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Ground Source Water Heat Pump System for Heating and Cooling of a building

DIPLOMA THESIS

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I declare that this diploma thesis entitled "**Ground Source Water Heat Pump System for Heating and Cooling of a building**" is my own work performed under the supervision of Dr. Miloš Lain with the use of the literature presented at the end of my diploma thesis in the list of references.

In Prague Raman Sridharan Chary

1. ABSTRACT

The thesis deals with a comprehensive study of a Heat Pump system involving two heat pumps and it's relating components installed in a really old building belonging to the historical Charles University in central Prague. The Heat Pumps installed are the latest and one of the best in the market which have advanced control and in-depth monitoring of every working parameter. The whole system has been under continuous monitoring for the past two years. There are 27 boreholes in total dug up to the depth of 135 meters under the ground, of which two of them being only for the measurement of temperature. The best part of the Heat Pump system is its ability to simultaneously work for cooling and for heating. The energy derived from the heat pump is used to heat or cool according to the requirements of the two adjacent buildings. Then the thesis also involves the study of individual working schemes of the system according to different seasons and the requirements in the building which are very haywire taking into account the experimental laboratories in the same. Subsequently the inferences are drawn from the working parameters and recommendations are made for this system as well as the potential for energy savings in various other similar systems around the world.

2. ACKNOWLEDGMENTS

I feel great pleasure in submitting this thesis on ‘Ground Source Water Heat Pump System for Heating and Cooling of a building’.

I wish to express the truest sense of gratitude towards my thesis guide, Dr. Miloš Lain who at every discrete step in study of this thesis contributed his invaluable guidance.

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Place: Prague, Czech Republic

Date:

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5. INTRODUCTION

5.1 Overview

The thesis is to deal with the in-depth analysis and review which has been done in order to optimize the energy profile of an existing Heat Pump system installed in a historical building in Prague.

5.2 Problem Definition

The thesis “Ground Source Water Heat Pump System for Heating and Cooling of a building’” is an attempt

- To study and analyse an advanced Heat Pump system deeply so as to completely understand its mode and regimes of functioning.
- Thus leading to analysing the effect of the environmental conditions on the working of the system.
- To suggest improvements or modifications to the present working scheme in order to supremely optimize energy usage.

5.3 Motivation and Objectives of the Study

This study was motivated by a need for a study of HVAC systems already functioning in large buildings because HVAC systems account to more than 50% of the energy consumption in any building. This in-depth study would help us to understand most of the Heat Pump systems in the market as a whole thus increasing our understanding about the best possible operating regimes and modes for energy optimization.

6. BACKGROUND AND LITERATURE REVIEW

6.1 Heat pumps

6.1.1 Introduction

A heat pump is a device that provides heat energy from a source of heat to a destination called a "heat sink". Heat pumps are designed to move thermal energy opposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one. A heat pump uses some amount of external power to accomplish the work of transferring energy from the heat source to the heat sink.

While air conditioners and freezers are familiar examples of heat pumps, the term "heat pump" is more general and applies to many HVAC (heating, ventilating, and air conditioning) devices used for space heating or space cooling. When a heat pump is used for heating, it employs the same basic refrigeration-type cycle used by an air conditioner or a refrigerator, but in the opposite direction - releasing heat into the conditioned space rather than the surrounding environment. In this use, heat pumps generally draw heat from the cooler external air or from the ground. In heating mode, heat pumps are three to four times more efficient in their use of electric power, than are simple electrical resistance heaters.

In heating, ventilation and air conditioning (HVAC) applications, the term heat pump usually refers to easily reversible vapour-compression refrigeration devices optimized for high efficiency in both directions of thermal energy transfer.

Heat spontaneously flows from warmer places to colder spaces. A heat pump can absorb heat from a cold space and release it to a warmer one. "Heat" is not conserved in this process, which requires some amount of external high grade (low-entropy) energy, such as electricity.

Heat pumps are used to provide heating because less high-grade energy is required for their operation than appears in the released heat. Most of the energy for heating comes from the external environment, and only a fraction comes from electricity (or some other high-grade energy source required for running a compressor). In electrically powered heat pumps, the heat transferred can be three or four times larger than the electrical power consumed, giving the system a coefficient of performance (COP) of 3 or 4, as opposed to a COP of 1 for a conventional electrical resistance heater, in which all heat is produced from input electrical energy.

Heat pumps use a refrigerant as an intermediate fluid to absorb heat where it vaporizes, in the evaporator, and then to release heat where the refrigerant condenses, in the condenser. The refrigerant flows through insulated pipes between the evaporator and the condenser, allowing for efficient thermal energy transfer at relatively long distances.

6.1.2 Reversible heat Pumps

Reversible heat pumps work in either thermal direction to provide heating or cooling to the internal space. They employ a reversing valve to reverse the flow of refrigerant from the compressor through the condenser and evaporation coils.

- In heating mode, the outdoor coil is an evaporator, while the indoor is a condenser. The refrigerant flowing from the evaporator (outdoor coil) carries the thermal energy from outside air (or soil) indoors, after the fluid's temperature has been augmented by compressing it. The indoor coil then transfers thermal energy (including energy from the compression) to the indoor air, which is then moved around the inside of the building by an air handler. Alternatively, thermal energy is transferred to water, which is then used to heat the building via radiators or by floor heating. The heated water may also be used for domestic hot water consumption. The refrigerant is then allowed to expand, cool, and absorb heat to reheat to the outdoor temperature in the outside evaporator, and the cycle repeats. This is a standard refrigeration cycle, save that the "cold" side of the refrigerator (the evaporator coil) is positioned so it is outdoors where the environment is colder. In cold weather, the outdoor unit is intermittently defrosted by briefly switching to the cooling mode. This will cause the auxiliary or Emergency heating elements (located in the air-handler) to be activated. At the same time, the frost on the outdoor coil will quickly be melted due to the warm refrigerant. The condenser/evaporator fan will not run during defrost mode.

- In cooling mode the cycle is similar, but the outdoor coil is now the condenser and the indoor coil (which reaches a lower temperature) is the evaporator. This is the familiar mode in which air conditioners operate.

6.1.3 Operating principles

Mechanical heat pumps exploit the physical properties of a volatile evaporating and condensing fluid known as a refrigerant. The heat pump compresses the refrigerant to make it hotter on the side to be warmed, and releases the pressure at the side where heat is absorbed.

Heat transport

Heat is typically transported through engineered heating or cooling systems by using a flowing gas or liquid. Air is sometimes used, but quickly becomes impractical under many circumstances because it requires large ducts to transfer relatively small amounts of heat. In systems using refrigerant, this working fluid can also be used to transport heat to a considerable distance, though this can become impractical because of increased risk of expensive refrigerant leakage. When large amounts of heat are to be transported, water is typically used, often supplemented with antifreeze, corrosion inhibitors, and other additives.

Heat sources/sinks

A common source or sink for heat in smaller installations is the outside air, as used by an air-source heat pump. A fan is needed to improve heat exchange efficiency.

Larger installations handling more heat, or in tight physical spaces, often use water-source heat pumps. The heat is sourced or rejected in water flow, which can carry much larger amounts of heat through a given pipe or duct cross-section than air flow can carry. The water may be heated at a remote location by boilers, solar energy, or other means.

Alternatively when needed, the water may be cooled by using a cooling tower, or discharged into a large body of water, such as a lake or stream.

Geothermal heat pumps or ground-source heat pumps use shallow underground heat exchangers as a heat source or sink, and water as the heat transport medium. This is possible because below ground level, the temperature is relatively constant across the seasons, and the earth can provide or absorb a large amount of heat. Ground source heat pumps work in the same way as air-source heat pumps, but exchange heat with the ground via water pumped through pipes in the ground. Ground source heat pumps are simpler and therefore more reliable than air source heat pumps as they do not need fan or defrosting systems and can be housed inside. Although a ground heat exchanger requires a higher initial capital cost, the annual running costs are lower, because well-designed ground source heat pump systems operate more efficiently.

Heat pump installations may be installed alongside an auxiliary conventional heat source such as electrical resistance heaters, or oil or gas combustion. The auxiliary source is installed to meet peak heating loads, or to provide a back-up system.

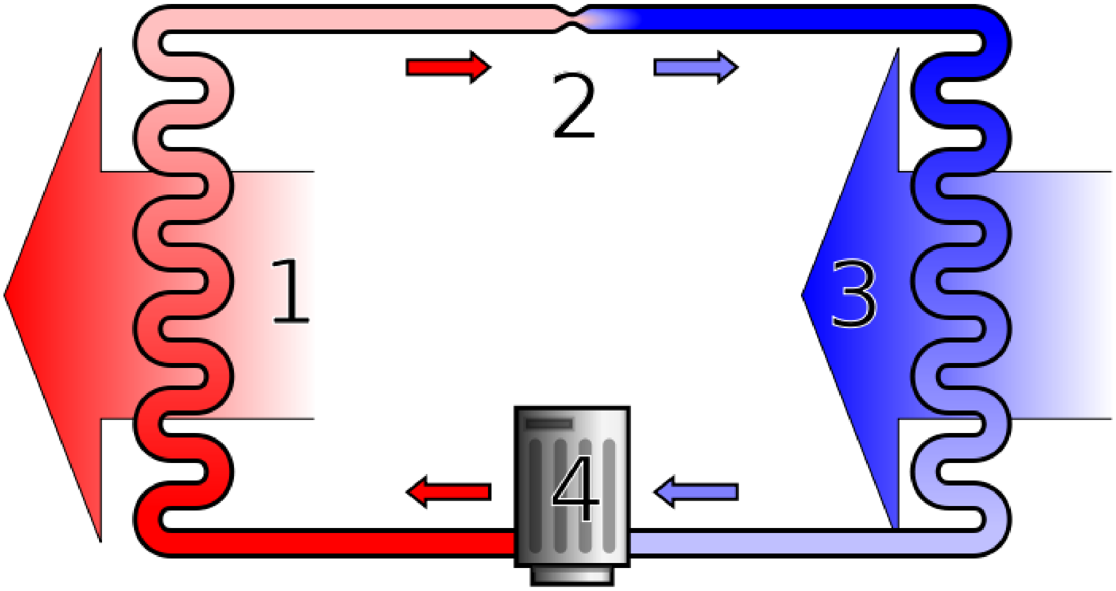

Figure 1 A simple stylized diagram of a heat pump's vapour-compression refrigeration cycle:
1) Condenser, 2) expansion valve, 3) evaporator, 4) compressor.

The working fluid, in its gaseous state, is pressurized and circulated through the system by a compressor. On the discharge side of the compressor, now hot and highly pressurized vapour is cooled in a heat exchanger, called a condenser, until it condenses into a high pressure, moderate temperature liquid. The condensed refrigerant then passes through a pressure-lowering device also called a metering device. This may be an expansion valve, capillary tube, or possibly a work-extracting device such as a turbine. The low pressure liquid refrigerant then enters another heat exchanger, the evaporator, in which the fluid absorbs heat and boils. The refrigerant then returns to the compressor and the cycle is repeated.

It is essential that the refrigerant reaches a sufficiently high temperature, when compressed, to release heat through the "hot" heat exchanger (the condenser). Similarly, the fluid must reach a sufficiently low temperature when allowed to expand, or else heat cannot flow from the ambient cold region into the fluid in the cold heat exchanger (the evaporator). In particular, the pressure difference must be great enough for the fluid to condense at the hot side and still evaporate in the lower pressure region at the cold side. The greater the temperature difference, the greater the required pressure difference, and consequently the more energy needed to compress the fluid. Thus, as with all heat pumps, the coefficient of performance (amount of thermal energy moved per unit of input work required) decreases with increasing temperature difference.

Insulation is used to reduce the work and energy required to achieve a low enough temperature in the space to be cooled.

To operate in different temperature conditions, different refrigerants are available. Refrigerators, air conditioners, and some heating systems are common applications that use this technology.

6.1.4 Heat Pump Types

By definition, all heat sources for a heat pump must be colder in temperature than the space to be heated. Most commonly, heat pumps draw heat from the air (outside or inside air) or from the ground (groundwater or soil).

The heat drawn from ground-sourced systems is in most cases stored solar heat, and it should not be confused with direct geothermal heating, though the latter will contribute in some small measure to all heat in the ground. True geothermal heat, when used for heating, requires a circulation pump but no heat pump, since for this technology the ground temperature is higher than that of the space that is to be heated, so the technology relies only upon simple heat convection.

Other heat sources for heat pumps include water; nearby streams and other natural water bodies have been used, and sometimes domestic waste water (via drain water heat recovery) which is often warmer than cold winter ambient temperatures (though still of lower temperature than the space to be heated).

A number of sources have been used for the heat source for heating private and communal buildings.

Air Source Heat Pump (ASHP)

Air-air heat pumps, that extract heat from outside air and transfer this heat to inside air, are the most common type of heat pumps and the cheapest. These are similar to air conditioners operating in reverse. Air-water heat pumps are otherwise similar to air-air heat pumps, but they transfer the extracted heat into a water heating circuit, floor heating being the most efficient, and they can also transfer heat into a domestic hot water tank for use in showers and hot water taps of the building. However, ground-water heat pumps are more efficient than air-water heat pumps, and therefore they are often the better choice for providing heat for the floor heating and domestic hot water systems.

Air source heat pumps are relatively easy and inexpensive to install and have therefore historically been the most widely used heat pump type. However, they suffer limitations due to their use of the outside air as a heat source. The higher temperature differential during periods of extreme cold leads to declining efficiency. In mild weather, COP may be around 4.0, while at temperatures below around 0°C (32°F) an air-source heat pump may still achieve a COP of 2.5. The average COP over seasonal variation is typically 2.5-2.8, with exceptional models able to exceed this in mild climates.

In areas where only fossil fuels are available (e.g. heating oil only; no natural gas pipes available) air source heat pumps could be used as an alternative, supplemental heat source to reduce a building's dependence on fossil fuel. Depending on fuel and electricity prices, using the heat pump for heating may be less expensive than using fossil fuel. A backup fossil-fuel, solar hot water or biomass heat source may still be required for the coldest days.

The heating output of low temperature optimized heat pumps (and hence their energy efficiency) still declines dramatically as the temperature drops, but the threshold at which the decline starts is lower than conventional pumps, as shown in the following table (temperatures are approximate and may vary by manufacturer and model):

Air Source Heat Pump Type	**Full heat output at or above this temperature**	**Heat output down to 60% of maximum at**
Conventional	8.3 °C	0 °C
Low Temp Optimized	5 °C	-8.3 °C

Ground source heat pump (GSHP)

Ground-source heat pumps, also called geothermal heat pumps, typically have higher efficiencies than air-source heat pumps. This is because they draw heat from the ground or groundwater which is at a relatively constant temperature all year round below a depth of about 30 feet (9 m). This means that the temperature differential is lower, leading to higher efficiency. Well maintained ground-source heat pumps typically have COPs of 4.0

at the beginning of the heating season, with lower seasonal COPs of around 3.0 as heat is drawn from the ground. The trade-off for this improved performance is that a ground-source heat pump is more expensive to install, due to the need for the drilling of boreholes for vertical placement of heat exchanger piping or the digging of trenches for horizontal placement of the piping that carries the heat exchange fluid (water with a little antifreeze).

When compared, groundwater heat pumps are generally more efficient than heat pumps using heat from the soil. Closed loop soil or ground heat exchangers tend to accumulate cold if the ground loop is undersized. This can be a significant problem if nearby ground water is stagnant or the soil lacks thermal conductivity, and the overall system has been designed to be just big enough to handle a "typical worst case" cold spell, or is simply undersized for the load. One way to fix cold accumulation in the ground heat exchanger loop is to use ground water to cool the floors of the building on hot days, thereby transferring heat from the dwelling into the ground loop. There are several other methods for replenishing a low temperature ground loop; one way is to make large solar collectors, for instance by putting plastic pipes just under the roof, or by putting coils of black polyethylene pipes under glass on the roof, or by piping the tarmac of the parking lot.

Exhaust air (EAHP)

Exhaust air heat pump (extracts heat from the exhaust air of a building, requires mechanical ventilation)

- Exhaust air-air heat pump (transfers heat to intake air)
- Exhaust air-water heat pump (transfers heat to a heating circuit and a tank of domestic hot water)

Water source heat pumps (WSHP)

Uses flowing water as source or sink for heat

- Single-pass vs. recirculation
    - Single-pass — water source a body of water or a stream
    - Recirculation
        - When cooling, closed-loop heat transfer medium to central cooling tower or chiller (typically in a building or industrial setting)
        - When heating, closed-loop heat transfer medium from central boilers generating heat from combustion or other sources

Hybrid (HHP)

Hybrid (or twin source) heat pumps: when outdoor air is above 4 to 8 Celsius, (40-50 Fahrenheit, depending on ground water temperature) they use air; when air is colder, they use the ground source. These twin source systems can also store summer heat, by running ground source water through the air exchanger or through the building heater-exchanger, even when the heat pump itself is not running. This has dual advantage: it functions as a low running cost for air cooling, and (if ground water is relatively stagnant) it cranks up the temperature of the ground source, which improves the energy efficiency of the heat pump system by roughly 4% for each degree in temperature rise of the ground source.

Air/water-brine/water heat pump (hybrid heat pump)

The air/water-brine/water heat pump is a hybrid heat pump, developed in Rostock, Germany, that uses only renewable energy sources. Unlike other hybrid systems, which usually combine both conventional and renewable energy sources, it combines air and geothermal heat in one compact device. The air/water-brine/water heat pump has two evaporators — an outside air evaporator and a brine evaporator — both connected to the heat pump cycle. This allows use of the most economical heating source for the current external conditions (for example, air temperature). The unit automatically selects the most efficient operating mode — air or geothermal heat, or both together. The process is controlled by a control unit, which processes the large amounts of data delivered by the complex heating system.

6.2 Energy consumption of AC systems

6.2.1 Monitoring

Monitoring is the most important part of any Energy consuming system. It helps to provide feedback on energy use patterns to those system owners/operators which should allow them to achieve measurable energy savings in operation in practice.

•This will allow activity-based benchmarks to be derived against which the comparative energy performance of an HVAC system can be compared. Those systems showing poor performance could then be considered in need of the more detailed Physical Inspection.

•Provide evidence-based information to HVAC system manufacturers, Professional Building Services Bodies and HVAC system owner/operators on how to improve the in-use energy efficiency of HVAC systems.

•Potentially allow owner/operators of systems showing good energy performance to avoid needless Inspections.

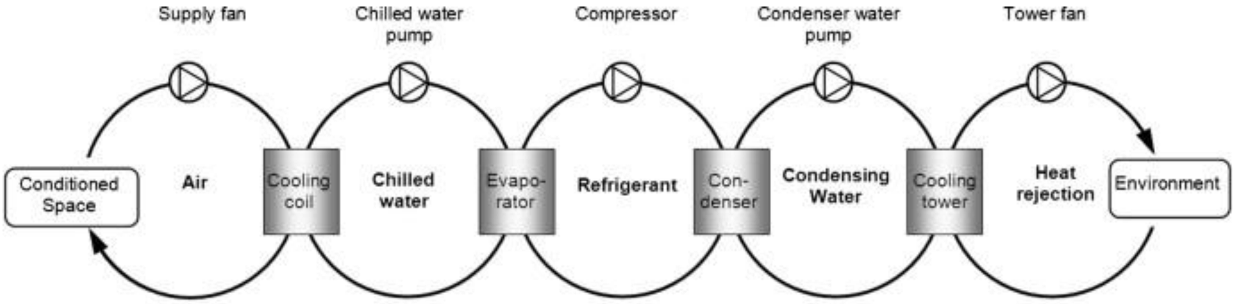

Figure 2 HVAC thermal chain for hydronic systems in the cooling mode. Water-cooled chiller.

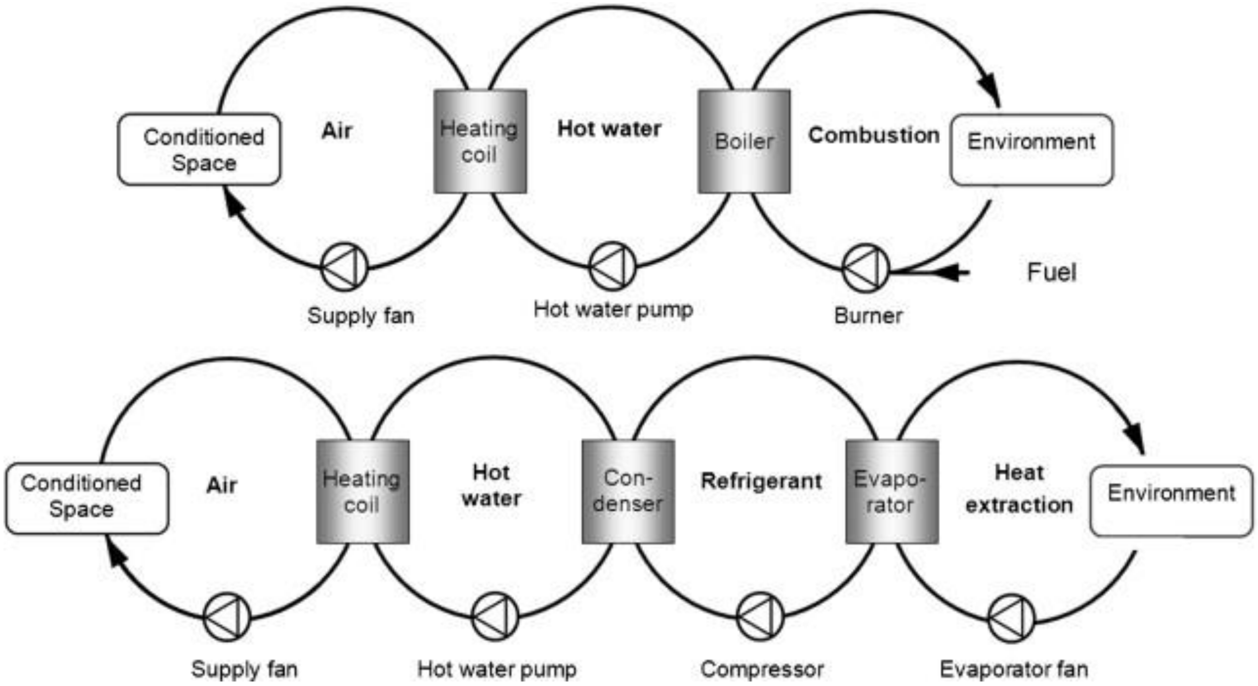

Figure 3 HVAC thermal chain for hydronic systems in the heating mode. (a) Hot water boiler. (b) Air to water heat pump

6.2.2 Commissioning

Commissioning "is a systematic process of assuring that a building performs in accordance with the design intent and the Owner's operational needs". Simply stated, commissioning is making sure the building runs right. Commissioning is the most important part of setting up any system. It involves developing, designing, implementing, monitoring over a period of time and then finally optimizing to the best possible working environment and performance.

