

Appendix-C

Appendix C - BHE operational data - missing data details

Table C-1 presents the dates in between the BHE operational data were unknown and filled-in and Table C-2 presents the percentage of unknown data for each months. Table C-3 summarises the quantity of missing data for all the three loops: ground, heating and cooling. As the flow and temperature data were logged by different data loggers during initial period, the amount of unknown data were listed separately for Temperatures and flow rates. This section outlines the process followed to fill the unknown values of temperature and flow rate in ground loop.

Since, the flow meter installed on the ground loop only started producing data during March 2010, the first two months had 100% unknown flow rate readings. Further, during December 2010 holiday period, the monitoring system was not accessible and the failure of data logging was unnoticed. Moreover, during October 2011, there was miscommunication between logger and PC, and the failure of data collection was unnoticed. During May and June 2012, due to power failure the data logging failed. Apart from the above-said incidents, the remaining months have small percentage of unknown data that is around 1%, and it was due to data transfer process.

Missing Temperature data filling

Before December 2011, the smaller gap (less than 1% of data per month) of missing temperatures were filled-in, other greater length of missing data were left as un-known. The historical temperature change pattern was used to fix the temperature values.

After December 2011, the BMS (Building Management System) temperature logging records were used to fill-in the unknown temperature data of the monitoring system.

Missing Flow rate data filling

After December 2011, the data collected by BMS was helpful for filling-in the unknown data. These BMS data included inlet and outlet temperatures of all three loops and individual heat pumps load and source-sides. Moreover, the BMS supplied on/off status of all compressors, heating and cooling status of individual heat pump, and speed of all circulating pumps. The unknown data of monitoring system were filled-in through using these available BMS data. The pattern change in the temperature, the speed of the pump, and compressor on/off timing have been used to fix the flow rate values.

Before December 2011, any available useful data from monitoring setup was considered for the particular time period to calculate the missing ground loop fluid flow rate during that time period. Generally, useful available data were temperatures and flow rate of the other loops (chill and warm), and in some cases the temperatures of ground loop fluid. The temperature pattern for each loop was analysed by considering absolute temperature as well as the positive rate of change for heating, negative rate of change for cooling and the temperature difference between inlet and outlet would indicate the ON/OFF timing of the compressor and the fluid circulation. Any available flow rate value of chilled and heating loop showed the number of heat pumps under operation. As the GSHP System operated under BMS control, the prediction of the value of the flow rate was based on the BMS control. This analysis and data filling procedure was implemented as rules and formulae in a spreadsheet. The historical change of flow rate and temperature values of other loops also have been considered during the process and the data has been manually scrutinized as a final quality check.

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Table C-1 Dates between ground loop data (Temperature and Flow) filled in and left unknown

