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Magnetic Resonance Imaging facility planning

Climate conditions versus image quality

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PREFACE

Magnetic Resonance Imaging (MRI) system is a powerful tool for imaging purposes. MRI is able to show soft tissues better than any other method. It does not emit ionizing radiation, which is harmful for humans. For example X-ray systems and gamma-ray cameras are based on radiation. MRI´s only disadvantage is time: MR scanning takes more time than for example X-ray based Computed Tomography (CT) scanning. That is why it is very important that MR scanning´s efficiency and usability are optimal. It is superseding ionizing imaging systems and the number of MRI systems is increasing quickly. MRI systems can be found in many different settings ranging from university and regional hospitals to private clinics and even truck containers in order to have an MRI system in places where there is no fixed systems.

This study´s purpose is to help plan better facilities for MRI systems and their users. It aims to show in practice what good planning means for the image quality of a hospital or a clinic by presenting examples of the MRI systems that are suffering bad climate conditions and therefore bad image quality. The study is done for my employer Philips Oy, but it is also of use in planning MRI systems that use any other brand´s technology as well. Outcome of this study is this thesis.

I would like to give big thanks to all the people close to me who got me going and pushed me forward with this study. Special thanks to my inspirational instructor OM Janne Vanninen, colleagues, senior MR expert Markku Arola, Longterm RSE Timo Koistinen, highly skilled SDM Kimmo Saarela, all lecturers, especially Mikael Soini and Ville Jääskeläinen. Big thanks also to my wife Karina Musakka and my whole family, for all their support (especially to Sampo Saari for extreme fast language check), time given for working and silence when needed. I am grateful!

In Nurmijärvi, 24-April 2020
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Magnetic Resonance Imaging (MRI) is a sensitive imaging method. Radio Frequency (RF) disturbances and local climatic conditions together can destroy image data. MR scanner is installed in a special room called RF room. An RF room needs specific climatic conditions to ensure good image quality performance and patient comfort during imaging.

The study is divided into a theoretical part and a practical part. The theoretical part focuses on explaining MRI system´s operating principles, components and needs. The typical site layout and challenges of planning are also described in the theory part. The practical part goes thru data collecting, sorting and analyzing. After analyzing, conclusions and suggestions are given as an outcome of the study.

The study is done to clarify issues with climate conditions in hospitals and clinics, which can cause image quality issues if climate conditions are not in manufacturer's recommendation. Climate condition is wide entirety. The study focuses to relative humidity and its correlation to image quality performance.

Image quality problems are one of the most affecting issues for imaging department patient workflow. Issues with workflow are causing longer patient queues. Long turnaround has financial affect for clinic/hospital as well. Therefore, it is important to prevent those incidents, which are caused by facility climate condition functions.

Data was collected from five existing MRI systems. Collected anonymized data was analyzed. Data-analysis show correlation with relative humidity and image quality issue clearly. One of the systems´ climate conditions was so bad that images were not diagnostically valid. On the other hand, the reference system has its climate conditions within specification and no image quality issues were occurred.

MRI manufacturers have self-explanatory specifications for MRI system environment. On MRI facility planning phase these are easy and cost-effective to take care of. This small investment on planning/construction phase saves a lot of money thru MRI system life cycle.

Keywords	MRI, climatic conditions, department, planning

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List of Abbreviations

ACR	American Community of Radiology
CMD	Command Prompt
CT	Computed Tomography
dB	Decibel
ECG	Electrocardiogram
ESD	Electrostatic Discharge
g	Gravity (acceleration)
G	Gauss
HIS	Hospital Information System
Hz	Hertz
IQ	Image Quality
m	Meter
MB	Megabyte
MR	Magnetic Resonance
MRI	Magnetic Resonance Imaging
NMR	Nuclear Magnetic Resonance
PACS	Picture Archiving and Communication System
PCB	Printed circuit board
QPI	Quality Performance Index
R&D	Research & Development (department)
RF	Radio Frequency
RMS	Root Mean Square
RX	Receiver / Receiving
RIS	Radiology Information System
SRN	System Reference Number
T	Tesla
TE	Time Echo
TR	Repetition Time
TX	Transmitter / Transmitting
V	Volt