In basic commissioning: only energy using systems are commissioned

- HVAC
- Lighting and Lighting Controls
- DHW

HVAC, Domestic Hot Water and Lighting Controls

- Design Reviews by Professional Engineers
- Construction Installation Inspections
- Functional Testing of Equipment
- Data Logging of Energy Use and Interior Comfort Conditions
- O&M Manuals, Training of Operating Personnel, 10Personnel, 10--month standard inspection

6.2.3 Computer Simulation

- **Microsoft Excel**: Microsoft Excel is a spreadsheet application developed by Microsoft for Microsoft Windows, Mac OS, and iOS. It features calculation, graphing tools, pivot tables, and a macro programming language called Visual Basic for Applications. It has been a very widely applied spreadsheet for these platforms, especially since version 5 in 1993, and it has replaced Lotus 1-2-3 as the industry standard for spreadsheets. Excel forms part of Microsoft Office.

- **TRNSYS**: TRNSYS is a simulation program primarily used in the fields of renewable energy engineering and building simulation for passive as well as active solar design.

  TRNSYS is a commercial software package developed at the University of Wisconsin. One of its original applications was to perform dynamic simulation of the behaviour of a solar hot water system for a typical meteorological year so that the long-term cost savings of such a system could be ascertained. TRNSYS is a transient systems simulation program with a modular structure. It recognizes a system description language in which the user specifies the components that constitute the system and the manner in which they are connected. The TRNSYS library includes many of the components commonly found in thermal and electrical energy systems, as well as component routines to handle input of weather data or other time-dependent forcing functions and output of simulation results. The modular nature of TRNSYS gives the program tremendous flexibility, and facilitates the addition to the program of mathematical models not included in the standard TRNSYS library. TRNSYS is well suited to detailed analyses of any system whose behaviour is dependent on the passage of time. TRNSYS has become reference software for researchers and engineers around the world. Main applications include: solar systems (solar thermal and photovoltaic systems), low energy buildings and HVAC systems, renewable energy systems, cogeneration, fuel cells.

6.3 Legislation

- EU Directive 2002/ 91 / EC on the energy performance of buildings was one of the first and most important legislations to be sanctioned in the start of the millennium.
- EP and Council Directive 2010/31/ EU of 19 May 2010 on the energy performance of buildings was the latest renewal of the main Legislation sanctioned by the EU.
- Decree 193/2013 Sb. (28.6) on the control of air conditioning systems is the newest Legislation which deals with the control of all HVAC systems.

- 318/2012 of 19 July 2012 amending Act no. 406/2000 on energy management is the latest Czech Legislation which has been released on par with the latest EU Legislation which deals with the Energy management of all systems.
- BEE – Bureau of Energy Efficiency India – Guidelines for Energy Efficiency in Buildings has been released in 2013 which is on par with the world standards such as in ASHRAE and REHVA and deals with the energy efficiency in buildings according to different categories of the buildings.

6.3.1 LEED Certification

Leadership in Energy and Environmental Design (LEED) is a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes and neighbourhoods.

Developed by the U.S. Green Building Council (USGBC), LEED is intended to help building owners and operators be environmentally responsible and use resources efficiently. Proposals to modify the LEED standards are offered and publicly reviewed by USGBC's member organizations, which number almost 20,000.

Unlike Model Building Codes, such as the International Building Code, only members of the USGBC and specific "in-house" committees may add, subtract or edit the standard, based on an internal review process. Model Building Codes are voted on by members and "in-house" committees, but allow for comments and testimony from the general public during each and every code development cycle at Public Review hearings, generally held multiple times a year.

USGBC's Green Building Certification Institute (GBCI) offers various accreditations to people who demonstrate knowledge of the LEED rating system, including LEED Accredited Professional (LEED AP), LEED Green Associate, and since 2011, LEED Fellows, the highest designation for LEED professionals. GBCI also certifies projects pursuing LEED.

Prerequisites

To participate in LEED 2009, a building must comply with environmental laws and regulations, occupancy scenarios, building permanence and pre-rating completion, site boundaries and area-to-site ratios. Its owner must share data on the building's energy and water use for five years after occupancy (for new construction) or date of certification (for existing buildings).

Each of the performance categories also have mandatory measures in each category, which receive no points.

Credit Weighting Process

The weighting process has three steps:

- A collection of reference buildings are used to estimate the environmental impacts of any building seeking LEED certification in a designated rating scheme.

- NIST weightings are used to judge the relative importance of these impacts in each category.

- Data regarding actual impacts on environmental and human health are used to assign points to individual categories and measures.

This system results in a weighted average for each rating scheme based upon actual impacts and the relative importance of those impacts to human health and environmental quality.

The LEED council also appears to have assigned credit and measure weighting based upon the market implications of point allocation.

6.3.2 BREEAM certification

BREEAM is the world's foremost environmental assessment method and rating system for buildings, with 425,000 buildings with certified BREEAM assessment ratings and two million registered for assessment since it was first launched in 1990.

BREEAM sets the standard for best practice in sustainable building design, construction and operation and has become one of the most comprehensive and widely recognized measures of a building's environmental performance. It encourages designers, clients and others to think about low carbon and low impact design, minimizing the energy demands created by a building before considering energy efficiency and low carbon technologies.

A BREEAM assessment uses recognized measures of performance, which are set against established benchmarks, to evaluate a building’s specification, design, construction and use. The measures used represent a broad range of categories and criteria from energy to ecology. They include aspects related to energy and water use, the internal environment (health and well-being), pollution, transport, materials, waste, ecology and management processes.

A certificated BREEAM assessment is delivered by a licensed organisation, using assessors trained under a UKAS accredited competent person scheme, at various stages in a buildings life cycle. This provides clients, developers, designers and others with:

- market recognition for low environmental impact buildings,
- confidence that tried and tested environmental practice is incorporated in the building,
- inspiration to find innovative solutions that minimise the environmental impact,
- a benchmark that is higher than regulation,
- a system to help reduce running costs, improve working and living environments,
- A standard that demonstrates progress towards corporate and organisational environmental objectives.

BREEAM addresses wide-ranging environmental and sustainability issues and enables developers, designers and building managers to demonstrate the environmental credentials of their buildings to clients, planners and other initial parties, BREEAM:

- uses a straightforward scoring system that is transparent, flexible, easy to understand and supported by evidence-based science and research,

- has a positive influence on the design, construction and management of buildings,
- Defines and maintains a robust technical standard with rigorous quality assurance and certification.

6.4 Case Studies

6.4.1 Bombay Sapphire Distillery Process Buildings

The Bombay Sapphire Distillery and Process Buildings, at Laverstoke Mill in Hampshire, are linked and closely related existing buildings that have been subject to major refurbishment. This has transformed a former Victorian Paper Mill into the new home of Bombay Sapphire Gin, which includes a visitors' centre and bar.

Figure 4 Interior of Distillery

The five acre Laverstoke Mill is a complex site that includes Grade II listed buildings in a conservation area, a site of special scientific interest (SSSI) and a section of the River

Test, which flows directly through the site. Central to the 2500m^2 distillery are three still houses, which accommodate traditional copper stills that use renewable energy from a biomass boiler, photovoltaic array and hydro-electric turbine. The scheme was the first ever refurbishment project to achieve a BREEAM 'Outstanding' rating, anywhere in the world. It is also the first distillery to be BREEAM 'Outstanding' certified.

Key BREEAM facts

BREEAM version: Industrial 2008 v4.0
Stage: Design Stage
BREEAM rating: Outstanding
Score: 86.81%

Green strategy

Sustainability was vitally important to Bombay Sapphire at Laverstoke Mill. The design of a low carbon, BREEAM assessed, flagship distillery underpinned the design brief, which was supported by the client and design team from the outset.

There was a strong desire to reduce any impact on the existing environment, and 'cradle to grave' considerations formed a major part of the design philosophy. This included the recycling and reuse of existing building materials from demolished buildings across the site, and an ingenious idea to reuse spent botanicals from the distillation process as fuel for the biomass boiler – supplying heat and hot water to the whole site.

The use of cutting edge technologies was encouraged by the client. This has seen a multi-functional renewable energy strategy implemented – including a 6kW hydro-electric turbine located in the River Test.

Arguably the most impressive element has been the level of consultation and social responsibility adopted by the design and construction teams. In addition to engagement with a host of local and national bodies, there has been extensive community involvement. This has seen local residents build up a strong relationship with the construction works, which played host to local parish council meetings and local/national media events.

Major environmental features

The key environmental features of the site include:

- EPC rating of 'A' – CO_2 Index of 14
- Building related carbon emissions less than $4kgCO_2/m^2$
- Renewable and low carbon energy, provided by a biomass boiler, photovoltaic array and hydro-electric turbine in the River Test, gives carbon savings of 38%
- The biomass boiler also provides heat and hot water, using by-products from the gin distillation process as a fuel source
- Key building materials, including bricks and roof tiles, have been recycled and reused from demolished buildings
- More than 80% of the existing building structure retained

- Rainwater harvesting and flow restricted water devices specified throughout
- Ecology and biodiversity in the conservation area SSSI significantly enhanced
- Part of the works included a major river diversion – the fish were relocated by a team of specialists by hand
- Contractor site management, CCS and stakeholder consultation reached exemplar levels.

The BREEAM Assessment

The project scored 100% of available credits in the Energy and Management categories and more than 90% of credits in the Water, Materials and Waste categories. There was an additional 5% worth of innovation credits scored for exemplar performance levels achieved.

Figure 5 Bombay Sapphire Distillery

6.4.2 A TRNSYS Simulation Case Study on Utilization of Heat Pump For both Heating and Cooling

Abstract

This paper presents a TRNSYS simulation case study on the integration of a heat pump into a hot water and cold water storage systems for the purpose of providing heating and cooling to a residential home or office building in a tropical climate. The motivation is to utilize waste heat rejected by the heat pump. The heat pump is integrated with two water storage tanks. One is the cold water tank where heat is extracted by the heat pump and the other is the hot water which stores the heat rejected by the heat pump. The cold water tank provides cooling water for air conditioning to the building. The hot water tank is used for daily usage like bathing and washing. The sizing of the two storage tanks and the balancing of the heat transfer between the two tanks are important design factors to maintain suitable temperatures in the storage tanks. The paper discusses the performance of the integrated system under different operational modes and the effects of each storage tank size on the performance.

TRNSYS Model

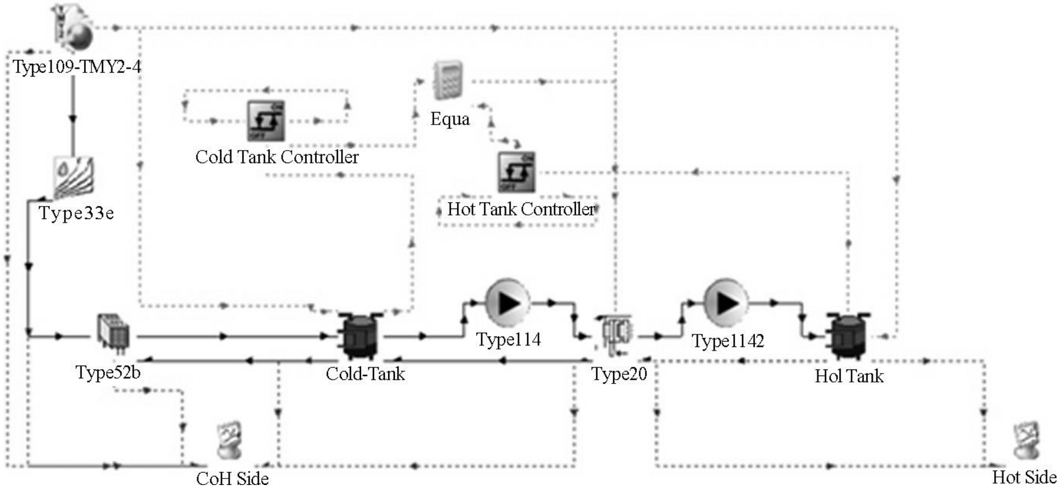

Figure 6 Schematic Diagram of Heat Pump for Air Conditioning and Hot Water Production

Comparison under different operating modes

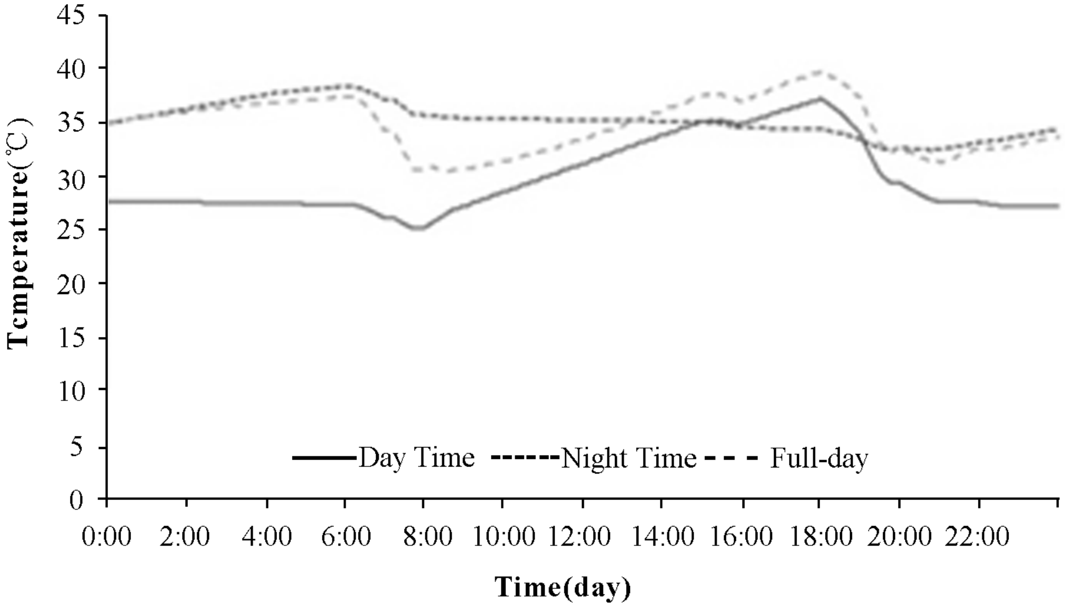

Figure 7 Temperature vs. Time of the Day

7. DESCRIPTION AND METHODOLOGY

7.1 Building

The Mathematics and Physics Faculty at Prague's Charles 2 is interesting not only for its history and tradition, but also a number of various technologies and laboratory instruments, which are found in them. Starting with powerful lasers and microscopes to say the least. Most of these devices require high power of cooling. The devices of the past were cooled by water from the water system and heated waste water was discharged into the sewer system.

With increasing prices of water became intolerable due to this this method and thus was sought a way to cool in a cheaper way and possibly use thermal energy contained in the waste water. The next logical step was the construction of a central cooling circuit.

Looking at the large garden of Albertová belonging to MFF UK, immediately offered solutions to utilize natural heat for heating buildings. And in case of excess heat on the contrary it could be reverted back to the ground for regeneration. This water cooled heat used for removing the heat could then be used as a coolant in the central cooling circuit.

Figure 8 Mathematics and Physics Faculty, Charles University

7.2 HVAC system of Building

Existing heat source for both buildings is a 1360 kW gas boiler, which provides The Charles 5 a heating of-400 kW (from archival documents), The Charles 3 a heating of-400 kW (estimate) and DHW (Domestic Hot Water) 100 kW (estimated). Rated thermal gradient of the source is 90/70°C. Design data correspond with the actual consumption of the boiler room which is around approximately 1800 MWh / year.

Real ambient temperature gradient 70/55°C at -12 ° C is not equal to nominal, which allows use of heat pumps to fully cover the needs of the building at an outdoor temperature of 0°C and higher. Up to 0°C is considered necessary heat output of 250 kW, for which 270 kW has been installed.

To regenerate the drill field will be used for waste heat from cooling technology, or active cooling mode of the heat pump. During this operation, a profit of 500 MWh for heating demand can be realized and consumption of 80 MWh of waste heat from cooling.

The appliances used in the building are as follows:

Serial Number	Appliance	Power (kW)
1	Equipment	43
2	Preparation	21
3	Fan Coil Unit (FCU)	120.3
4	Apparatus (Experimental)	136

7.3 Source for heating and cooling

The original source of heat for both buildings was a gas boiler with a rating of 1360kW. Constructed bivalent heat source consists of the gas boiler and new heat pumps with a total output of 270 kW. Bivalence point is 0 ° C. For this temperature is required heat output of 250 kW.

Therefore two heat pumps were installed each with a rated heat output of 135 kW and 100 kW of cooling power (for primary water inlet temperature of 10 °C and outlet temperature of the secondary water 55 °C). Heat pumps are connected in parallel to the charging circuit storage tank with a capacity of 1 m^3. The storage tank heating water is pumped into the manifold heating system.

The drilling field is regenerated by the use of waste heat from cooling technology, or heat generated during the active cooling mode of heat pumps. In this mode is covered the need for a central cooling system.

7.4 Component Specifications

Below are the technical descriptions of every major component which has been installed and is an integral part of the main system.

7.4.1 Heat Pump

Model	Viessmann 300-G PRO
Output	Heating - 135kW
	Cooling - 100kW
Power Consumption	26 kW
COP	4.73

Figure 9 Heat Pump

7.4.2 Storage Tanks

Brand	Regulus PS-1000
Tank Volume	927 litres

7.4.3 Heat Exchangers

Brand	Alfa Laval CB76-50l and CB200-80l
Plate Heat Exchangers with cross and parallel flow together.	

7.4.4 Pumps

Brand: Grundfos

No	Model Number	Capacity (Output)
1	TP – 50 – 190/2	1.5kW
2	TP – 50 – 190/2	1.5kW
3	MAGNA 50 – 60 F	34 – 334 W
4	MAGNA 50 – 60 F	34 – 334 W
5	MAGNA 50 – 120 F	35 – 800 W
6	TP – 65 – 120/2	1.1kW
7	TP – 65 – 240/4	4kW
8	MAGNA 65 – 120F	35 – 900W

7.5 Bore holes

Every large and complex project based on deep water wells requires a systematic approach. Geothermal Response Test - GRT, field test the thermal conductivity of the subsoil was conducted. The actual test of test wells revealed a higher average temperature of bedrock than the expected level.

The result of the survey was that the site was able to satisfy both the anticipated needs for heating and cooling. The obtained data was subsequently processed by the firm GEROtop that performed calculations, simulations and optimized design of the drilling fields.

The result was then concluded with a need to implement 27 wells with a depth of 135 meters layout divided into two drilling fields. As a technology for collecting geothermal heat system was chosen GEROtherm, which is among the leaders in this field. Using the system GEROtherm and protection PUSH on the bottom of wells to take advantage of extended warranty Swiss manufacturer of kits wells and up to 20 years.

For scientific purposes, the four boreholes fitted with a set of sensors and monitored in the control system - TRONIC 2000® supplier of the engine technology TRONIC CONTROL® Ltd. Temperatures are recorded at regular intervals automatically for future analysis with an optional rock mass behaviour in relation to the removal of heat from return and storage of waste heat.

Figure 10 Picture of one of the boreholes

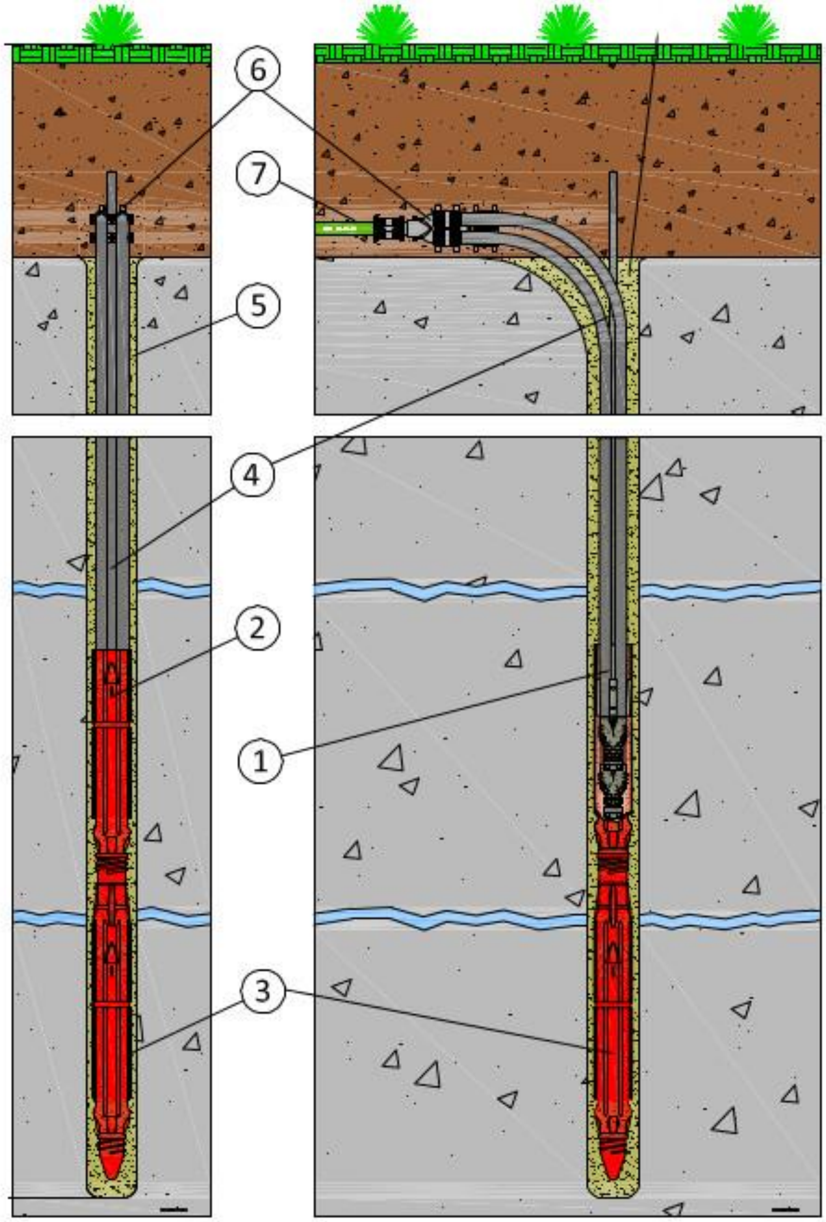

Figure 11 Example underground picture of a bore hole

7.6 Measurements

There are 140 sensors in total all over the system which measure the various parameters throughout the system. These sensors continuously monitor values such as the temperature in the bore holes at various depths, temperatures in the system, calorimeters near the heat pumps, hot and cold storage and the heat exchangers too.

