostat or on/off switch)

<u>Domestic hot water (DHW) system</u>

- Isolating valve, check valve in the incoming cold water supply to the heat exchanger.

A heat meter is to be fitted. If no meter is fitted a 25 kPa restrictor will be fitted for the test to simulate the pressure drop across the heat meter.

3.3 Documentation

The manufacturer is to supply sufficient information in order that the test house is able to:

a) Document the exact technical specifications of the HIU model tested; and
b) Install, commission and operate the HIU for the purposes of the test program, without requiring technical input from the manufacturer.

More specifically, the following information is to be provided when an HIU is submitted for testing:

- Technical details and specification for key components: valves, DPCV, heat exchangers, pump, expansion vessels;
- A schematic diagram and drawings showing the structure and arrangement of the HIU, with dimensions and weights;
- Technical specification for electronic components (if any), including the version of software installed on the test model;
- Installation guide;
- Commissioning guide – Note: this should include sufficiently clear instructions that the test house is able to commission the HIU in preparation for the test procedure;
- Operation guide with a function description / description of operation, and care instructions, as suited to the intended user category
- Declaration of Conformity for CE-marked HIUs;
- Clear statement of the maximum primary side static operating pressure and maximum operating differential pressures. The pressure testing (Test 0) will be based on this data.

3.4 HIU setup

HIU settings are to be set at the start of testing and are not to be adjusted during the testing, with the exception of the secondary flow temperature adjustment prior to test 1d to meet test requirements

Note: HIU settings will be adjusted until the HIU delivers DHW / secondary flow temperature in the range +/- 0.5˚C of set point as measured by the test rig (i.e. an electronic control on the HIU may read a figure different to the set point). For all other tests if the HIU output varies from the set point it shall not be adjusted and the test will proceed at temperature the HIU delivers.

Commissioning will be carried out based on the commissioning guide provide (see Documentation). In the case that the HIU manufacturer alone can carry out commissioning (e.g. software based), full commissioning documentation must be completed recording all inputs and supplied to the test house.

4 Tests

The total group of tests of the HIU to be performed in the test rig is as follows:

- Pressure test of primary circuit.
- Static performance tests of the space heating parts of the unit: Test 1.
- Dynamic performance tests of the domestic hot water and standby function: tests 2, 3, 4 and 5.

4.1 Pressure test: Test 0

Objective: To test that there is a suitable margin of safety for the maximum pressure, the HIU will be pressure tested with cold water on the primary side at 1.43 times the design static and differential pressures for 30 minutes. During these tests the CWS to the HIU will be on and at 1.5 bar and the secondary circuit will be pressurised to 1.5 bar.

Test 0a: A static pressure of 1.43 times the HIUs rated maximum pressure to be exerted simultaneously on both the DH flow and return HIU connections. The HIU will be inspected to check no signs of leaks or component distortion.

Test 0b: A differential pressure of 1.43 times the HIUs stated maximum differential pressure will be exerted across the HIU flow and return with the static pressure at the DH flow connection at the HIU rated maximum pressure. The control valves shall be inspected to ensure that they remain tight when closed against this pressure.

4.2 Static testing: Test 1:

Objective: Perform static / steady state testing in order to investigate the performance characteristics of the HIU when meeting a specified space heating load.

Note that the static tests will be carried out for a minimum of 300 seconds of operation. The results will then be derived from the mean average over the test period.

In the case that space heating supply is not at the specified temperature, the set point is to be adjusted until the specified temperature is achieved. Where the set point needs to be adjusted this is to be noted. Eg an electronic HIU will be adjusted until the test rig sensors measure the secondary flow at 70˚C +/- 0.5˚C, this may be when the HIU controller setting is at 71 or 69˚C

4.2.1 *Static testing of the space heating circuit capacity: Test 1a, 1b, & 1c*

Objective: Perform static testing in order to investigate the performance characteristics of the HIU when meeting a space-heating load given a 70˚C/40˚C secondary heating circuit, as per the ADE CIBSE Heat Networks Code of Practice, Objective 3.4 (Table 6). The return temperatures recorded from these tests are used as the inputs for calculating the Space Heating Volume Weighted Average Return Temperature figure for the HIU – see Section 5.2.