Year	Temperature				Flow			
	left unknown		Filled in		left unknown		Filled in	
	From	To	From	To	From	To	From	To
2010	14/01/2010 15:30	14/01/2010 16:28	14/01/2010 11:07	14/01/2010 11:15			12/01/2010 17:12	11/03/2010 15:48
	20/01/2010 11:06	20/01/2010 12:04	19/01/2010 18:24	19/01/2010 18:30			01/04/2010 12:58	01/04/2010 13:08
	20/01/2010 17:32	20/01/2010 19:05	20/01/2010 15:24	20/01/2010 15:36			08/04/2010 13:05	08/04/2010 13:16
	22/01/2010 11:58	22/01/2010 12:14	10/02/2010 14:25	10/02/2010 14:29			14/04/2010 14:47	14/04/2010 15:12
	22/01/2010 17:42	22/01/2010 18:14	14/04/2010 12:33	14/04/2010 14:17			20/04/2010 14:02	20/04/2010 14:07
	25/01/2010 13:09	25/01/2010 13:45	14/04/2010 14:29	14/04/2010 14:40			23/04/2010 14:58	23/04/2010 15:02
	26/01/2010 03:55	26/01/2010 13:57	11/06/2010 11:11	11/06/2010 12:56			29/04/2010 12:47	29/04/2010 12:53
	01/02/2010 14:06	01/02/2010 14:54	12/08/2010 12:58	12/08/2010 13:04			05/05/2010 13:28	05/05/2010 13:36
	11/02/2010 03:27	11/02/2010 10:36	31/08/2010 15:51	31/08/2010 17:27			10/05/2010 12:38	10/05/2010 12:44
	19/02/2010 10:32	19/02/2010 12:50	16/09/2010 15:07	16/09/2010 15:09			14/05/2010 15:23	14/05/2010 15:40
	25/02/2010 03:16	01/03/2010 11:10	20/12/2010 09:32	23/12/2010 12:20			20/05/2010 15:34	20/05/2010 15:41
	01/04/2010 03:16	01/04/2010 12:27					26/05/2010 15:23	26/05/2010 15:32
	04/08/2010 03:18	04/08/2010 11:16					11/06/2010 14:01	11/06/2010 14:10
	11/08/2010 03:34	12/08/2010 11:44					23/06/2010 12:48	23/06/2010 12:58
	25/08/2010 13:28	25/08/2010 15:21					29/06/2010 13:25	29/06/2010 13:34
							06/07/2010 12:03	06/07/2010 12:11
							13/07/2010 14:15	13/07/2010 14:33
							19/07/2010 15:27	19/07/2010 15:33
							23/07/2010 11:27	23/07/2010 11:35
							29/07/2010 15:07	29/07/2010 15:15
							04/08/2010 15:01	04/08/2010 15:12
							10/08/2010 15:32	10/08/2010 15:40
							13/08/2010 14:56	13/08/2010 15:03
							19/08/2010 15:25	19/08/2010 15:37
							25/08/2010 12:31	25/08/2010 12:41
						25/08/2010 14:57	25/08/2010 15:05	
						25/08/2010 15:17	25/08/2010 15:25	
						31/08/2010 14:39	31/08/2010 16:04	
						06/09/2010 15:03	06/09/2010 15:13	
						10/09/2010 15:01	10/09/2010 15:07	
						16/09/2010 15:08	16/09/2010 15:17	
						21/09/2010 15:21	21/09/2010 15:27	
						22/10/2010 14:06	22/10/2010 15:41	
						20/12/2010 09:32	23/12/2010 12:20	
2011			01/02/2011 16:03	01/02/2011 16:37			01/02/2011 16:03	01/02/2011 16:37
			09/03/2011 14:43	09/03/2011 15:42			09/03/2011 14:43	09/03/2011 15:42
			24/03/2011 11:33	24/03/2011 11:49			24/03/2011 11:33	24/03/2011 11:49
			18/04/2011 13:39	18/04/2011 13:52			18/04/2011 13:38	18/04/2011 14:38
			18/07/2011 12:30	18/07/2011 13:05			18/07/2011 12:30	18/07/2011 13:05
			30/08/2011 13:55	30/08/2011 14:03			30/08/2011 13:55	30/08/2011 14:03
			15/09/2011 14:42	15/09/2011 14:50			15/09/2011 14:42	15/09/2011 14:50
			15/10/2011 18:56	01/12/2011 15:42			15/10/2011 18:56	01/12/2011 15:42
2012			21/12/2011 13:33	21/12/2011 13:50			21/12/2011 13:33	21/12/2011 13:50
			19/01/2012 12:41	19/01/2012 12:49			19/01/2012 12:41	19/01/2012 12:49
			27/02/2012 15:52	27/02/2012 16:03			27/02/2012 15:52	27/02/2012 16:03
			30/03/2012 13:10	30/03/2012 13:18			30/03/2012 13:10	30/03/2012 13:18
			18/04/2012 12:52	18/04/2012 13:21			18/04/2012 12:52	18/04/2012 13:21
			03/05/2012 16:17	11/05/2012 12:57			03/05/2012 16:17	11/05/2012 12:57
			13/06/2012 14:22	13/06/2012 15:01			13/06/2012 14:22	13/06/2012 15:01
			14/06/2012 07:50	25/06/2012 12:59			14/06/2012 07:50	25/06/2012 12:59
			22/10/2012 13:52	22/10/2012 14:01			22/10/2012 13:51	22/10/2012 14:01
			19/12/2012 12:25	19/12/2012 12:31			19/12/2012 12:25	19/12/2012 12:31

Table C-2 Monthly percentage of ground loop data (flow and temperature) filled in and left unknown for the period between Jan-2010 to Feb-2013

Month	Flow		Temperature	
	Left unknown	Filled in	Left unknown	Filled in
Jan-10	0.00	100.00	3.25	0.10
Feb-10	0.00	100.00	15.33	0.03
Mar-10	0.00	34.38	1.50	0.00
Apr-10	0.00	0.16	1.28	0.27
May-10	0.00	0.12	0.00	0.00
Jun-10	0.00	0.13	0.00	0.26
Jul-10	0.00	0.12	0.00	0.00
Aug-10	0.00	0.36	5.65	0.23
Sep-10	0.00	0.08	0.00	0.01
Oct-10	0.00	0.23	0.00	0.00
Nov-10	0.00	0.00	0.00	0.00
Dec-10	0.00	10.06	0.00	10.06
Jan-11	0.00	0.00	0.00	0.00
Feb-11	0.00	0.09	0.00	0.09
Mar-11	0.00	0.17	0.00	0.17
Apr-11	0.00	0.15	0.00	0.04
May-11	0.00	0.00	0.00	0.00
Jun-11	0.00	0.00	0.00	0.00
Jul-11	0.00	0.08	0.00	0.08
Aug-11	0.00	0.02	0.00	0.02
Sep-11	0.00	0.02	0.00	0.02
Oct-11	0.00	52.43	0.00	52.43
Nov-11	0.00	100.00	0.00	100.00
Dec-11	0.00	2.11	0.00	2.11
Jan-12	0.00	0.02	0.00	0.02
Feb-12	0.00	0.03	0.00	0.03
Mar-12	0.00	0.02	0.00	0.02
Apr-12	0.00	0.07	0.00	0.07
May-12	0.00	25.36	0.00	25.36
Jun-12	0.00	37.48	0.00	37.48
Jul-12	0.00	0.00	0.00	0.00
Aug-12	0.00	0.00	0.00	0.00
Sep-12	0.00	0.00	0.00	0.00
Oct-12	0.00	0.03	0.00	0.02
Nov-12	0.00	0.00	0.00	0.00
Dec-12	0.00	0.00	0.00	0.00
Jan-13	0.00	0.00	0.00	0.00
Feb-13	0.00	0.00	0.00	0.00