7.7 Control

Technology is controlled by a digital control system modularly expandable TRONIC 2000® with operator control. The control system provides optimal switching between operating modes described. The control system is connected via Ethernet communication to the superior central control room where it is installed visualization and supervisory control software assets.

The technology works in the following modes:

- **Heating mode without cooling** - heat pumps operate in cascade and prepare hot water depending on the outdoor temperature (the heating control), with a maximum of 55 °C.

- **Heating and cooling mode** - heat pumps operate in cascade and prepare hot water heating depending on the outdoor temperature (the heating control), maximum of 55 °C and basic cooling too.

- **Mode natural cooling** - heat pumps are out of circulation and heat transfer fluid in the primary circuit caters circulator. When the need for cooling water of 13 °C is there, then it is charged through the cold storage heat exchanger.

- **Mode active cooling** - heat pumps operate in cascade as required control cooling and heating water to prepare about 55 °C. Accumulated heat is transferred through the heat into wells - wells regeneration. The low temperature generated after removing heat is passed through a heat exchanger to cool the water tank of the central cooling circuit.

By installing the above-described technology heat pumps earth-water was achieved:

1. significant reduction in the consumption of drinking water,
2. use of waste heat for the regeneration of the earth spike (summer mode),
3. Use of waste heat for heating buildings (winter and transitional regime).

The gradual removal of the existing split / multi-split units from the facade of the building.

8. RESULTS AND ANALYSIS

8.1 Measurements

8.1.1 Heating, Cooling Loads and Bore Hole Temperature Gradient

As we start the analysis with the given data, we first take note of the most important parameters which would affect the outcome of the system.

The parameters noted were the bore hole temperature difference taken at 1m and 130m, the calorimetric reading from the 2 bore holes and the heating and cooling load taken from the calorimeters at cold and hot thermal storage.

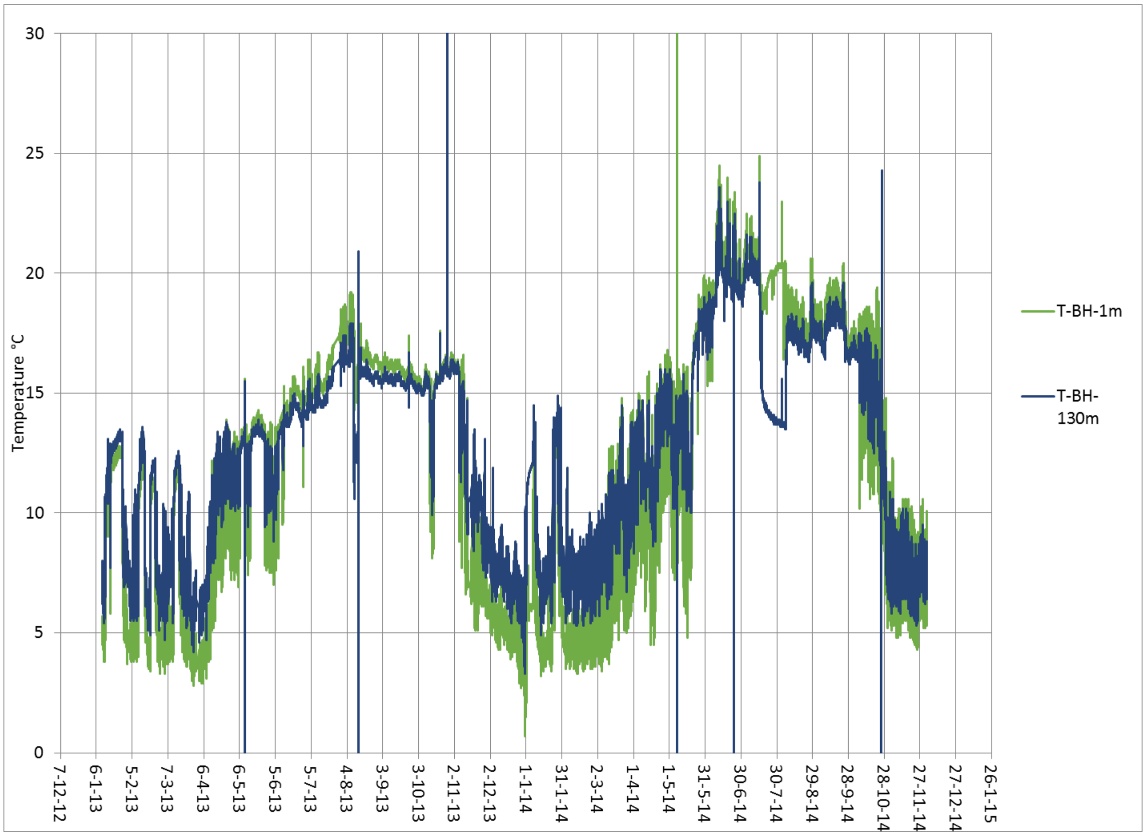

Figure 12 Bore Hole Temperature Gradient

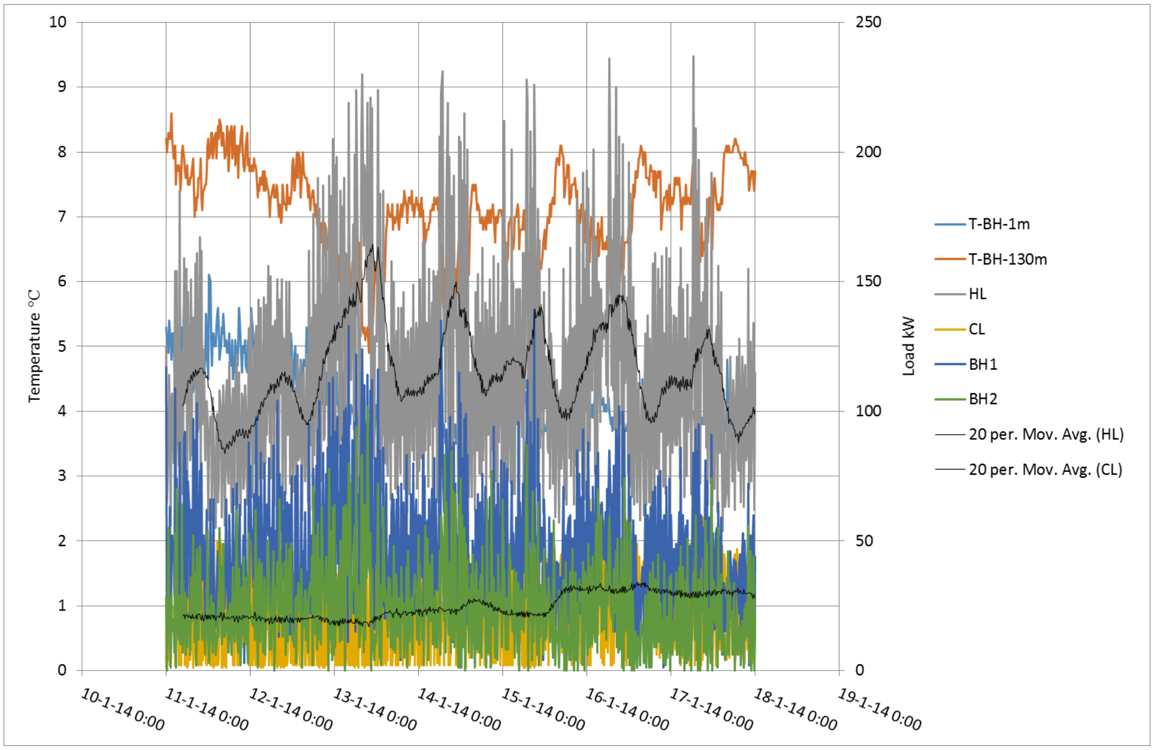

Figure 13 Graph Heating and Cooling Loads (January)

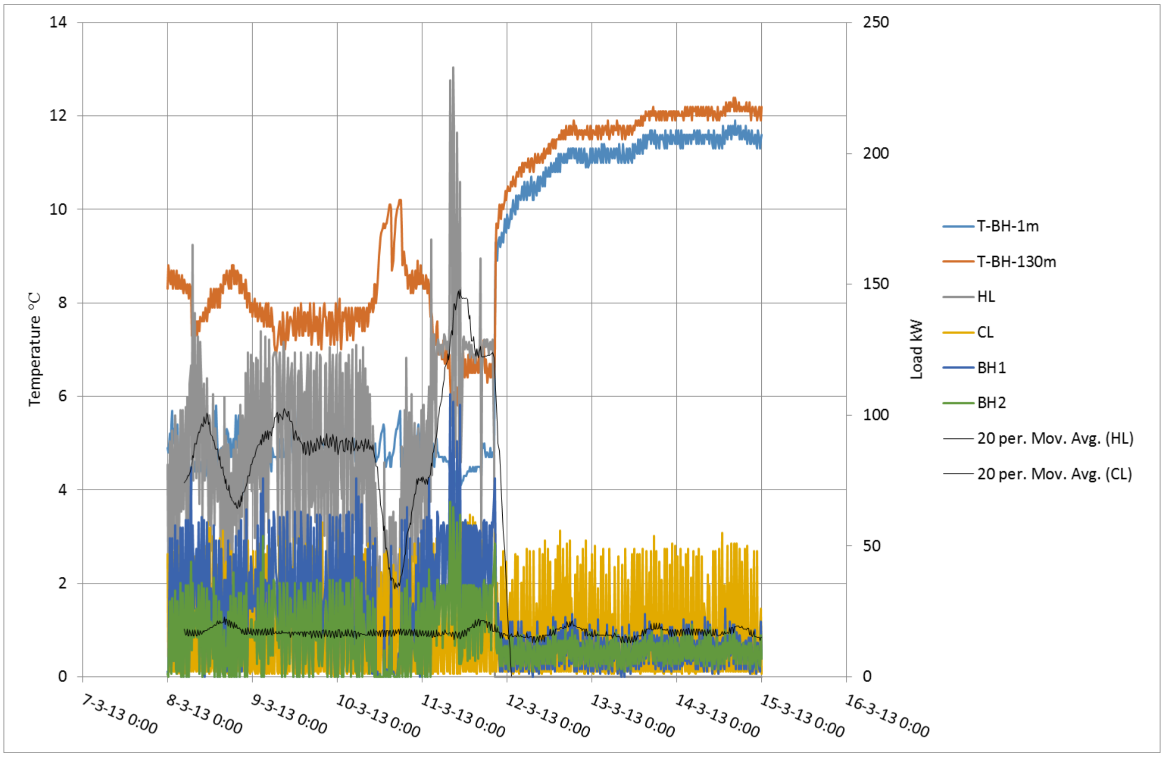

Figure 14 Graph Heating and Cooling Loads (March)

Observing the beginning of the data in hand, we can see that there are some error values of heating and cooling load which are way above the normal levels at about 16000 to 18000 which are totally absurd. This may be due to the beginning of the system afresh. Then we can see the gradual decrease of such haywire values as the sensors may have been calibrated to realistic values.

Thus looking at the first few weeks of the year, which is during the winter season we can see that the requirement of heating is pretty high at around 130 kW due to less outside temperature. Whereas the requirement for cooling is at 50 kW even during winter for some experimental purposes conducted in the building. [Ref: fig.13, 14, 15]

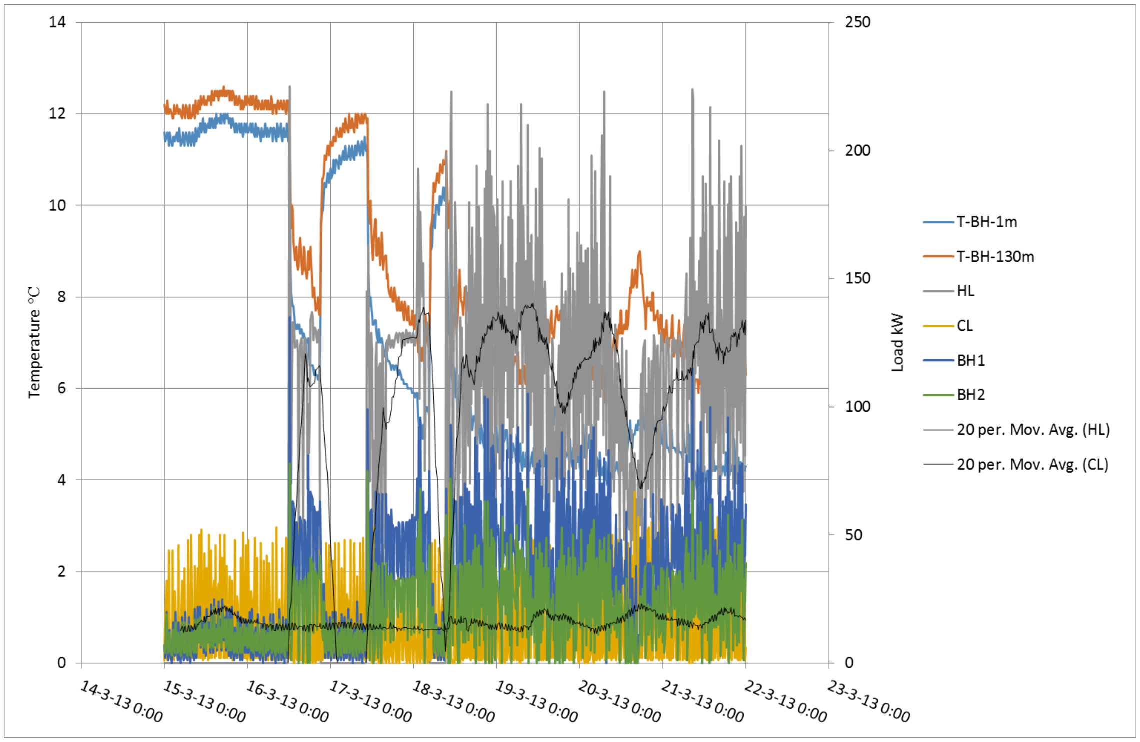

Figure 15 Graph Heating and Cooling Loads (March)

As we can see in the first week of March, the heating load is about 120kW and the cooling around 10kW. The output obtained from the borehole calorimeters 80kW together. The heating requirement is higher than the cooling requirement. As the cooling and heating requirements reduce in the second week of March we can subsequently see that the temperature in the bore holes again go back to their natural levels around 11 degree Celsius.

As the heating and cooling requirements increase it is shown by subsequent decrease in the temperature of bore holes as the energy from bore holes is utilized by the heat pump.

The continuous change in the modes of running of the operation of the heat pump system is followed simultaneously by the decrease and increase in the temperature in the bore holes according to the respective mode of operation. [Ref: fig.16]

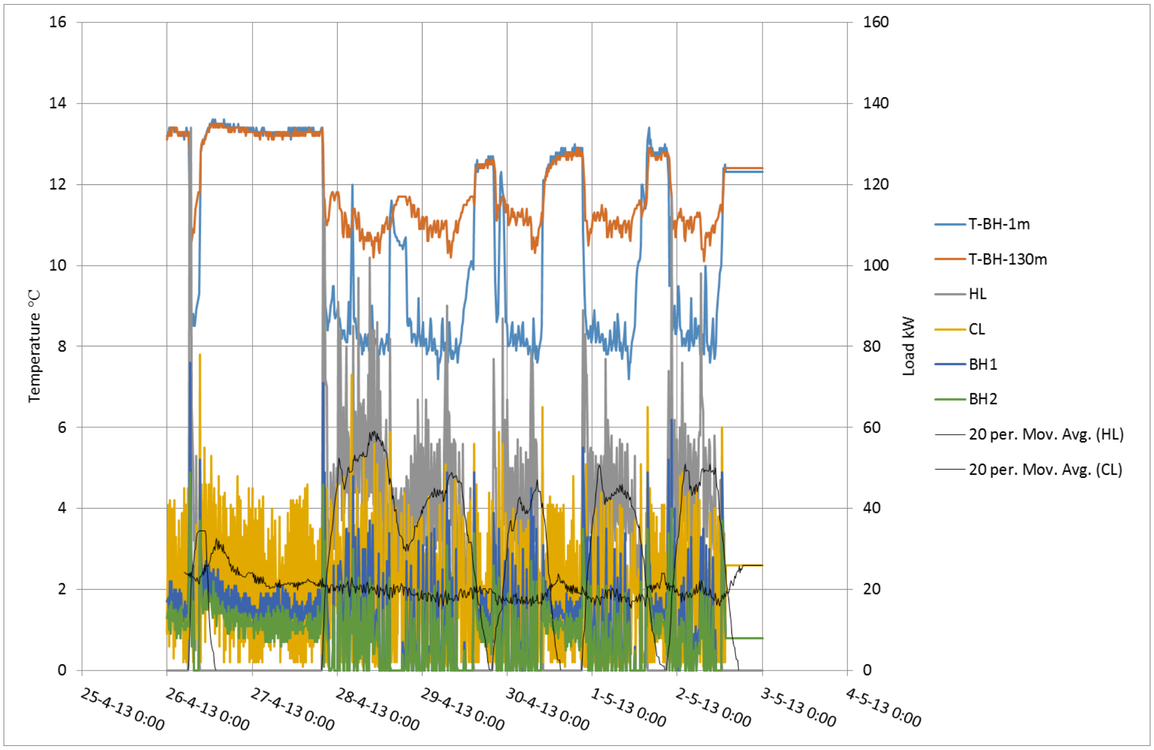

Figure 16 Graph Heating and Cooling Loads (April)

The period between winter and summer, which is during spring we are able to see varying heating and cooling loads on the system changing frequently at nearly regular intervals.

During summer, the heating load completely comes to zero and only the cooling load remains. There is also observed in the increase in the amount of the cooling load to around 70kW.