In these tests the space heating load will be simulated by the heat exchanger on the test rig, with 70˚C secondary flow temperature and 40˚C secondary return temperatures. The HIU pump is to be deactivated, with flow rates adjusted within the test rig to deliver the required space-heating load.

In all three tests the primary flow temperature is 75˚C, with a 0.5 bar differential pressure across the HIU.

Test 1a: 1.0 kW heat output.

Test 1b 2.0 kW heat output.

Test 1c: 4.0 kW heat output.

The HIU case will be in place for these tests.

4.2.2 *Static testing of the space heating circuit capacity: Test 1d*

Objective: Perform static testing in order to investigate the performance characteristics of the HIU when meeting a heating load given lower operating temperatures, as compared with 1a – 1c.

As with 1a – 1c, the space heating load will be simulated by the heat exchanger on the test rig, with 55˚C secondary flow temperature and 35˚C secondary return temperatures. The HIU pump is to be deactivated, with flow rates adjusted within the test rig to deliver a 4 kW space-heating load.

In this test the primary flow temperature is 65˚C, with a 0.5 bar differential pressure across the HIU.

The HIU case will be in place for this test.

4.3 Dynamic testing: Tests 2, 3, 4 & 5

Objective: To explore the performance of the HIU under changing loads, as would be the case in practical operation. Key performance criteria are: speed and consistency of DHW delivery to customer; DHW staying at a safe temperature at all times; and the volume weighted return temperature when supplying space heating or DHW.

Load changes occur in the hot water system during the dynamic performance tests in accordance with the draw-off rates and durations detailed below.

Before starting the dynamic tests, domestic hot water is to be drawn off at 0.13 l/s for >60 seconds, 180 seconds prior to commencing the test in order to establish steady-state conditions.

4.3.1 *Dynamic testing of the HIU operation –Tests 2a and 2b*

Objective: To investigate the performance of the HIU when delivering DHW, at a range of flow rates, given 65˚C and 75˚C DH primary flow temperatures. The test investigates HIU operation in terms of DHW delivery and impacts on primary heat network return temperatures.

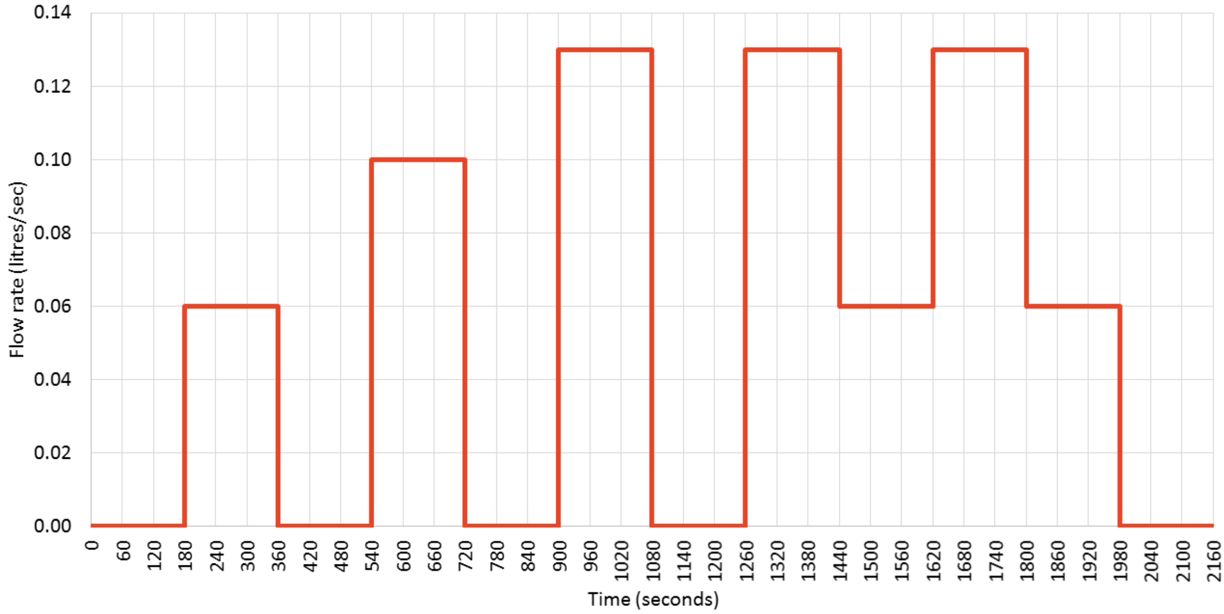
For this test the DHW set point is to be 55˚C DHW, with a cold-water supply temperature of 10˚C at 1.5 bar and a 0.5 bar differential pressure across the HIU.