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Table C-3 Data availability analysis for temperature and flow measurements of three loops(ground, chilled, warm) during the whole monitoring period 12th Jan 2010 to 13th Feb 2013

Month-Year	Temperature									Flow								
	Not available (%)			Filled in (%)			Left Unknown (%)			Not available (%)			Filled in (%)			Left Unknown (%)		
	Ground Loop	Chill Loop	Warm Loop	Ground Loop	Chill Loop	Warm Loop	Ground Loop	Chill Loop	Warm Loop	Ground Loop	Chill Loop	Warm Loop	Ground Loop	Chill Loop	Warm Loop	Ground Loop	Chill Loop	Warm Loop
Jan-10	3.35	0.00	0.00	0.10	0.00	0.00	3.25	0.00	0.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00
Feb-10	15.36	15.36	15.36	0.03	0.01	0.01	15.33	15.35	15.35	100.00	60.64	60.65	100.00	48.04	48.05	0.00	12.60	12.60
Mar-10	1.50	1.51	1.51	0.00	0.00	0.00	1.50	1.51	1.51	34.38	34.43	1.66	34.38	32.93	0.16	0.00	1.50	1.50
Apr-10	1.55	1.28	1.28	0.27	0.00	0.00	1.28	1.28	1.28	0.16	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00
May-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00
Jun-10	0.26	0.26	0.26	0.26	0.00	0.00	0.00	0.26	0.26	0.13	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
Jul-10	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.12	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00
Aug-10	5.89	5.89	5.89	0.23	0.00	0.00	5.65	5.89	5.89	0.36	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00
Sep-10	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.08	0.00	0.03	0.08	0.00	0.00	0.00	0.00	0.03
Oct-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00
Nov-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec-10	10.06	10.06	10.06	10.06	10.06	10.06	0.00	0.00	0.00	10.06	10.06	10.06	10.06	10.06	10.06	0.00	0.00	0.00
Jan-11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb-11	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.09	0.09	0.09	0.09	0.09	0.09	0.00	0.00	0.00
Mar-11	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.17	0.17	0.17	0.17	0.17	0.17	0.00	0.00	0.00
Apr-11	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00
May-11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jun-11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul-11	0.08	0.08	0.08	0.08	0.08	0.08	0.00	0.00	0.00	0.08	0.08	0.08	0.08	0.08	0.08	0.00	0.00	0.00
Aug-11	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00
Sep-11	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00
Oct-11	52.43	52.54	52.54	52.43	52.54	52.54	0.00	0.00	0.00	52.43	52.54	52.54	52.43	52.54	52.54	0.00	0.00	0.00
Nov-11	100.00	100.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00
Dec-11	2.11	2.15	2.15	2.11	2.15	2.15	0.00	0.00	0.00	2.11	2.15	2.15	2.11	2.15	2.15	0.00	0.00	0.00
Jan-12	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00
Feb-12	0.03	0.03	0.03	0.03	0.03	0.03	0.00	0.00	0.00	0.03	0.03	0.03	0.03	0.03	0.03	0.00	0.00	0.00
Mar-12	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00
Apr-12	0.07	0.07	0.07	0.07	0.07	0.07	0.00	0.00	0.00	0.07	0.07	37.97	0.07	0.07	37.97	0.00	0.00	0.00
May-12	25.36	25.36	25.36	25.36	25.36	25.36	0.00	0.00	0.00	25.36	25.36	100.00	25.36	25.36	100.00	0.00	0.00	0.00
Jun-12	37.48	37.48	37.48	37.48	37.48	37.48	0.00	0.00	0.00	37.48	37.48	100.00	37.47	37.47	100.00	0.00	0.00	0.00
Jul-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	100.00	0.00	0.00	0.00
Aug-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sep-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oct-12	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Nov-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dec-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jan-13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Feb-13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(The yellow colour indicates the months where the missing data have been filled in)