Similar behaviour is observed for most of the months during the summer period until the start of October. Here we can see that the requirement of heating again comes as there is a decrease in the outside temperature. [Ref: fig.17, 18, 19, 20]

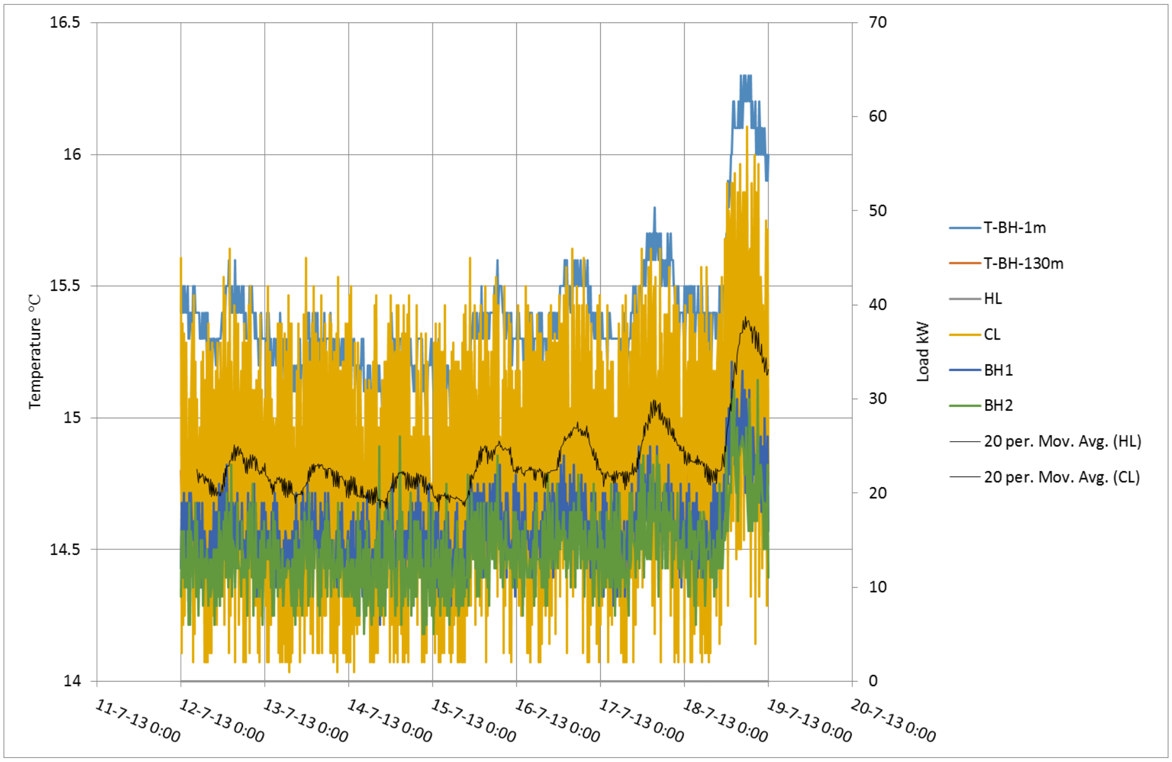

Figure 17 Graph Heating and Cooling Loads (July)

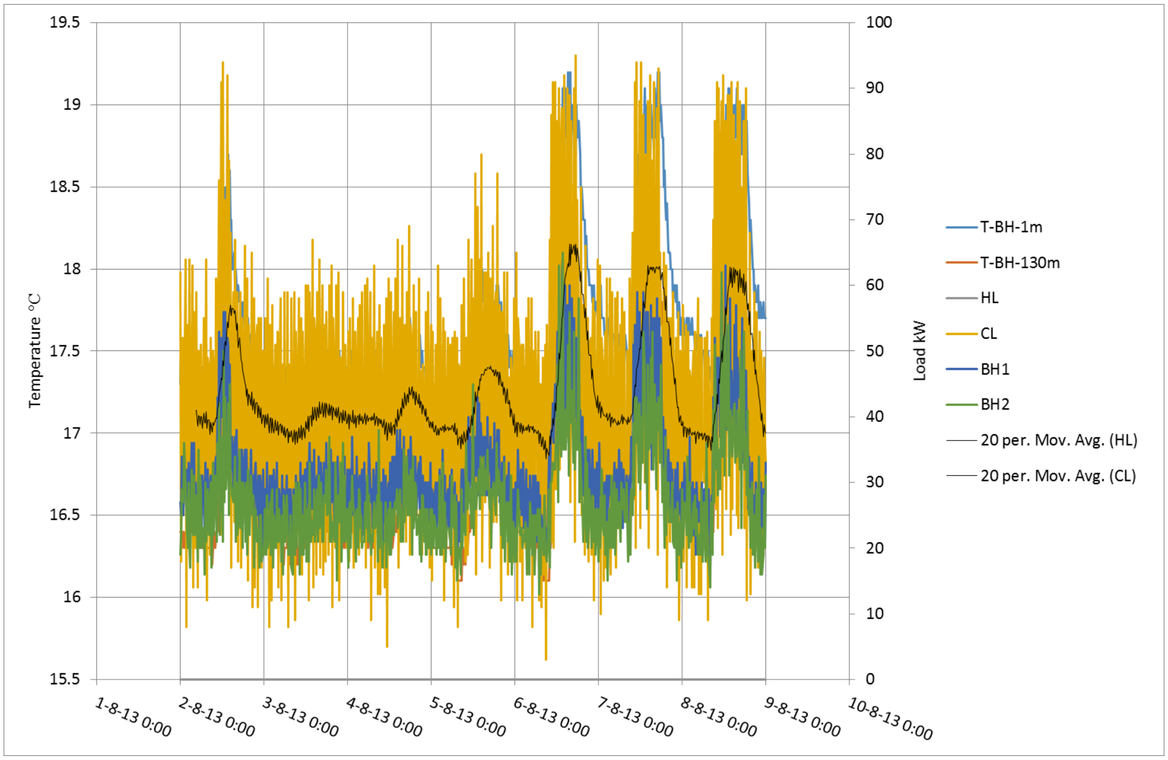

Figure 18 Graph Heating and Cooling Loads (August)

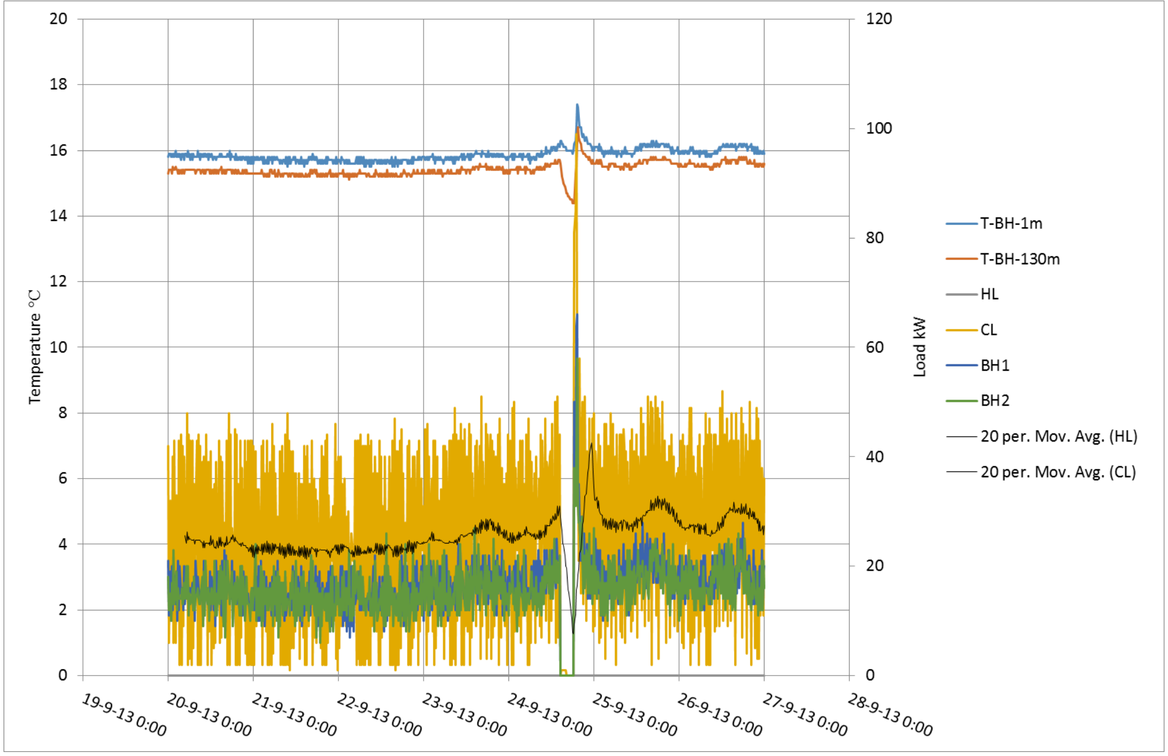

Figure 19 Graph Heating and Cooling Loads (September)

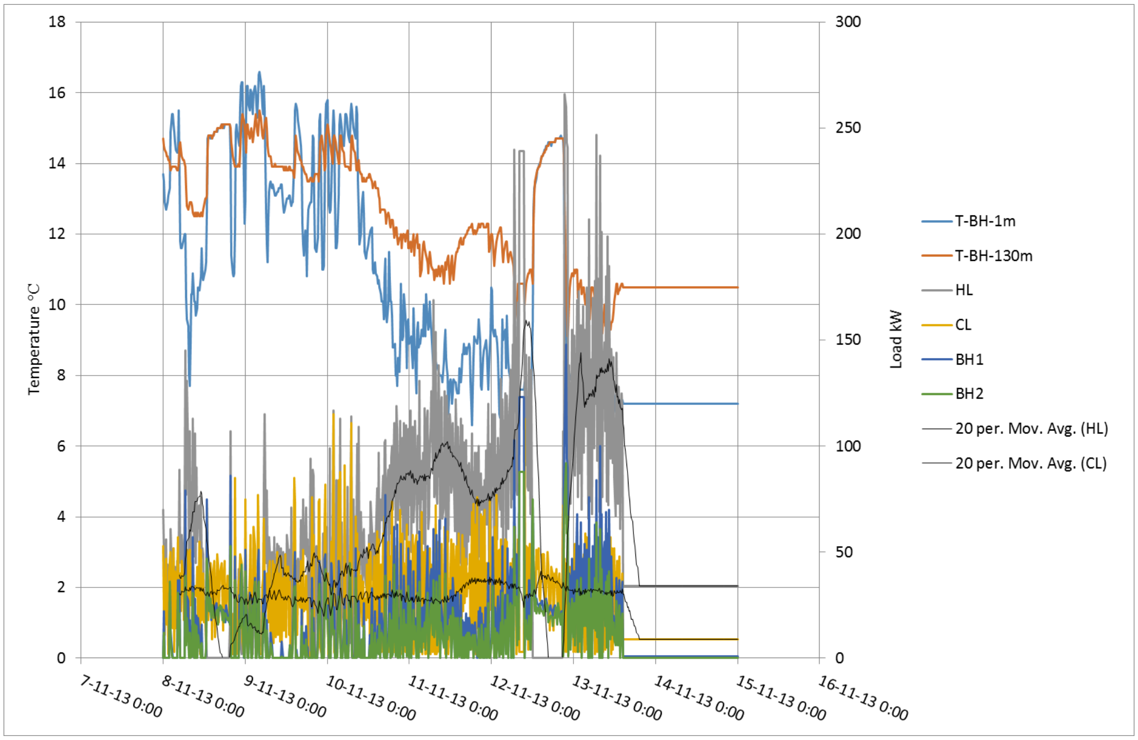

Figure 20 Graph Heating and Cooling Loads (November)

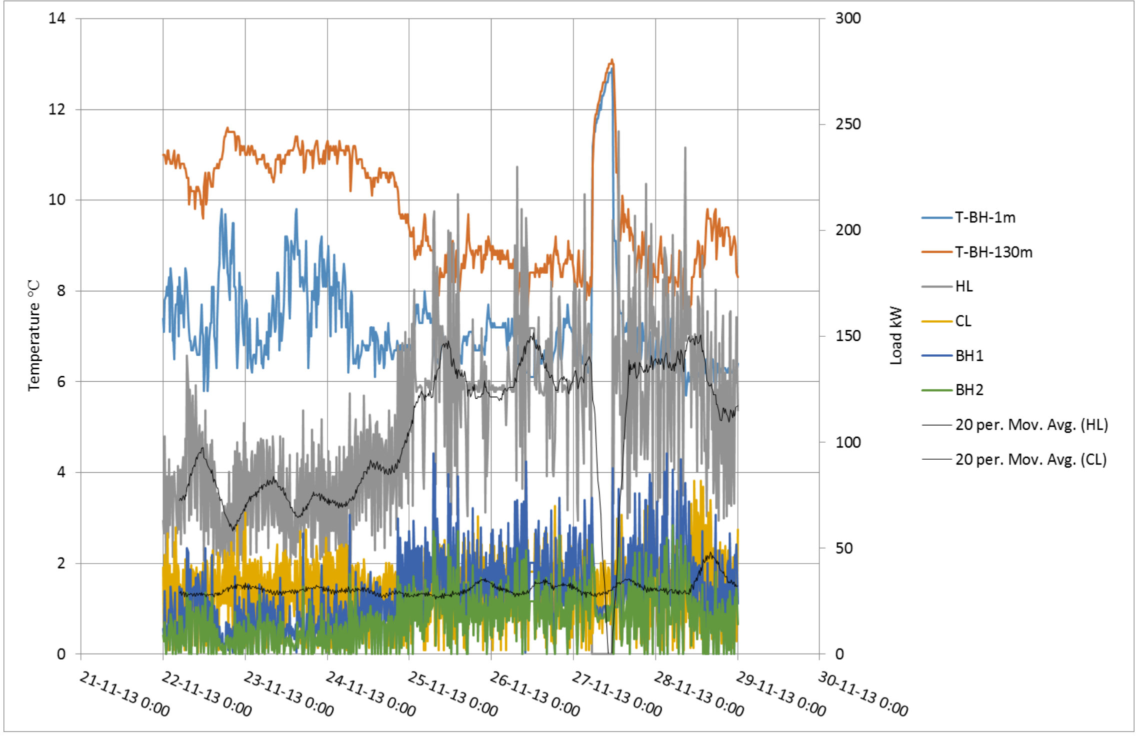

Figure 21 Graph Heating and Cooling Loads (November)

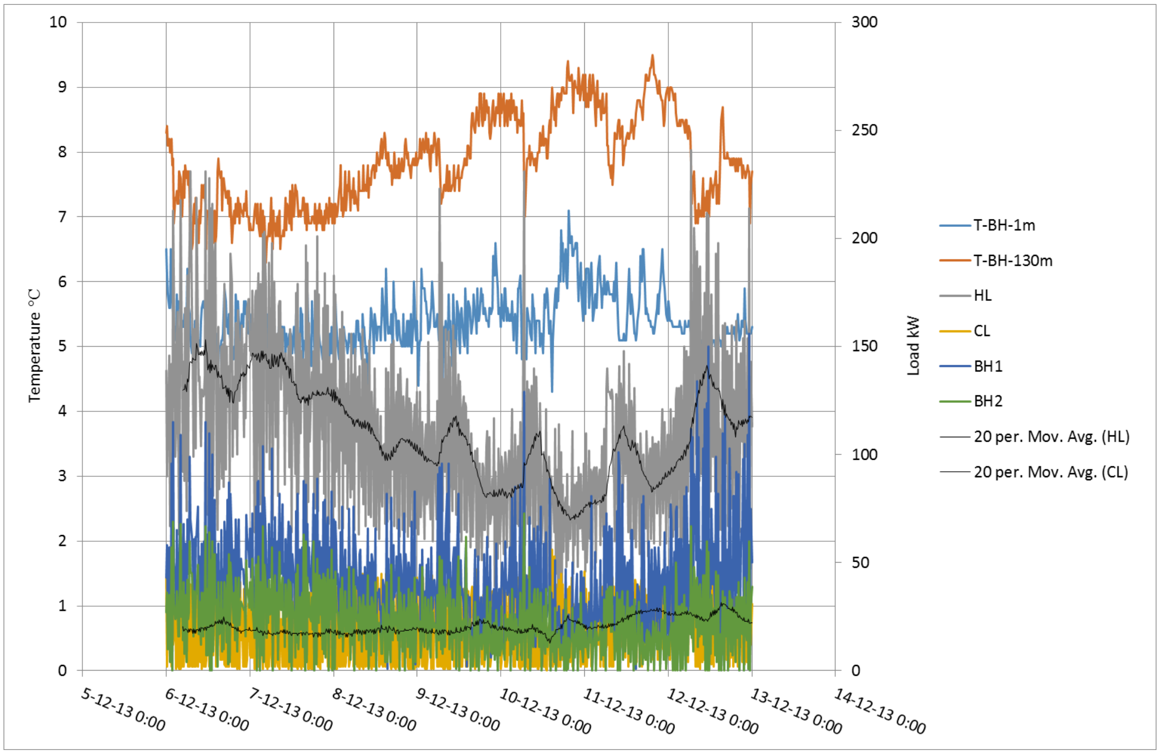

Figure 22 Graph Heating and Cooling Loads (December)

Thus the calendar year ends as it began showing winter conditions of more heating load than cooling.

The most important point which is observed is that the cooling load is always there irrespective of the outside temperatures even during the winter because of the requirements for experimental purposes whereas the heating totally becomes zero during the summer period. [Ref: fig.21, 22]

8.1.2 Analysis of COP

Here we have done the analysis of the Combined COP (Coefficient of Performance) of the both the Heat Pump systems together. The main reason for having directly taken into account the combined COP is because of the continuous change in the operating regimes of the system which in turn depend on the requirements in the building. The requirements in the building being irregular, the analysis of the combined COP seems to be logical.

A separate graph comparing the Carnot COP and the real COP has also been shown for every significant time period.

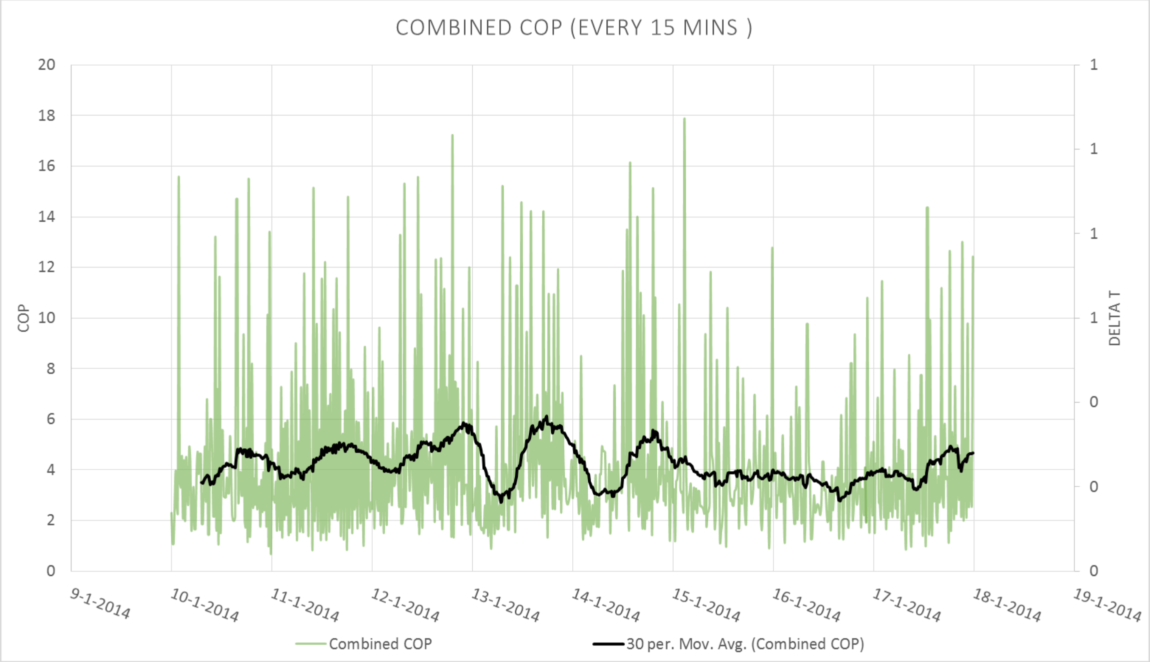

Figure 23 Graph COP (January)

We start with the behaviour of the system during the start of the calendar year.

In January, the requirements for heating load is quite high compared to the cooling load. The heat pumps run at full capacity trying to convert waste heat from the bore holes to usable heat in the building by trying to consume as low electrical energy as possible. Thus we can see that the average value of combined COP is around 3.7 which is a pretty considerable value for a heat pump system. [Ref: fig.23, 24]

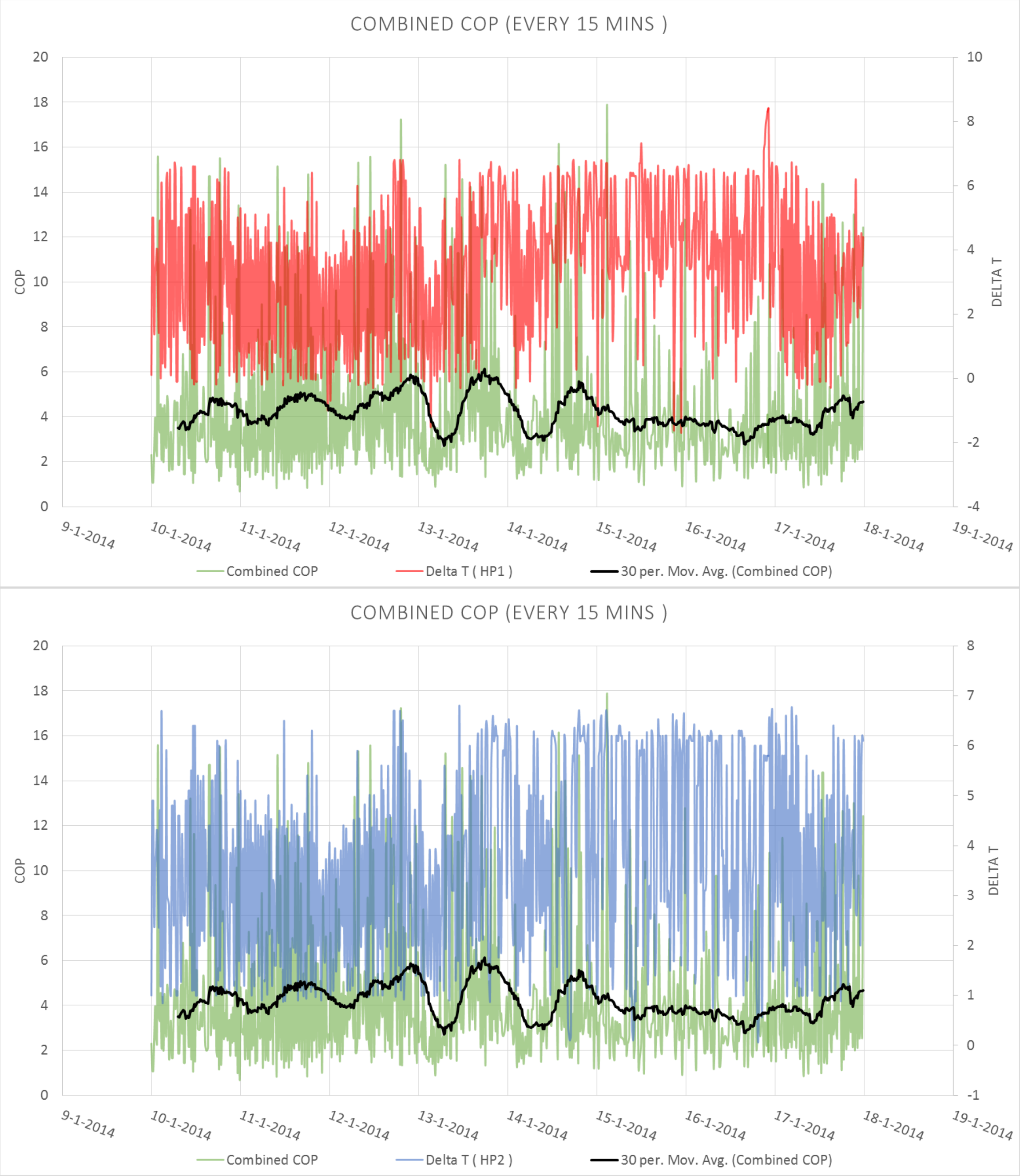

Figure 24 Graph COP with HP delta T (January)