In the case that DHW supply is not at the specified temperature, the set point is to be adjusted until the specified temperature is achieved. Where the set point needs to be adjusted this is to be noted (e.g. following adjustment to achieve DHW of 55˚C +/- 0.5˚C at the test rig sensors, the HIU controller settings may be at a lower or higher temperature, such as 54 or 56˚C).

The dynamic tests are to be carried out with varying domestic hot water draw-off rates. The draw-off cycles of domestic hot water flow rates to be used in 2a, and 2b, tests are as follows:

- 0.00 l/s for 180 seconds
- 0.06 l/s for 180 seconds
- 0.00 l/s for 180 seconds
- 0.10 l/s for 180 seconds
- 0.00 l/s for 180 seconds
- 0.13 l/s for 180 seconds
- 0.00 l/s for 180 seconds
- 0.13 l/s for 180 seconds
- 0.06 l/s for 180 seconds
- 0.13 l/s for 180 seconds
- 0.06 l/s for 180 seconds
- 0.00 l/s for 180 seconds.

Figure 1DHW profile for DHW only tests (Tests 2a and 2b)



Test 2a: 75˚C primary flow temperature.

Test 2b: 65˚C primary flow temperature.

Note: The test results from Test 2a for the 0.06 l/s flow, 0.10 l/s flow and 0.13 l/s flow are to be used for calculating the Volume Weighted Average Return Temperature for the HIU, utilising the 180 seconds at load and the 60 seconds directly proceeding it for each flow rate – see Section 5.2 for the calculation methodology.

4.3.2 *Testing the control equipment at low domestic hot water flow rates - Test 3*

Objective: To investigate the stability of DHW temperature at low flow rates.

During operation, domestic hot water is sometimes drawn off at extremely low flow rates. Test 3 investigates the ability of the system to meet this condition by measuring the temperature at test point t32 at a flow rate of 0.02 l/s.

For this test the DHW set point is to be 55˚C DHW, with a cold-water supply temperature of 10˚C at 1.5 bar and a 0.5 bar differential pressure across the HIU. Primary flow temperature is to be 75˚C.

4.3.3 *No-load characteristics of units in "keep warm" mode – Test 4*

Objective: To establish HIU performance during periods of no load, when operating in keep warm mode.

During those times of the year when no space heating is required, or at times when no domestic hot water is being drawn off, various types of temperature-holding functions come into operation in order to ensure that domestic hot water will be quickly available. Test 4 investigates how this function operates and the impact on primary heat network, where the HIU keep warm mode is the primary means of keeping the primary network up to temperature.

For HIUs that can either have the 'keep warm' function turned on or off then this function should be turned on for this test. The settings should be such that one of the following two operating conditions is met over the course of the test:

- Minimum average primary volume of [5] litres/hour OR
- Minimum weighted average primary flow temperature of [45˚C]

For HIUs with a range of standby options it will need to be recorded what the settings were.

With no space-heating load, draw off domestic hot water at a rate of 0.13 l/s and then turn off the hot water. Measure the primary flow rate and the primary supply and return temperatures for a period of 8 hours after the initial hot water draw-off has been completed.

The heat consumed by the HIU over the 8-hour test period will be used as a measure of the standby heat losses from each HIU. The HIU case will be fitted for this test to allow a representative estimate of standby losses to be made.