We can simultaneously see the behaviour of the COP in relation with temperature difference across both the heat pumps. The temperature difference across the 1st heat pump is having a higher average than the 2nd heat pump. But the COP doesn't have adverse effect due to this as the average of both seems to be nearly equal. [Ref: fig.25, 26, 27, 28]

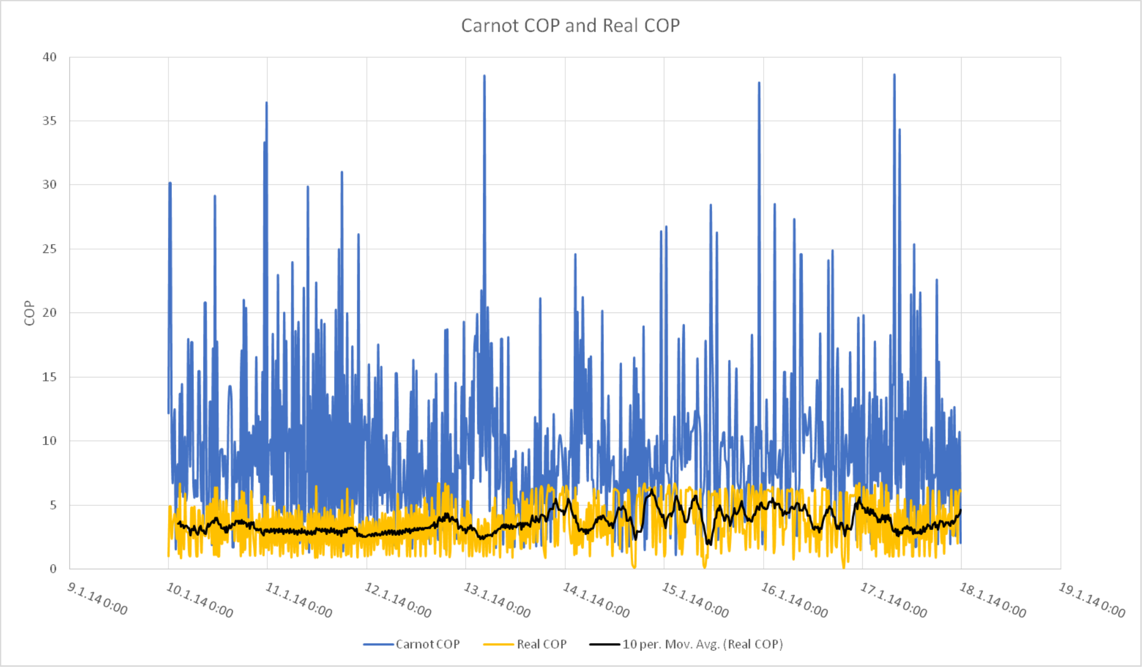

Figure 25 Carnot COP and Real COP

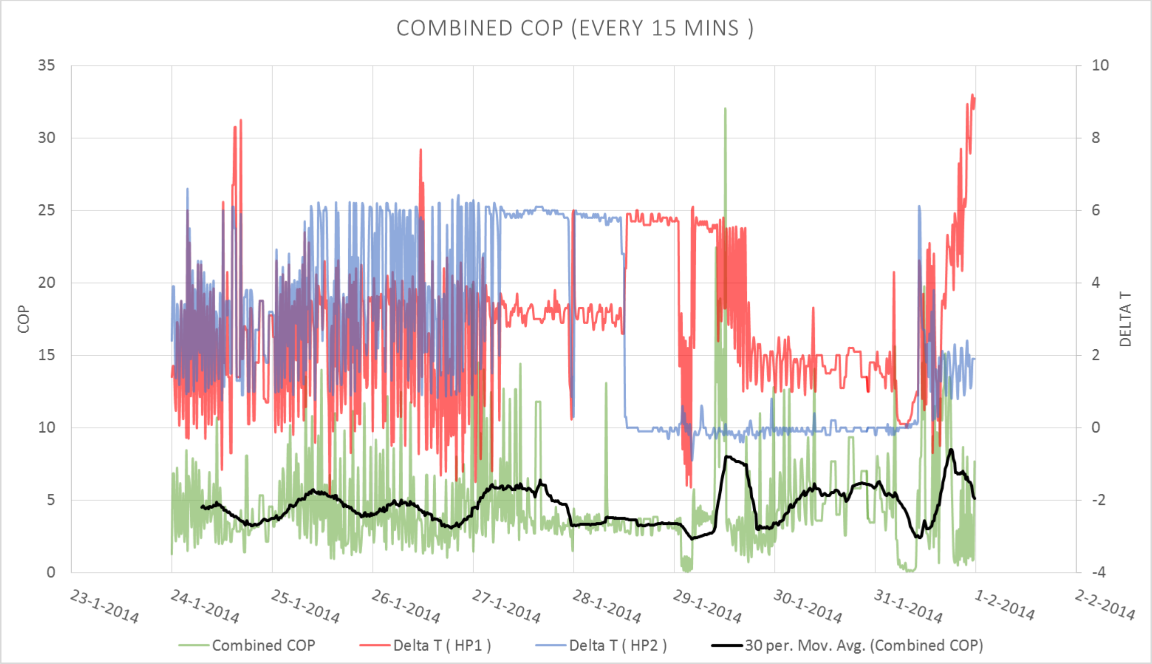

Figure 26 Graph COP with HP delta T (January)

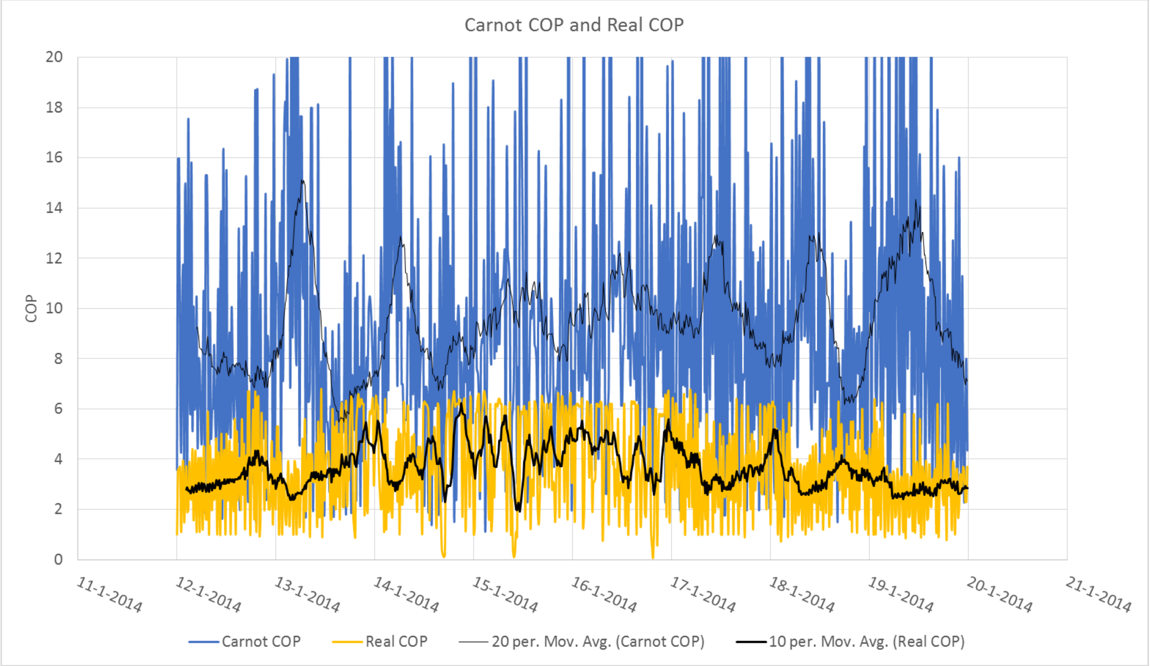

Figure 27 Carnot COP and Real COP

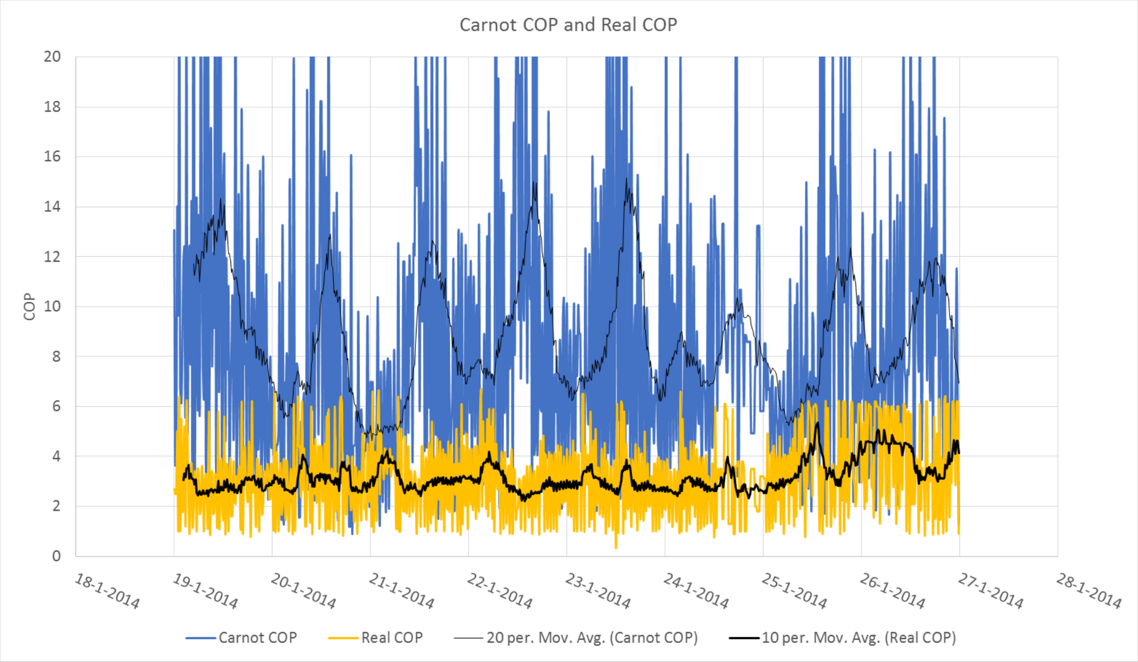

Figure 28 Carnot COP and Real COP

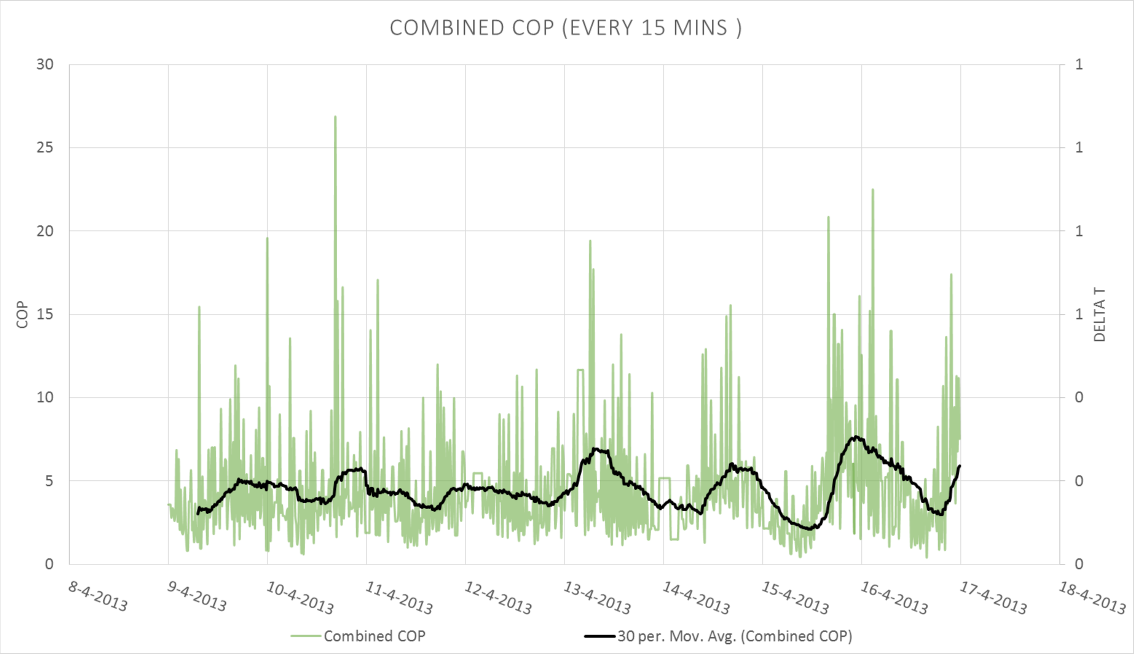

Figure 29 Graph COP (April)

As we come to March-April we can see constant fluctuation in the working regimes which results in the constant oscillation of the COP value. But the most important point is that the average value of COP is always maintained at a certain high value. When we compare the COP values with the temperature difference across the heat pumps we can observe that more the temperature difference lesser the fluctuations in the value of COP and vice versa. Lower temperature differences show higher COP and vice versa.

We can also see the most fundamental aspect of a heat pump that higher the temperature difference the lower the COP as high amount of electrical energy is required. This is so because higher temperature difference results in higher pressure differences thus resulting in higher amount of energy required to compress the fluid. [Ref: fig.29, 30, 31, 32]

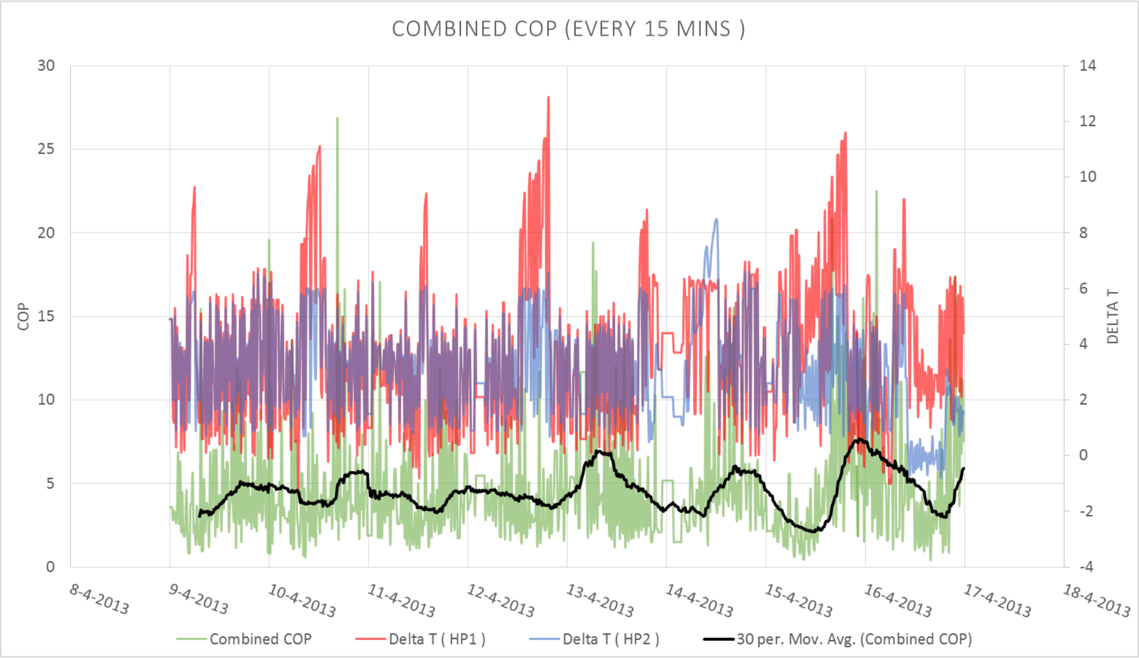

Figure 30 Graph COP with HP delta T (April)

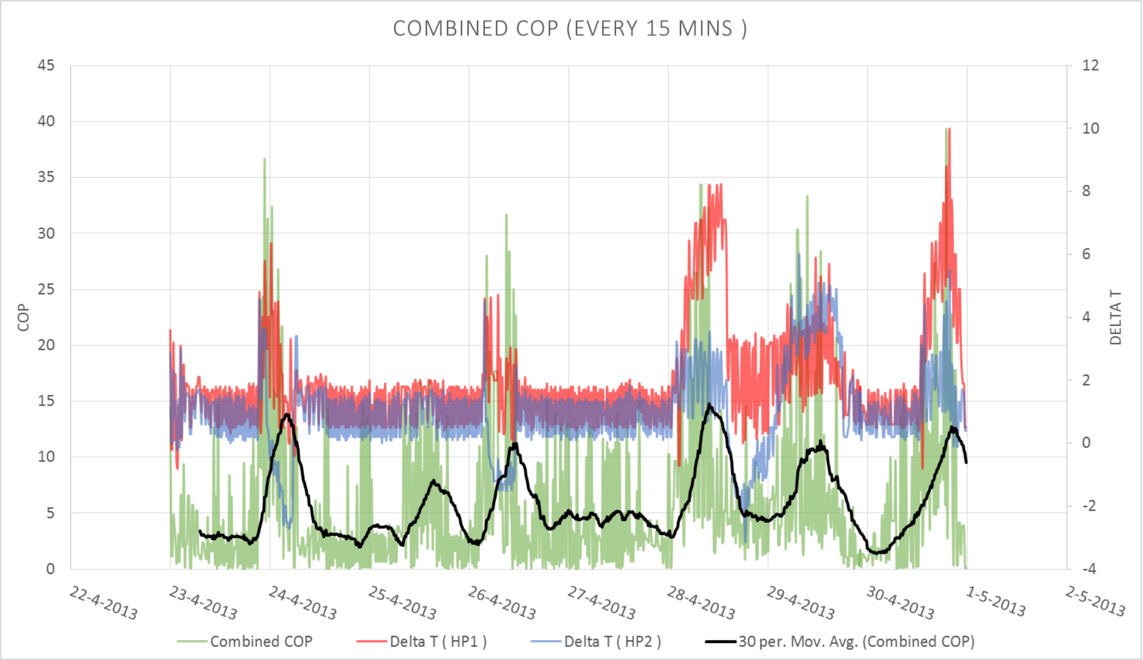

Figure 31 Graph COP with HP delta T (April)

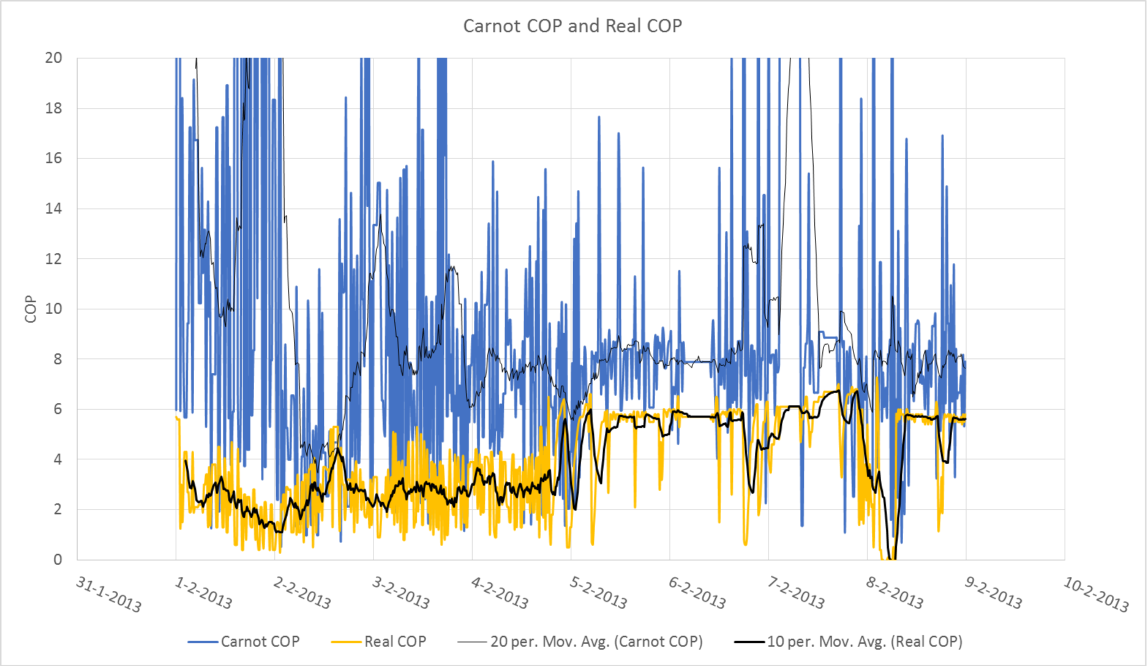

Figure 32 Carnot COP and Real COP

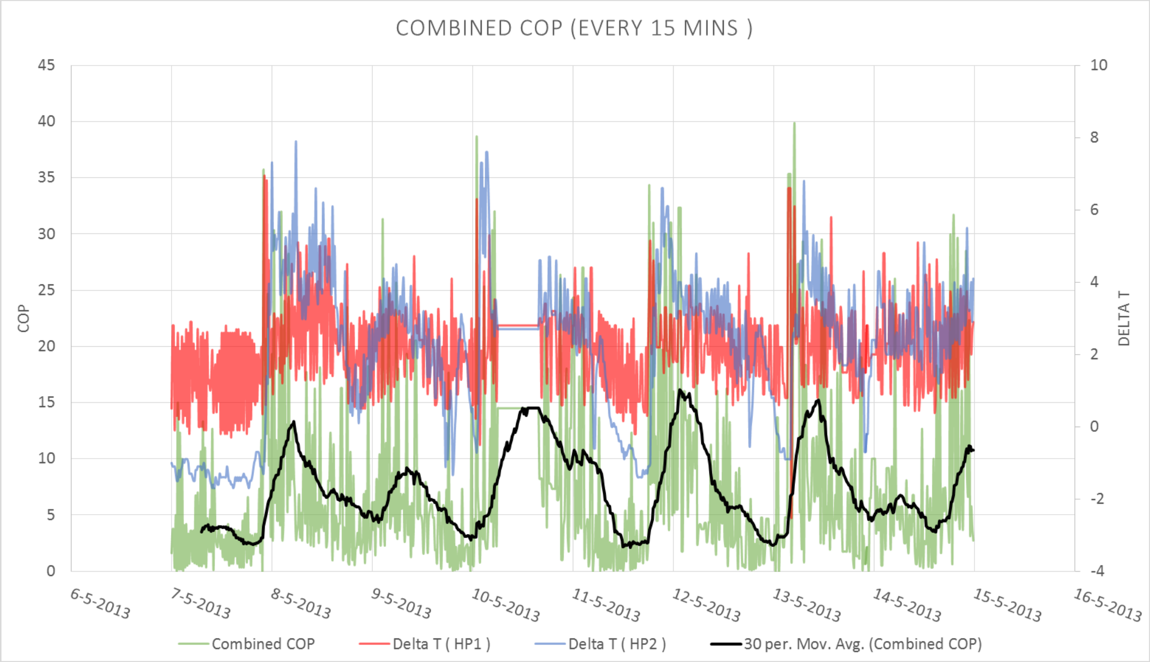

Figure 33 Graph COP with HP delta T (May)

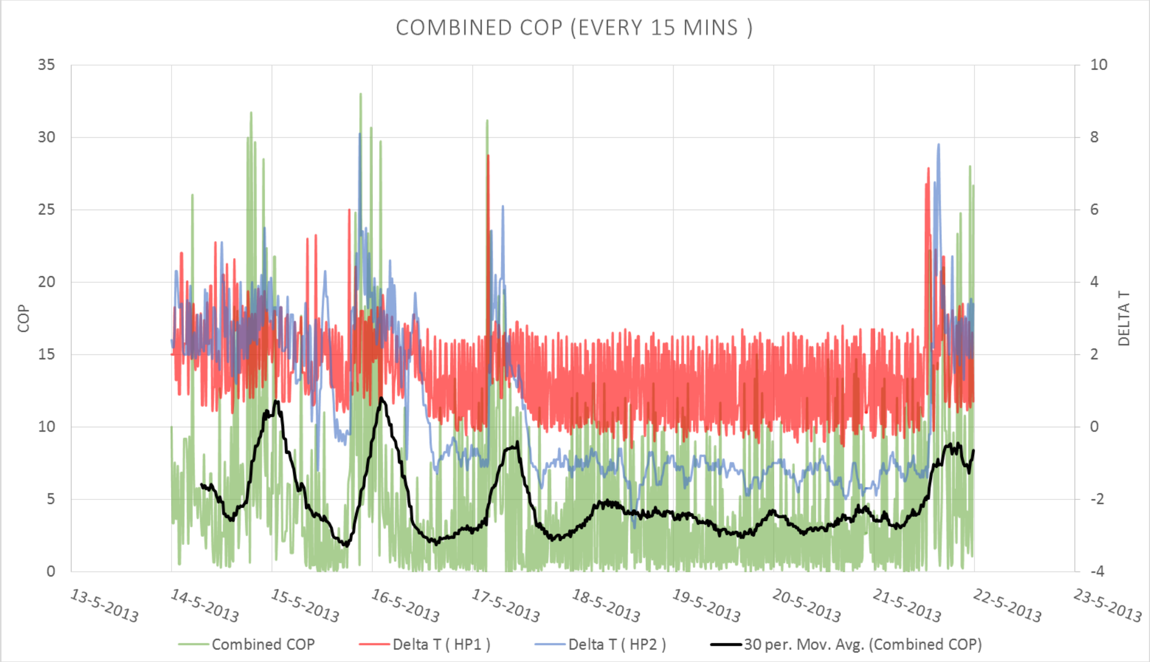

Figure 34 Graph COP with HP delta T (May)

As summer approaches we can see that the temperature difference in the one of the heat pumps is higher than the other. This is because probably one has been switched off and the free cooling mode is put into operation. The temperature difference across the one heat pump is quite low below 1 degree Celsius and the other pretty high at around 3 degree Celsius. [Ref: fig.33, 34, 35, 36, 37, 38, 39, 40, 41, 42]

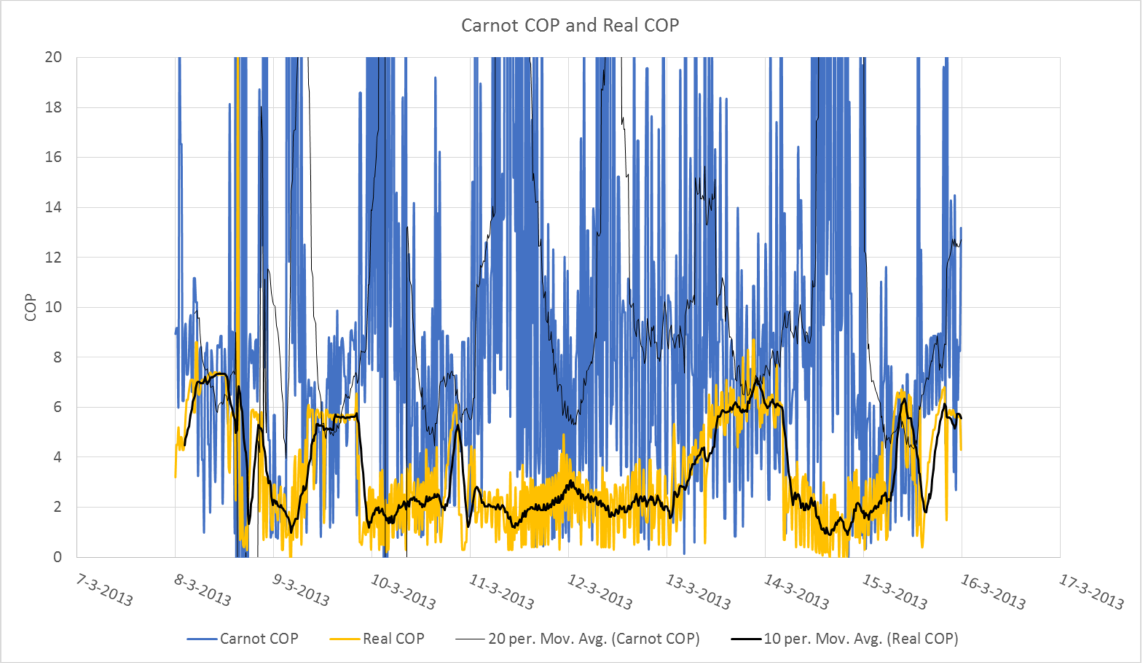

Figure 35 Carnot COP and Real COP

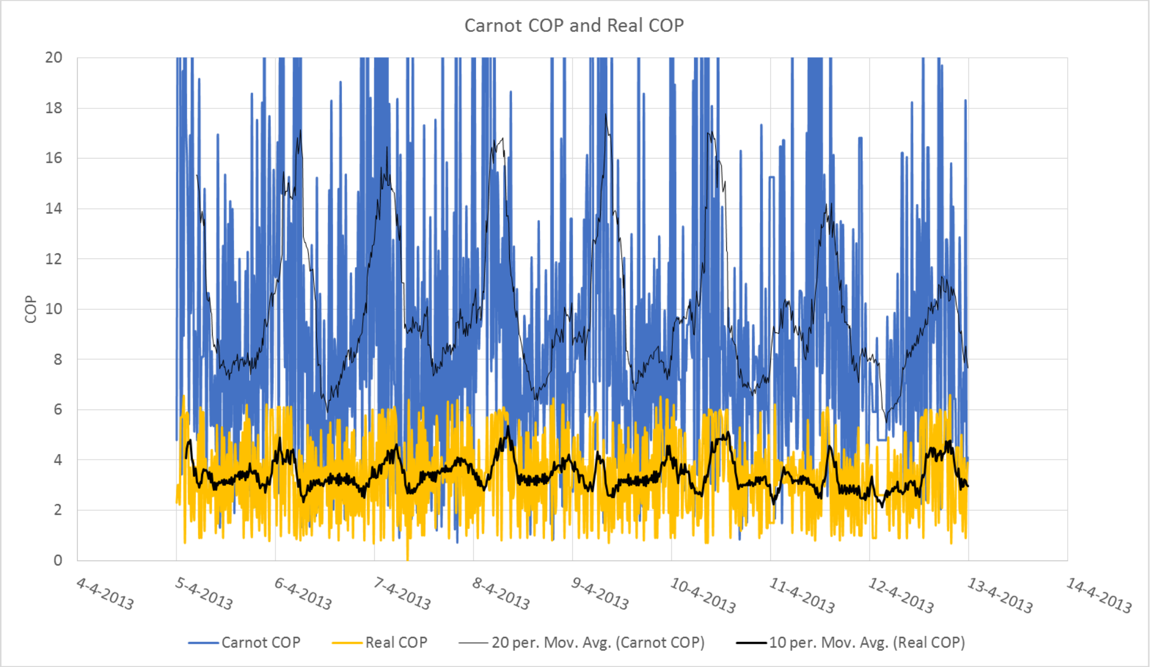

Figure 36 Carnot COP and Real COP

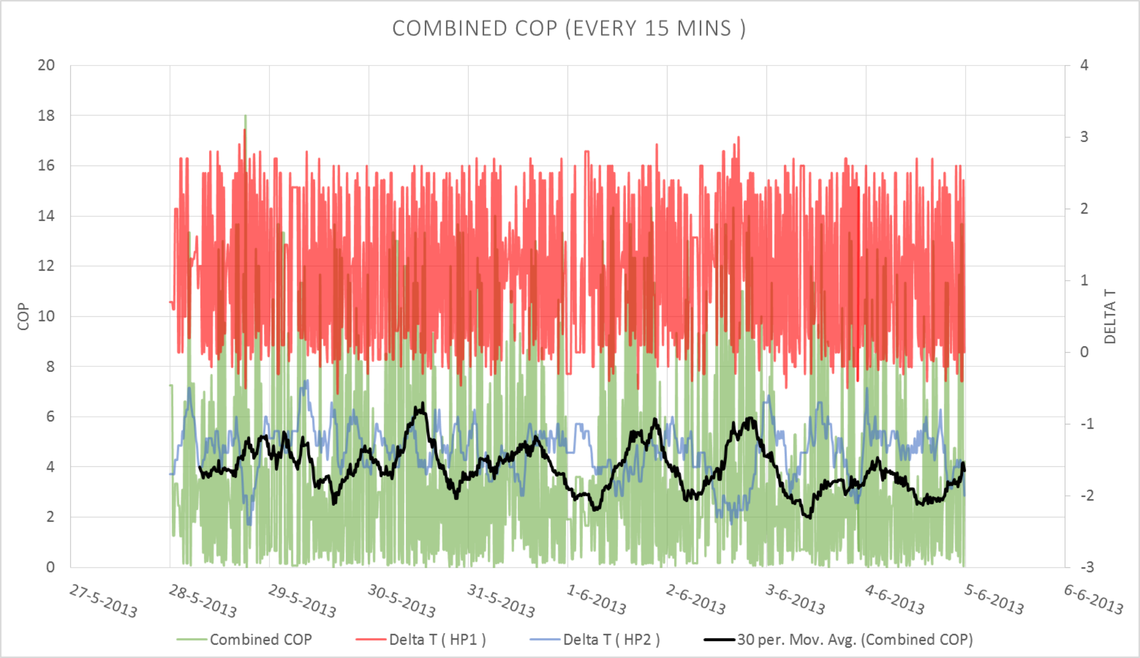

Figure 37 Graph COP with HP delta T (June)

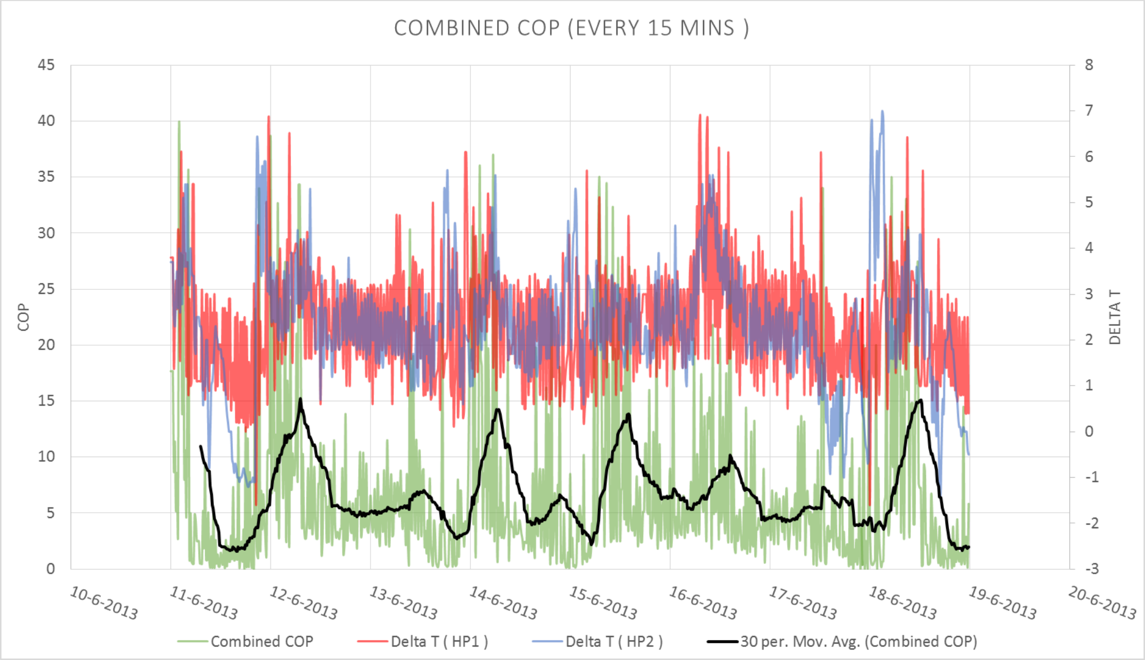

Figure 38 Graph COP with HP delta T (June)

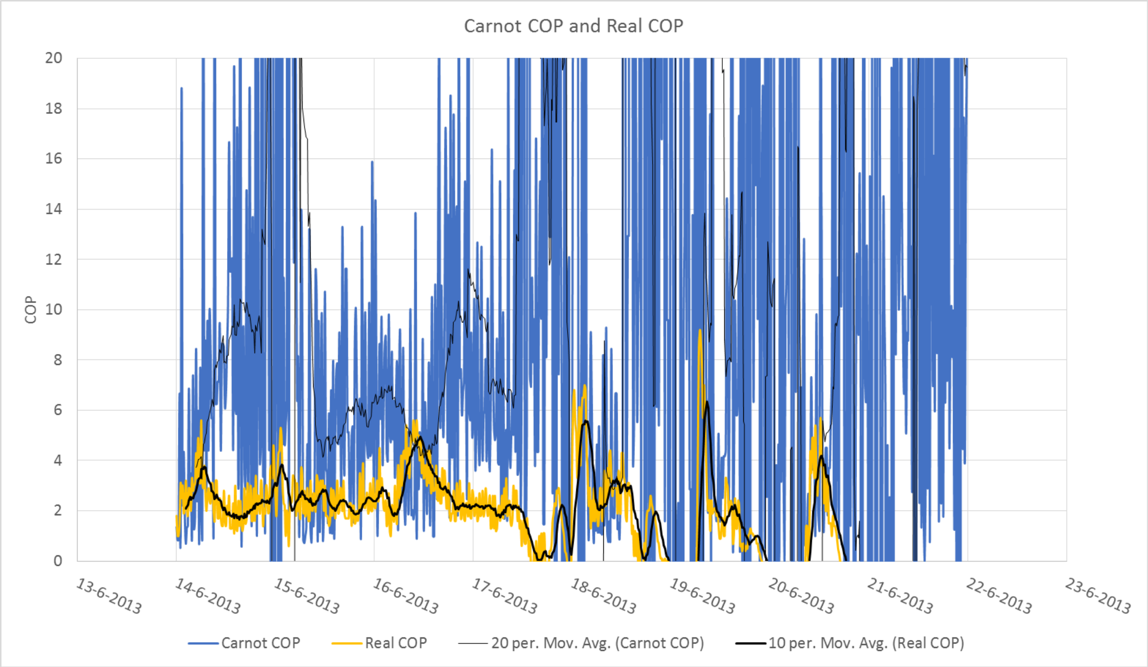

Figure 39 Carnot COP and Real COP

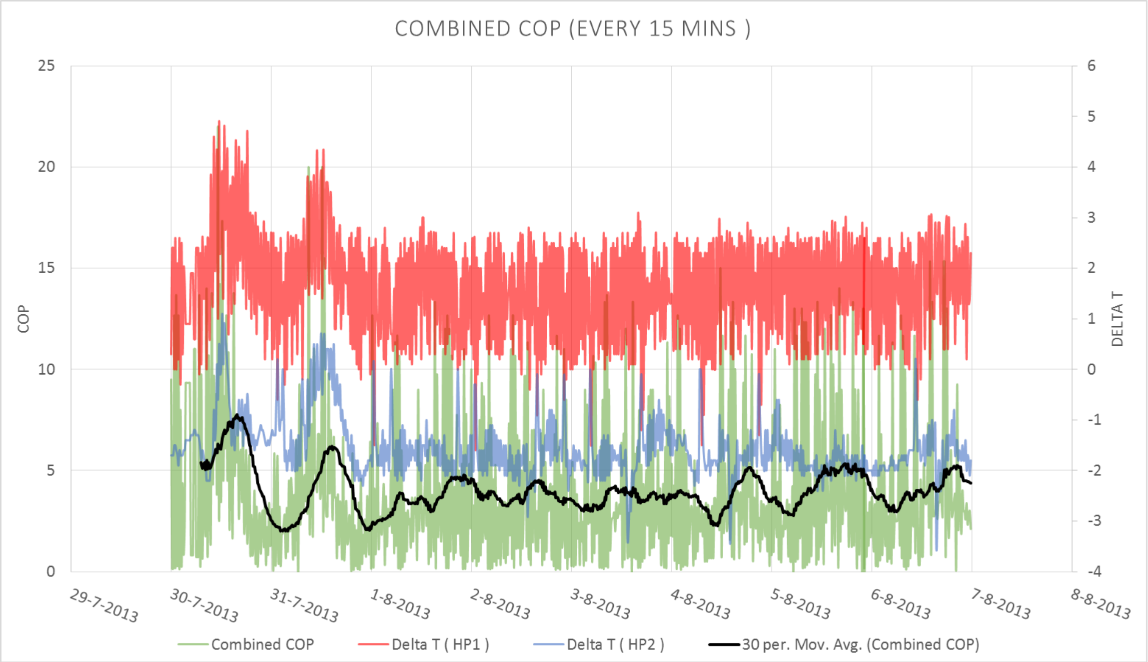

Figure 40 Graph COP with HP delta T (August)

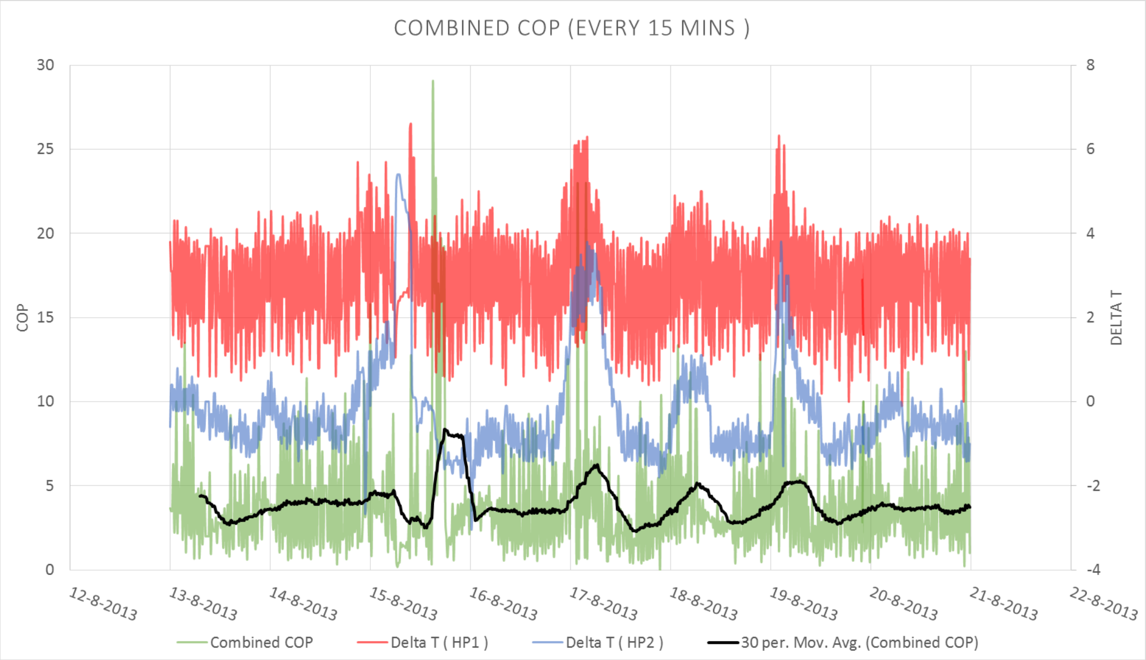

Figure 41 Graph COP with HP delta T (August)