The test results from Test 4 are to be used for calculating the Volume Weighted Average Return Temperature for the HIU – see Section 5.2 for the calculation methodology.

For this test the DHW set point is to be 55˚C DHW, with a cold-water supply temperature of 10˚C at 1.5 bar and a 0.5 bar differential pressure across the HIU. Primary flow temperature is to be 75˚C. Secondary set point set to 70˚C.

4.3.4 *Domestic hot water response time – Test 5*

Objective: To investigate DHW delivery time, as being able to obtain domestic hot water within a reasonable time of turning on the tap is a basic comfort requirement.

Immediately after testing the no-load characteristics for Test 4, steady-state conditions, without domestic hot water draw-off or space heating load, will have been established. At this point, DHW is to be drawn off at 0.13 l/s. The time taken for the DHW to reach the 55˚C set point will be recorded. For this test, the HIU's standby / keep warm function will have been enabled during the previous no-load test. The HIU's service connection is represented by the connection hoses from the test rig, which is consistent for all HIUs tested (as detailed in 2.3).

For HIUs that cycle during standby with a cycle period of greater than 10 minutes, Test 5 will be timed to start at the midpoint of the standby cycle (i.e. half the cycle time after the DH primary flow has ceased).

For this test the conditions are to be as for 7a: i.e. DHW set point is to be 55˚C DHW, with a cold-water supply temperature of 10˚C at 1.5 bar and a 0.5 bar differential pressure across the HIU. Primary flow temperature is to be 75˚C.

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Table 1: Test schedule

Test No	Test	static pressure on return	dP across HIU	Primary flow temp	Hot water setpoint	DHW flow rate	DHW power	space heat output	space heat flow temp	space heat return temp
		bar	bar	˚C	˚C	l/s	kW	kW	˚C	˚C
			dP1	t11	t32	q3	P3	P2	t22	t21
Static tests										
0a	Static pressure test (same static pressure on both flow and return connections)	1.43 times rated value		75	55	-	-	-	n/a	n/a
0b	Differential pressure test (DH flow at higher pressure than DH return)		1.43 times rated value	75	55	-	-	-	n/a	n/a
1a	Space Heating 1 kW	2.5	0.5	75	55	-	-	1	70	40
1b	Space Heating 2 kW	2.5	0.5	75	55	-	-	2	70	40
1c	Space Heating 4 kW	2.5	0.5	75	55	-	-	4	70	40
1d	Space Heating 4kW, at lower operating temperatures	2.5	0.5	65	55	-	-	4	55	35
Dynamic tests										
2a	DHW only DH 75˚C flow	2.5	0.5	75	55	see DHW test profile	see DHW test profile	-	-	-
2b	DHW only DH 65˚C flow	2.5	0.5	65	55			-	-	-
3	Low flow DHW	2.5	0.5	75	55	0.02	Record value	-	-	-
4	Standby	2.5	0.5	75	55	0	0	-	-	-
5	DHW response time	2.5	0.5	75	55	0.13	Record value	-	-	-

The cold water supply to the HIU on test rig shall be at 10˚C and at 1.5 bar for all tests, excepting Test 3, where the cold water supply shall be at 10˚C and at 2.5 bar.

5 Presentation of results

After each test, a test report shall be prepared showing the results of dynamic tests in diagram form. Diagram scales shall be the same for all tests.

Notes, details of any actions taken, and observations during the tests shall be recorded under 'Other Information' in the test report.

5.1 Test Reporting and Assessment Criteria

HIU performance will be: (a) assessed against set criteria where appropriate; (b) qualitatively assessed based on observation of performance; and (c) quantitatively assessed on a comparative basis (e.g. by deriving volume weighted average return temperatures).

The basis for reporting against each test is set-out below.

Table 2: Test Reporting

Test	Description	Reporting
Static Tests		
0	Pressure tests	Pass/Fail as to whether HIU manages pressure test without leaks or damage.
1a	Space Heating 1 kW	t_{12}- primary return temperature. Plot of key metrics over duration of test. Note: Outputs used as input data to Space Heating Volume Weighted Average Return Temperature calculation.
1b	Space Heating 2 kW	
1c	Space Heating 4 kW	
1d	Space Heating 4kW, at lower operating temperatures	t_{12}- primary return temperature Observations on impact of lower operating temperatures on performance. Plot of key metrics over duration of test.
Dynamic Tests		
2a	DHW only, DH 75˚C flow	Pass/Fail on DHW exceeding 65˚C (at t_{32}) for more than 10 seconds. Comment on stability of DHW temperature. Assessment of scaling risk, based on extent and duration of temperatures in excess of 55˚C. Plot of key metrics over duration of test. Note: Outputs used as input data to DHW Volume Weighted Average Return Temperature calculation
2b	DHW only, DH 65˚C flow	Pass/Fail on DHW exceeding 65˚C (at t_{32}) for more than 10 seconds. Assessment of whether return temperatures remain under control at the lower flow temperature. Assessment of scaling risk, based on extent and duration of temperatures in excess of 55˚C. Plot of key metrics over duration of test.
3	Low flow DHW	Pass/Fail on DHW exceeding 65˚C (at t_{32}) for more than 10 seconds. Assessment of scaling risk, based on extent and duration of temperatures in excess of 55˚C Commentary if DHW supply not stable. Plot of key metrics over duration of test.
4	Standby	Observation on the operation of the HIU during standby. Assessment of scaling risk, based on extent and duration of temperatures in excess of 55˚C. Comment on HIU standby controls options. Plot of key metrics over duration of test.

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Test	Description	Reporting
		If cycling is observed, plot of the key metrics over the duration of a typical standby cycle. State heat loss in Watts, State primary flowrate. Note: Outputs used as input data to Standby Volume Weighted Average Return Temperature calculation
5	DHW response time	Pass/Fail on DHW exceeding 65˚C (at t_{32}) for more than 10 seconds. State time to achieve 50˚C (at t_{32}) Comment on stability of DHW temperature. Plot of key metrics over duration of test.

5.2 Volume Weighted Average Return Temperatures Derivation

Please note that the FairHeat VWART Calculation Model, which can be used for calculating the Volume Weighted Average Return Temperature (VWART) of an HIU, is available at www.fairheat.com.

In order to assess overall performance of HIUs tested according to the *UK HIU Test Regime Technical Specification* published by FairHeat, a number of derived results will be calculated from the output from the tests, assuming 'standard' UK operating conditions of:

- 75˚C primary flow temperature
- 55˚C DHW set point
- 70˚C / 40˚C secondary flow and return temperatures
- 0.5 bar differential pressure across the HIU

The following six derived measures will be calculated based on the outputs of the test:

i) DHW Volume Weighted Return Temperature, $VWART_{DHW}$
ii) Space Heating Volume Weighted Return Temperature, $VWART_{SH}$
iii) Standby Volume Weighted Return Temperature, $VWART_{SBY}$
iv) Annual Volume Weighted Return Temperature for Heating Period, $VWART_{HEAT}$
v) Annual Volume Weighted Return Temperature for Non-Heating Period, $VWART_{NONHEAT}$
vi) Total Annual Volume Weighted Return Temperature, $VWART_{HIU}$

These derived results will be calculated by FairHeat using the methodology set-out below.

5.2.1 Interpretation of test data

DHW Draw-Off

Each of the three domestic hot water draw-off events (6 l/min, 10 l/min, 13 l/min) are to be calculated between the following two data points:

- Start: First non-zero hot water flow read as recorded by q_3.
- End: The preceding hot water flow read to the first zero read for the relevant hot water test point as recorded by q_3.

DHW Post Draw-Off

Each of the three domestic hot water post draw-off events (6 l/min, 10 l/min, 13 l/min) are to be calculated between the following two data points:

- Start: First non-zero hot water flow read proceeding the relevant hot water test point as recorded by q_3.

- End: 60 seconds post start point reading as recorded by q_3.

Space Heating

Each of the three space heating load events (1 kW, 2 kW, 4 kW) are to be calculated using the entirety of the dataset.