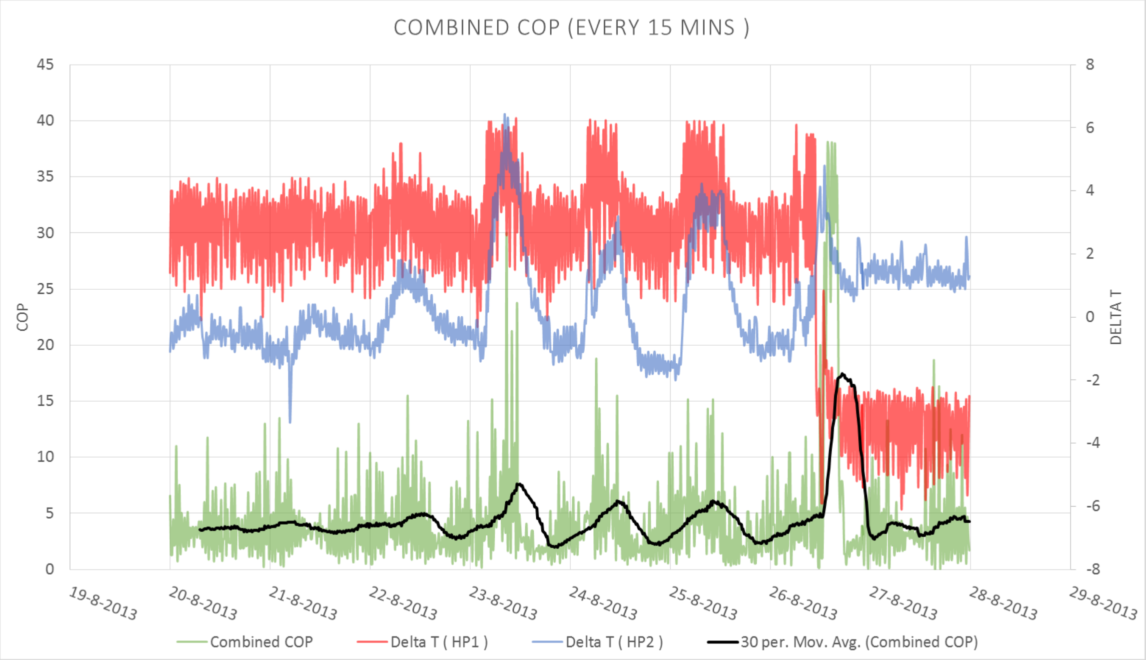

Figure 42 Graph COP with HP delta T (August)

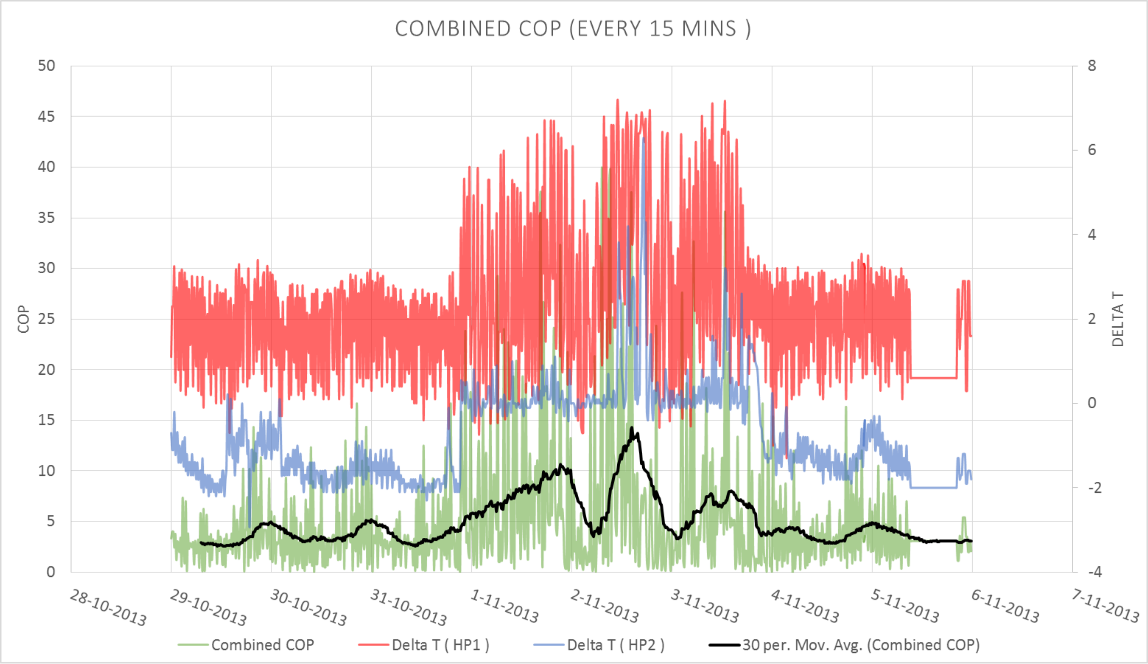

Figure 43 Graph COP with HP delta T (November)

These drastic changes in values also show to us that the waste heat has been used in the regeneration of the earth spike, that is waste heat from the heat pump is sent to the bore holes where excess heat is discarded.

This is also confirmed by the fact that we can also see a drop in the average values of the combined COP that one of the heat pumps might have been switched off or the free cooling mode is active. This is mainly done because of the reduction in the heating load requirements due to the rise in the ambient temperature levels of the environment.

As we approach the end of the year the ambient temperature levels begin to reduce of the outside environment. This also affects the working modes of the heat pump. The free cooling mode is reverted back to normal operating mode due to return of the heating load on the system and this is followed by the increase of the overall COP levels of the system.

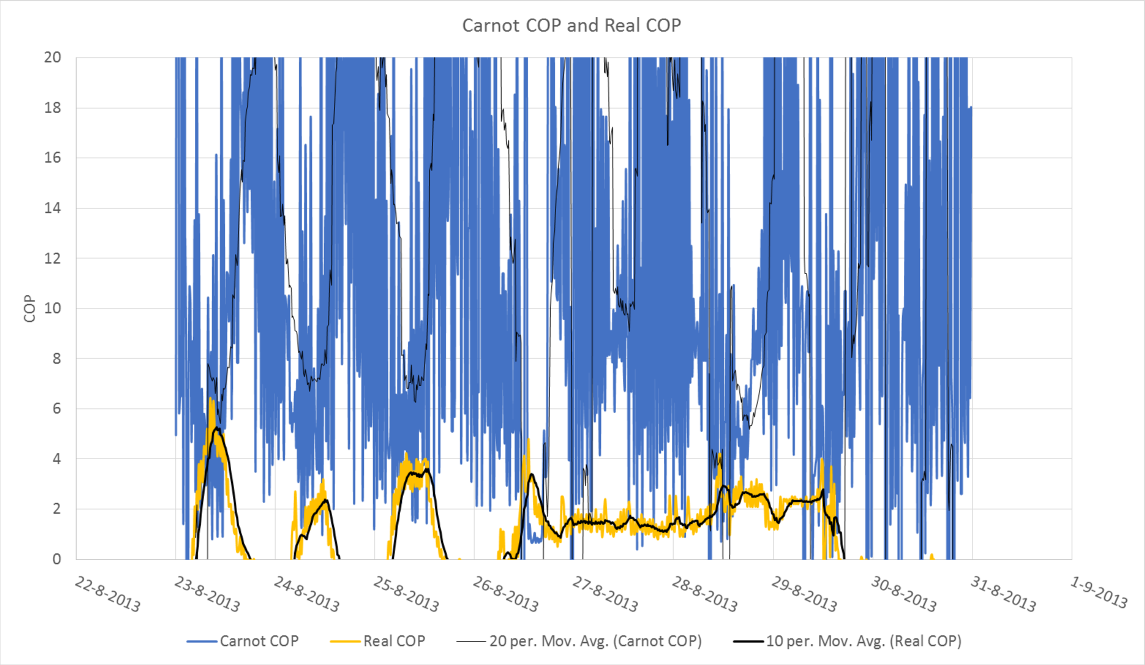

Figure 44 Carnot COP and Real COP

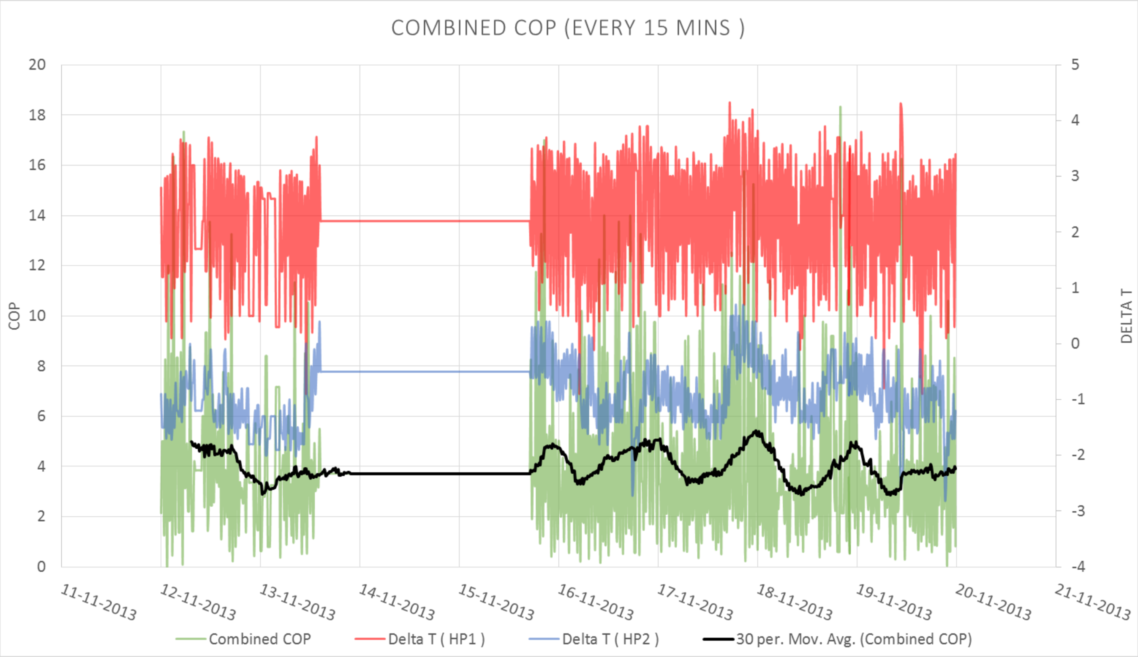

Figure 45 Graph COP with HP delta T (November)

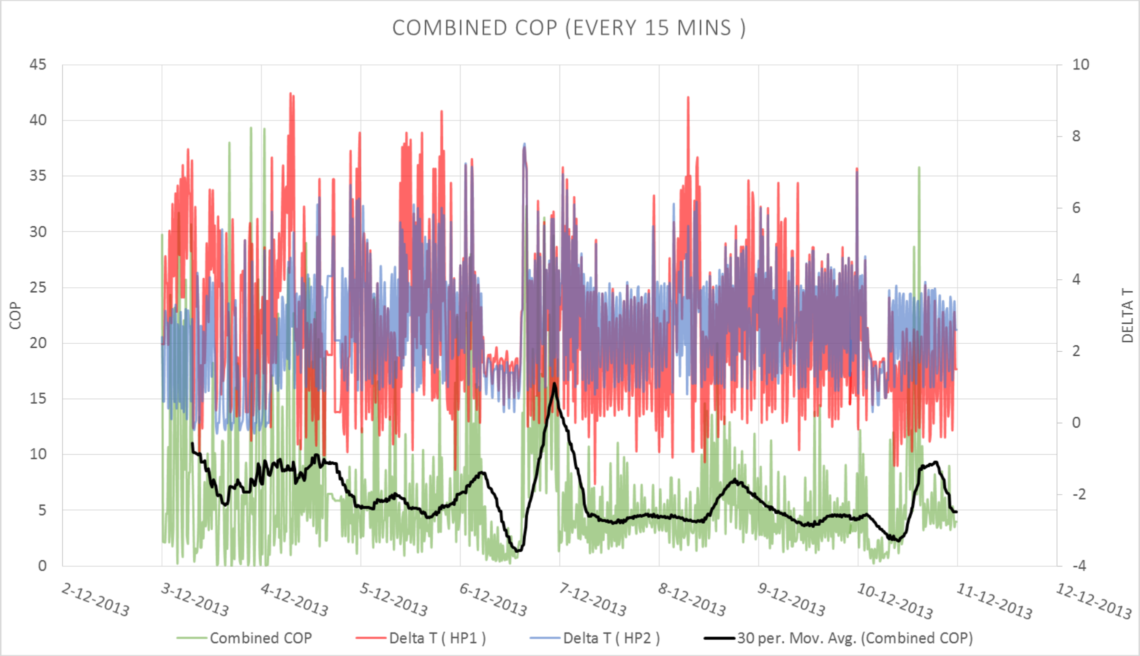

Figure 46 Graph COP with HP delta T (December)

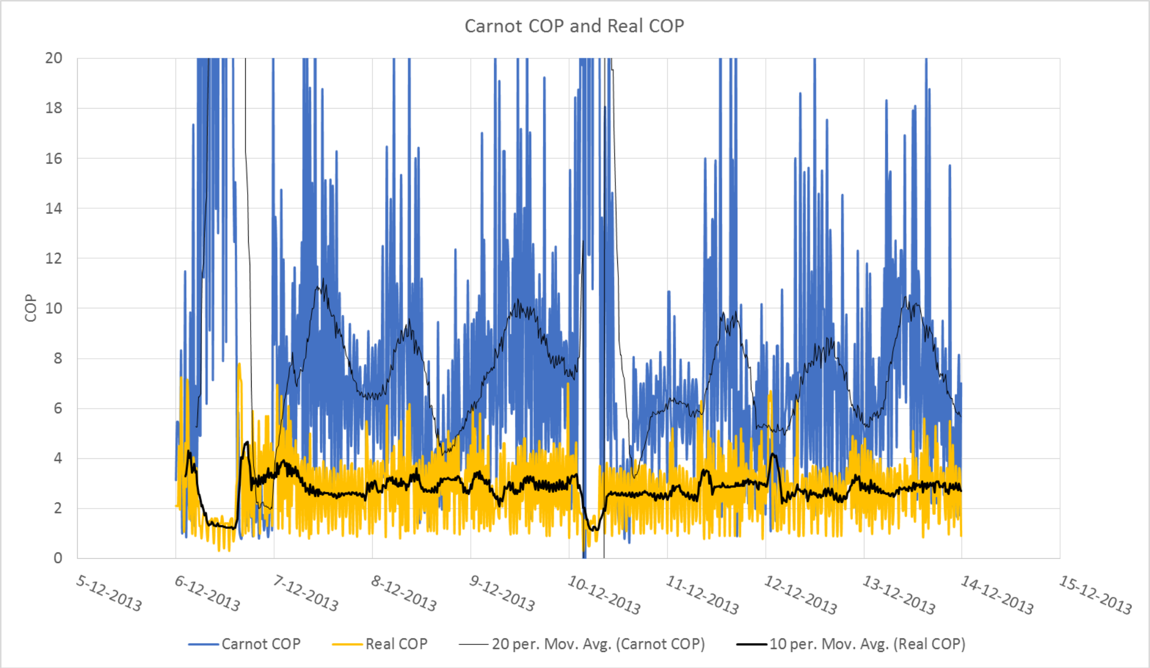

Figure 47 Carnot COP and Real COP

We can conclude our analysis by saying that higher values of COP are observed when both the heat pumps are running together. Usually one of the heat pumps is switched off only during low requirement in the building or the energy available is far higher than the energy required. Free cooling mode is a pretty advantageous mode considering the regeneration of the underground thermal gradient by letting out the waste heat from the system into the boreholes. [Ref: fig.43, 44, 45, 46, 47, 48]

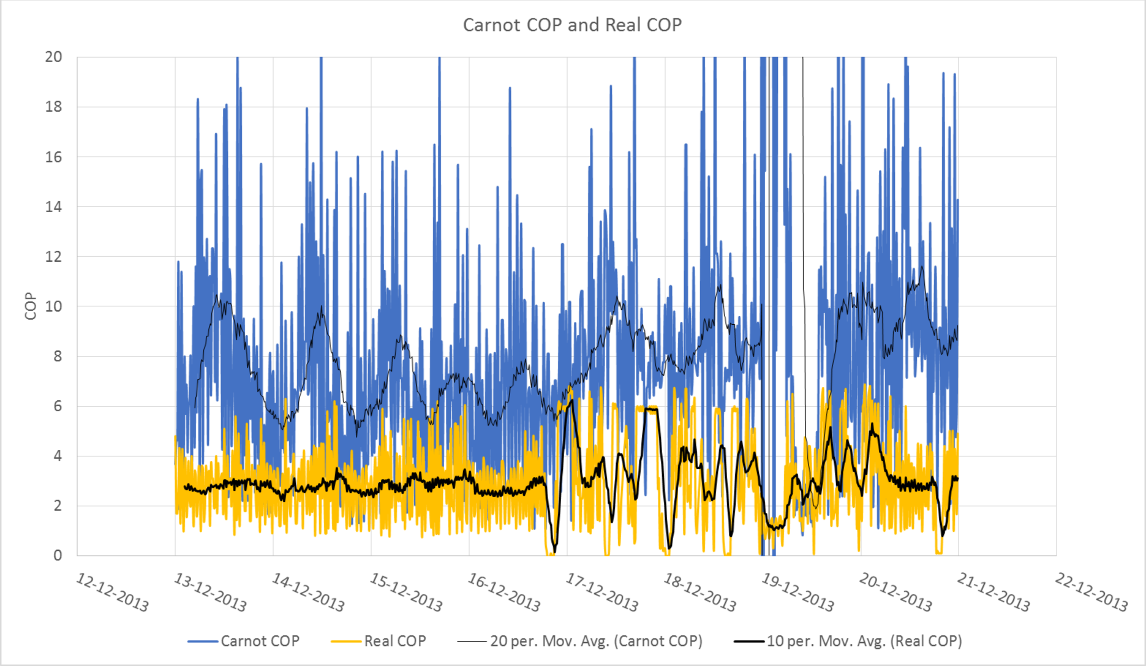

Figure 48 Carnot COP and Real COP

9. CONCLUSION

There are many important conclusions which can be drawn from the Thesis. The most important of them are as follows:

The value of COP realized in the system throughout the operating time is considerably on the higher side compared to an average Heat Pump system. The overall average for the system for two years of operation comes out to around **3.39** which is pretty high. The comparison with the given data provided by the control company is 3.33.

The monthly averages of the heat pumps show that the COP is higher during the winter compared to the values achieved during the summer by a considerable amount. This is mainly due the working of the Heat Pump for both Heating and cooling together during the winter season whereas only for cooling during the summer. Thus we can say that Heat Pump systems are good especially for the systems where heating and cooling is required simultaneously for longer periods of time.

Another point which also be observed is the dependence on the Carnot cycle. Although the Ideal COP values according to the Carnot cycle are pretty high but the behaviour of both the Carnot and the ideal COP values seem pretty much the same.

Some recommendations to the functioning of the Heat pump system for better COP values would be the use of low temperature heating during winter. Because sometimes due to very low outside temperatures the heating requirements are very high and it has to be heated till 90°C, the heat pump system should be used to heat till around 55°C and the rest should be heated by boiler or heater.

The other recommendation would be the reduction in the frequency of changing the regimes of operation of the system. Reduction in the intermittent switching would result in higher values of COP throughout. The operating range should also be maintained at average values.

Use of waste heat for the regeneration of the earth spike (summer mode).

The above point has been proved especially during the summer when the heating load is radically reduces. Therefore only cooling load is acting on the system. This is taken care of with the help of free cooling mode. But there is still some excess heat left in the system and this is used to recharge the boreholes by sending the waste heat into them.

Use of waste heat for heating buildings (winter and transitional regime).

This is one of the main advantageous point of any heat pump system especially geothermal. The waste heat from underneath the ground produced due to the temperature gradient is converted to usable heat with the help of the heat pumps. And then this converted energy is used to heat the building. Maximum utilization of this process is observed during the winter season when there is very high heat load plus the abnormal cooling load in the building for experimental purposes.

Overall we can say that this analysis has helped us understand and reinforce the knowledge regarding the fundamental aspects of a Heat Pump system by studying it in its Grass root level.