Standby

The standby event is to be calculated between the following two data points:

- Start: First zero hot water flow read as recorded by q_3.
- End: 28,800 seconds (8 hours) post start point reading as recorded by q_3.

5.2.2 Annual Operational Distributions

DHW Draw Volumes pa

Total annual domestic hot water demand calculated as 1,470 kWh using SAP v9.92 methodology for a typical sized modern flat in London.

Distribution of low, medium and high DHW draw-off events based on analysis of EST "Measurement of Domestic Hot Water Consumption in Dwellings, 2008" data as follows:

Table 3: Domestic Hot Water Annual Demand

Description	Flow Rate (litres/min)	Estimated Annual Demand (kWh/year)
Low	6	729
Medium	10	297
High	13	444

DHW operating hours for each HIU (and therefore volumes), are to be calculated by dividing the respective annual kWh figures set out above, by the average actual power output measured in the test.

Post DHW Draw Volumes pa

Total annual number and average duration of low, medium and high DHW draw-off events based on analysis of EST "Measurement of Domestic Hot Water Consumption in Dwellings, 2008" data, as below:

Table 4: Domestic Hot Water Annual Events and Duration

Description	Number of events, n (events/year)	Average Duration, d (seconds)
Low	10,000	30
Medium	660	75
High	300	145

Space Heating

Total annual space heating demand calculated as 1,450 kWh using modified SAP v9.92 methodology for an 85 unit, 6-storey residential block built to 2013 Part L Building Regulations in London. Distribution of 1 kW, 2 kW and 4 kW consumption loads based on analysis of Guru Systems data for a typical modern high-rise residential block in London as follows:

Table 5: Space Heating Estimated Annual Demand

Space Heating Load (kW)	Estimated Annual Demand (kWh/year)
1	98
2	787
4	565

Space heating operating hours for each HIU (and therefore volumes), are to be calculated by dividing the respective annual kWh figures set out above, by the average actual power output measured in the test.

Standby

Standby annual operational hours defined as subtraction of DHW Draw-Off and Space Heating operation hours from total annual hours (8,760).

5.2.3 Volume Weighted Average Return Temperature Calculations

Please note that the FairHeat VWART Calculation Model, which can be used for calculating the Volume Weighted Average Return Temperature (VWART) of an HIU, is available at www.fairheat.com.

For all relevant test points (as outlined in 5.2.1 Interpretation of test data), the Volume Weighted Average Return Temperature (VWART) for each test is defined as follows:

$$\mathrm{VWART} = \frac{\sum(\mathrm{t}_{12,\mathrm{t}} \times \mathrm{q}_{1,\mathrm{t}})}{\sum \mathrm{q}_{1,\mathrm{t}}} \qquad (1)$$

where t represents each read during the test period (i.e. every second).

Domestic Hot Water

The DHW VWART consists of the HIU performance during draw-off and for 60 seconds post draw-off in order to account for any delay in the DHW primary valve closing.

Therefore, six calculations in total must be carried out, three during DHW draw-off (Table 3) and three post DHW draw-off (Table 4).

Regarding DHW draw-off, for each of the three tests described in Table 3, the following calculations should be made for the total test period as outlined in 5.2.1:

- arithmetic mean of domestic hot water power (P_3), $\overline{P_3}$
- arithmetic mean of primary volume flow rate (q_1), $\overline{q_1}$
- VWART as defined by equation (1)

The annual hours of operation for each of the three tests is then calculated as follows:

$$\text{Annual hours of operation, h} = \frac{\text{Estimated Annual Demand (from Table 3)}}{\overline{P_3}} \qquad (2)$$

The annual primary volume of each test is then calculated using (2) as follows:

$$\mathrm{V} = \overline{q_1} \times \mathrm{h} \qquad (3)$$

Regarding post DHW draw-off, for each of the three tests described in Table 4, the annual primary volume can be calculated as follows:

$$\mathrm{V} = \mathrm{n} \times \left(\frac{\mathrm{d}}{3600}\right) \times \overline{q_1} \qquad (4)$$

Note that, in this context, $\overline{q_1}$ relates to the arithmetic mean of the primary volume flow rate during the 60 seconds post DHW draw-off for each of the three tests as outlined in 5.2.1.

The total DHW annual primary volume is defined as:

$$\mathrm{V}_{DHW} = (3) + (4) \qquad (5)$$

The Domestic Hot Water VWART ($VWART_{DHW}$) can then be calculated by summing the product of the VWART and annual primary volume, V for each of the six tests and then dividing by the sum of the annual primary volumes, V for all of the six tests.

$$\mathrm{VWART}_{DHW} = \frac{\sum(\mathrm{VWART}_{\text{each test}} \times \mathrm{V}_{\text{each test}})}{\sum \mathrm{V}_{\text{all tests}}} \quad (6)$$

Space Heating

For each of the three tests described in Table 5, the following calculations should be made for the total test period as outlined in 5.2.1:

- arithmetic mean of domestic space heating power (P_2), $\overline{P_2}$
- arithmetic mean of primary volume flow rate (q_1), $\overline{q_1}$
- VWART as defined by equation (1)

The annual hours of operation for each of the three tests is then calculated as follows:

$$\text{Annual hours of operation, h} = \frac{\text{Estimated Annual Demand (from Table 5)}}{\overline{P_2}} \quad (7)$$

The annual primary volume of each test is then calculated using equation (3) and is referred to as V_{SH}.

The Space Heating VWART, $VWART_{SH}$, can then be calculated by summing the product of the VWART and annual primary volume, V, for each of the three tests and then dividing by the sum of the annual primary volumes, V, for all of the three tests. See equation (6).

Standby

For the single standby test, the annual hours of operation is calculated as follows:

$$\begin{aligned}\text{Annual hours of operation, h} &= 8760 \\ &- \left(\sum \text{h for all DHW draw off tests} + \sum \text{h for all space heating tests}\right)\end{aligned} \quad (8)$$

Note that the Stanby Annual hours of operation calculation does not include the annual hours of operation for the three DHW Post Draw-Off tests.

The annual primary volume, V, is then calculated using equation (3) and is referred to as $V_{SBY.}$

The Standby VWART is calculated as per equation (1) for the total test period as outlined in 5.2.1 and is referred to as $VWART_{SBY.}$

Overall

In order to calculate the overall VWART for the HIU, the Annual Heating Period and Annual Non-Heating Periods must be defined.

Regarding the Annual Heating Period, SH_{PROP}, the proportion of the year estimated to require space heating equates to the sum of hours calculated for the three space heating tests in equation (7) divided by the number of hours in a year as shown in the following equation:

$$\text{Annual Heating Period, } \mathrm{SH}_{PROP} = \frac{\sum \text{h for all space heating tests}}{8760} \quad (9)$$

The Annual Heating Period $VWART_{HEAT}$ is then calculated as follows:

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$$\mathrm{VWART}_{HEAT} = \frac{\left((VWART_{DHW} \times V_{DHW}) + (VWART_{SBY} \times V_{SBY})\right) \times \mathrm{SH}_{PROP} + (VWART_{SH} \times V_{SH})}{(V_{DHW} + V_{SBY}) \times \mathrm{SH}_{PROP} + V_{SH}} \quad (10)$$

Regarding the Annual Non-Heating Period, NSH_{PROP}, the proportion of the year when there is no heating load is calculated as follows:

$$\text{Annual Non} - \text{Heating Period}, \mathrm{NSH}_{PROP} = 1 - \mathrm{SH}_{\mathrm{PROP}} \quad (11)$$

The Annual Non-Heating Period $VWART_{NONHEAT}$ is then calculated as follows:

$$\mathrm{VWART}_{NONHEAT} = \frac{(VWART_{DHW} \times V_{DHW}) + (VWART_{SBY} \times V_{SBY})}{(V_{DHW} + V_{SBY})} \quad (12)$$

Finally, the Overall HIU VWART, $VWART_{HIU}$, is calculated as follows:

$$\mathrm{VWART}_{HIU} = (VWART_{NONHEAT} \times NSH_{PROP}) + (VWART_{HEAT} \times SH_{PROP}) \quad (13)$$