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11. Appendix

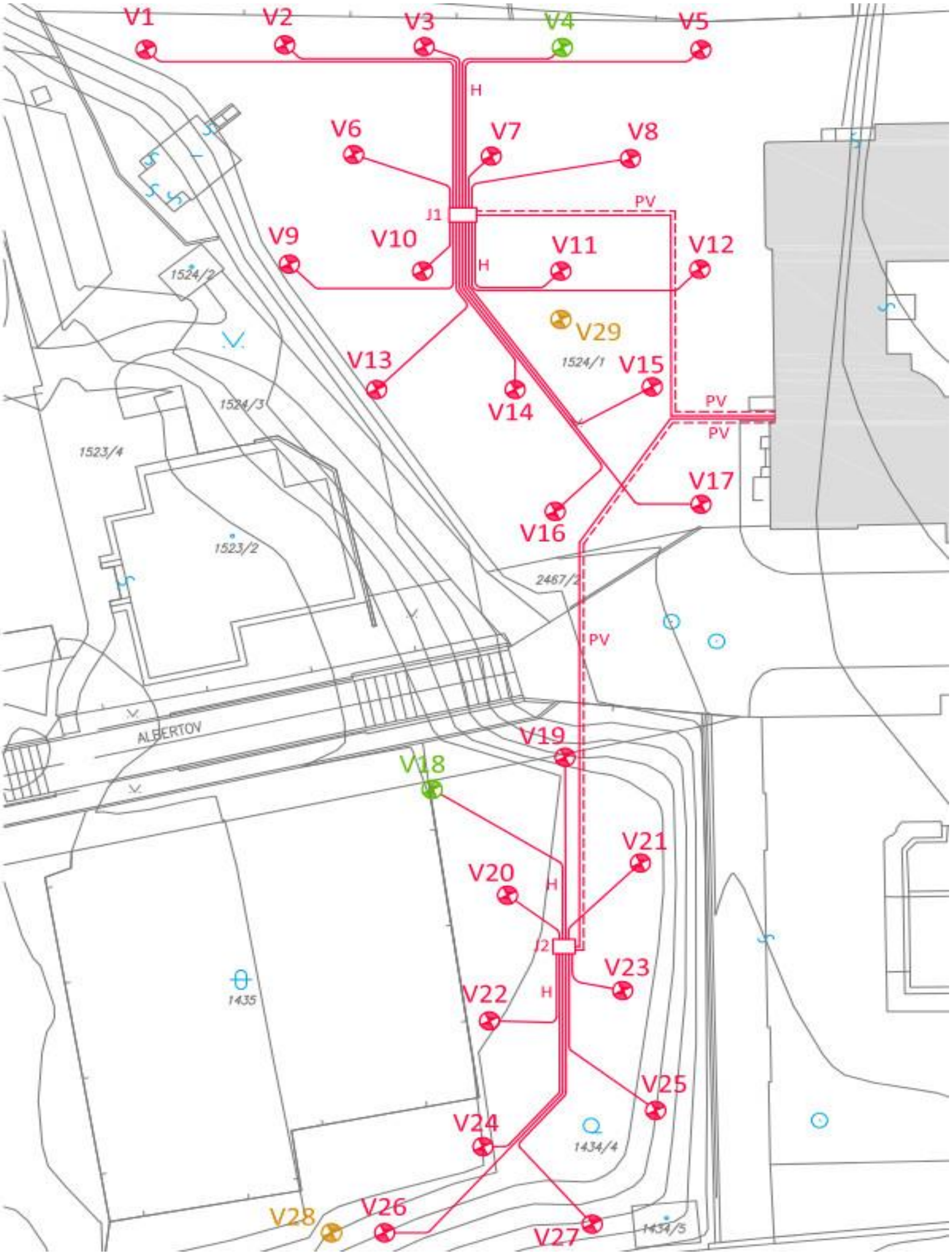

Figure 49 Location of Bore Holes

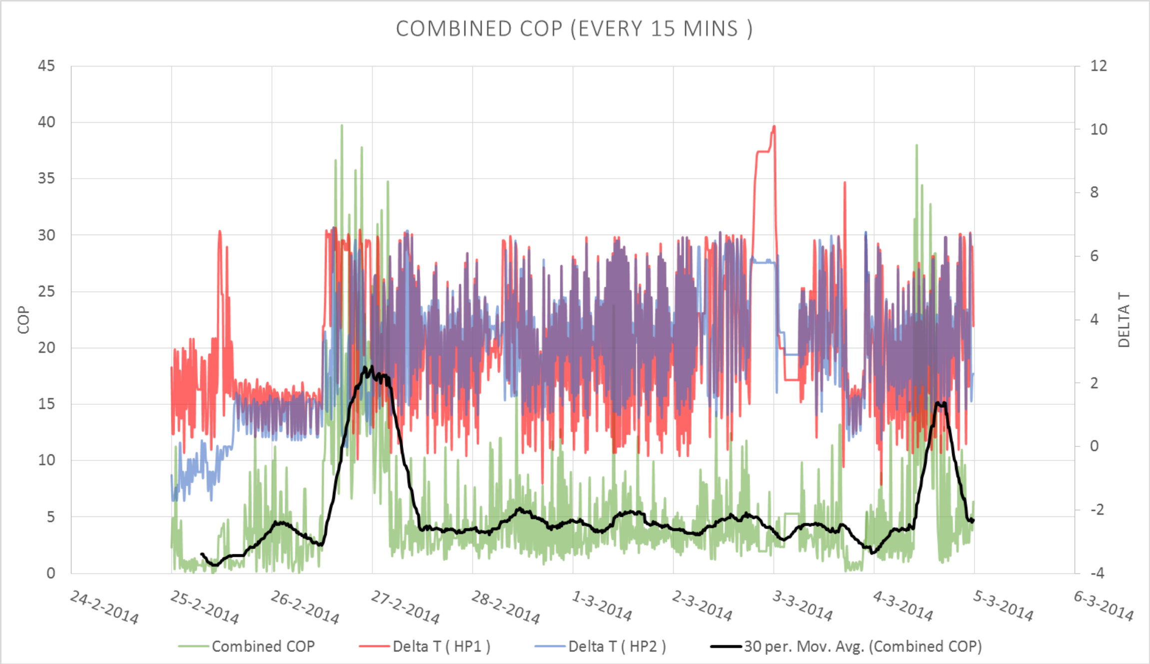

Figure 50 Graph COP with HP delta T

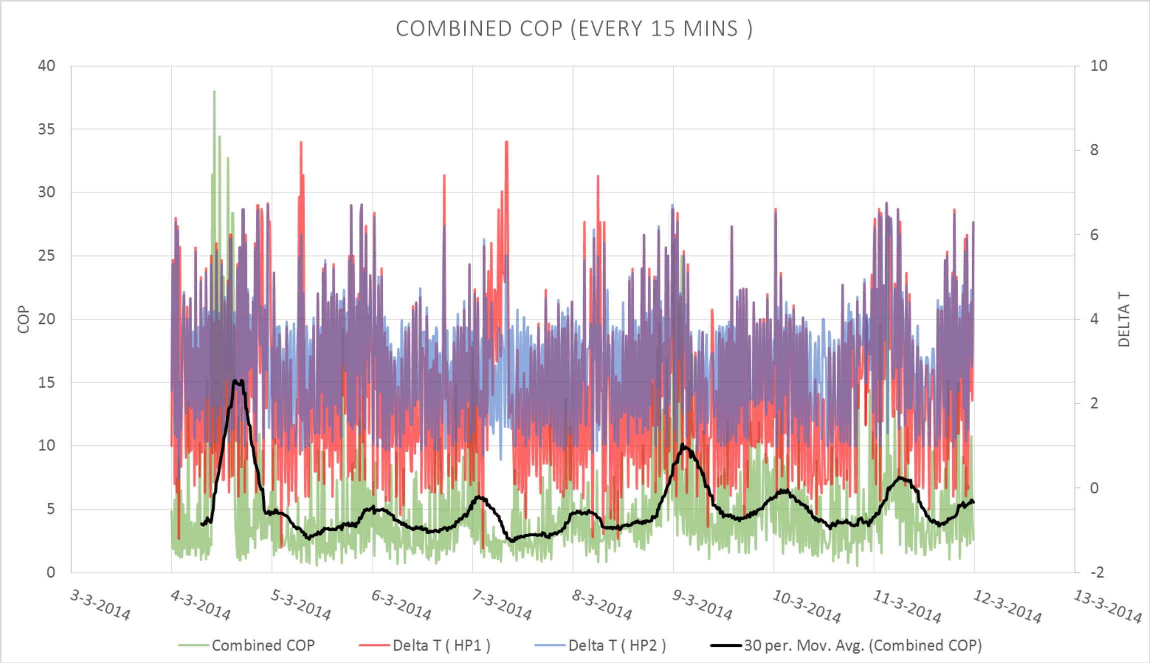

Figure 51 Graph COP with HP delta T

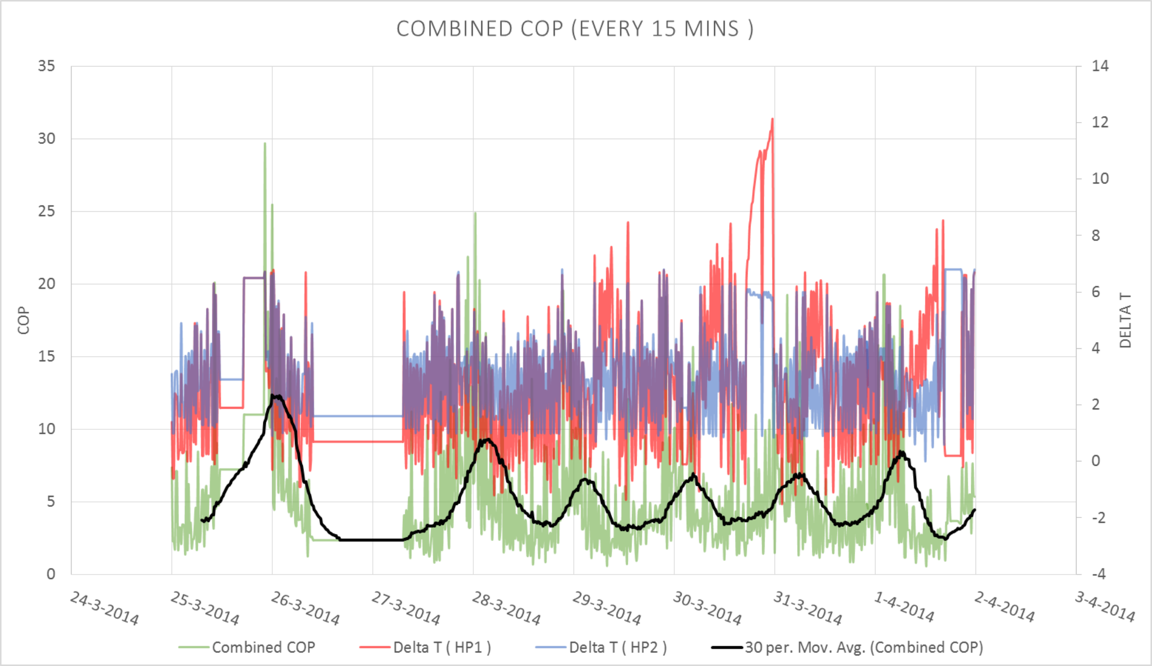

Figure 52 Graph COP with HP delta T

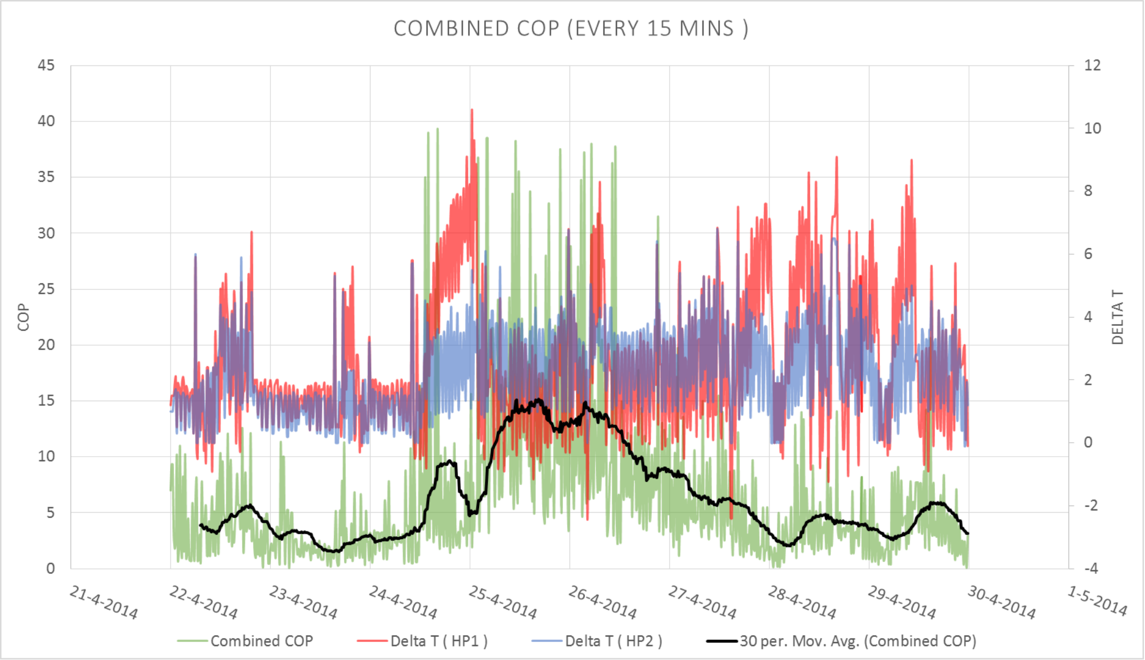

Figure 53 Graph COP with HP delta T

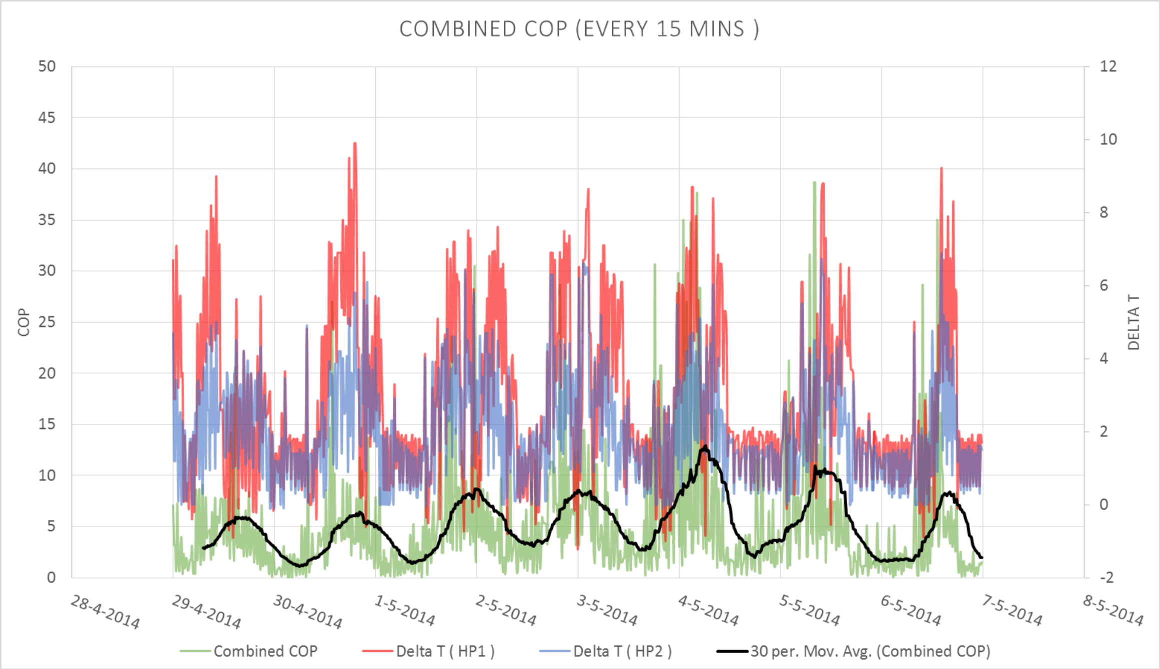

Figure 54 Graph COP with HP delta T

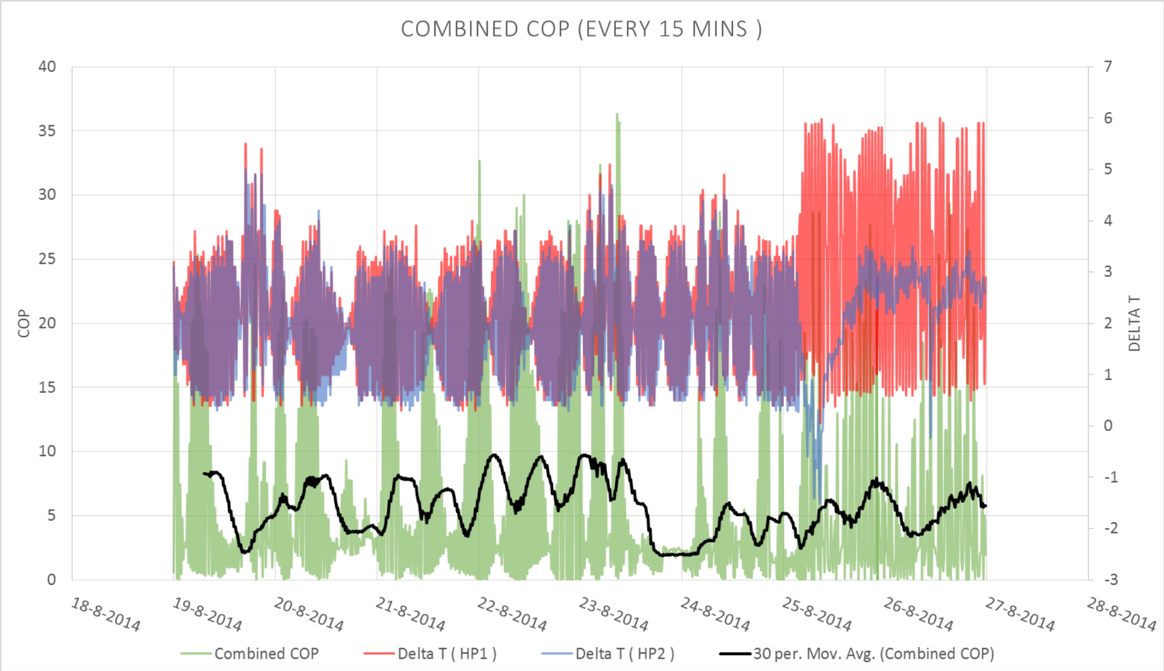

Figure 55 Graph COP with HP delta T

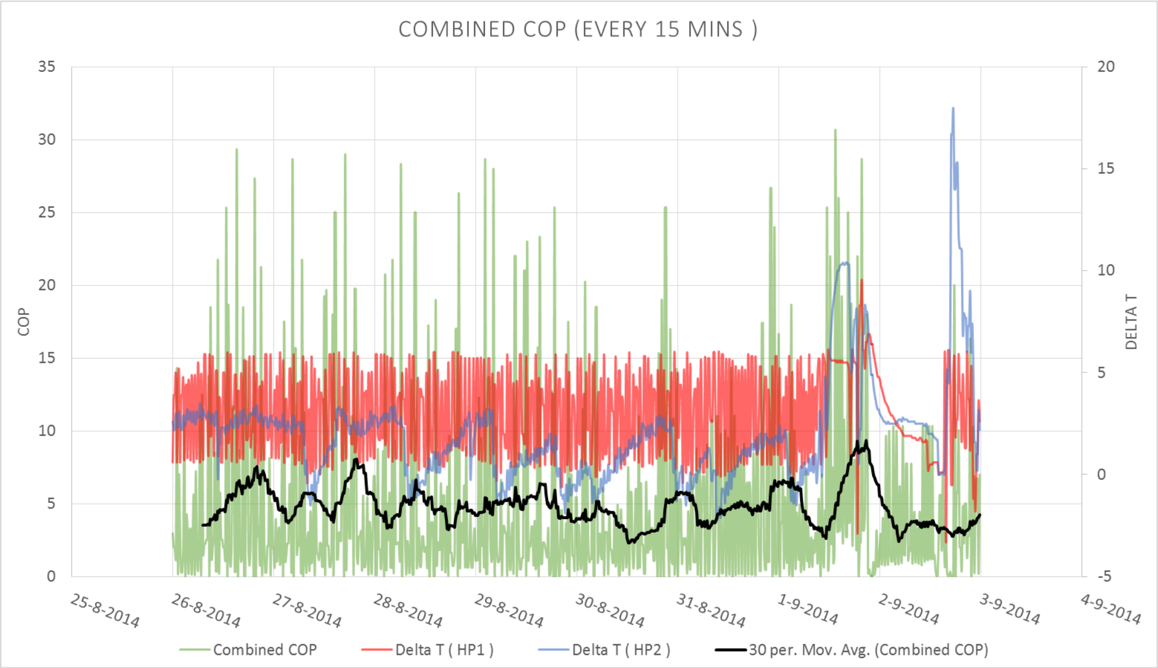

Figure 56 Graph COP with HP delta T

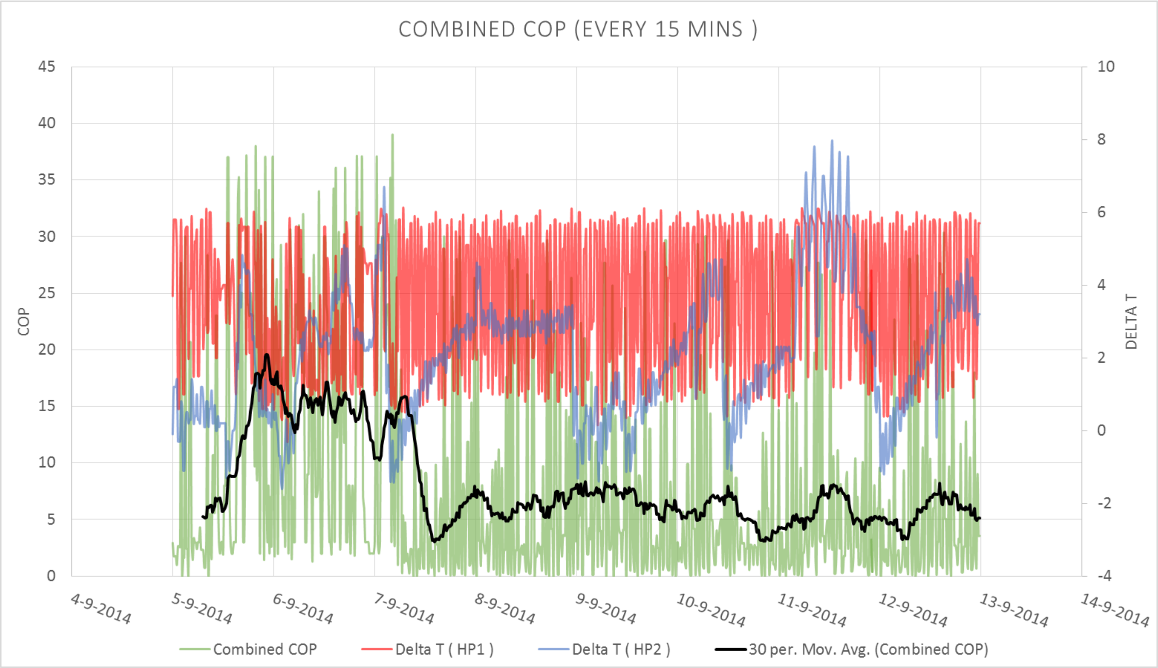

Figure 57 Graph COP with HP delta T