1 Introduction

The Nuclear Magnetic Resonance (NMR) phenomena was discovered by Bloch and colleagues at Stanford University and at Harvard by Purcell and coworkers in 1946. After that, the phenomenona was quickly adapted to medical applications. Within thirty years after its discovery, magnetic resonance principles were used to acquire the first images of a human subject. When the first superconductive whole body imager was created, it was quickly recognized that an Magnetic Resonance Imaging (MRI) system could produce images with soft tissue contrast superior to that obtained by other imaging techniques. In the past decades, MRI has become a very popular method in clinical diagnostic imaging. [1]

This study will focus on strong field magnets, which means field strength from 1.5 Tesla (T) up to 3.0T. Today an MRI system can be found in every university hospital, almost all local hospitals and in many private clinics. The number of MRI units in 2017 (per capita) in Finland is in the top three in the European Union. [3]

MRI can be used for imaging several different kinds of objects in human body. MRI can provide its best benefits with soft tissues and its use is growing. Soft tissue means for example brain, joints, vascular system, etc. Typically an MRI scan takes 10-15 minutes. Patient load in hospitals is big, so it is important to get good images for diagnostic at the first time. There are two major reasons why images are not good enough. First, the user has scanned a wrong area or from a wrong direction. Second, the image quality (IQ) is not good enough. This IQ issue in MRI system environment is the subject of this study. There are climatic factors which affect IQ. Most of these “climatic caused” cases can be handled by MRI system error detection and correction, but if conditions at site are totally off manufacturer’s specification, image quality issues are bound to arise.

Background of case company Philips Healthcare

The case company in this project is Philips Healthcare. It is an international company specializing in providing products and services for commercial and government customers in the field of medical imaging systems, patient monitoring and household products. The company was founded in 1891 by Frederik and Gerard Philips, and the headquarters is located in Amsterdam, the Netherlands. Company revenue was 1.1 billion euros

in 2018 and the worldwide number of employees is around 77400. In Finland, Philips Oy was founded in 1924 in Helsinki. The first article was lightbulbs, but during the1920s, Philips Oy started to import radios and televisions. Nowadays Philips has its sales and marketing office and Research & Development (R&D) department in Vantaa. [5]

Philips Oy, one of the subsidiaries of the parent company Koninklijke Philips N.V., has ordered this study. The offices of the Finnish subsidiary are located in Vantaa, Tampere and Oulu. The number of local employees is 166, consisting of administration, technical support, service and sales professionals. The product portfolio of Philips Oy is the same as that of the parent company.

Technology and business problem

MRI system environment challenges are causing image quality problems for customers and they generate workload for the company service organization even though the customers are responsible for the climate conditions in hospitals and clinics. For most cases, the reason for bad IQ is clear and easily correctable. Correlation between image quality and climatic condition challenges will be shown in this study. Productivity and fluency are highly valued, but both suffer if the facility is not well maintained. The reliability and quality of the imaging system are ranked high. The system needs to produce excellent image quality all the time without interruptions, regardless of whether they are caused by the system or by the environment. Using the system out of specified climate conditions can cause not only image quality issues as mentioned earlier but also more frequent system breakages. [9, 14]

Research question, scope and structure of the study

This study aims to help users to ensure that their MRI system facilities´ usability and efficiency are on the best level. To address this issue, the study adds to the knowledge of challenges with correlation of climate condition and image quality. The precise objective of this study is to analyze real data, search system events and produce suggestions based on the findings. The contribution of the study is to increase knowledge of typical issues with MRI facility climate conditions, what can happen if recommendations are not followed and how to avoid issues.

This thesis is divided into five sections. Section 1 outlines the introduction, objectives, scope and structure of the study. Section 2 describes the methods and material used in this study. Section 3 presents existing knowledge of MRI in Finland, basic technical specifications and environment needs of the MRI. The purpose of this section is to explain the characteristics of MRI system, MRI technical specification, environment specification and correlation of image quality and climate conditions. Section 4 introduces data collection and analysis to show the phenomenon, the correlation between image quality and climate conditions. The focus in this section is on data collection setup, the data mining from real MRI systems and analysis of the data. Section 5 provides practical implications for the MRI departments as well as a planning proposal for MRI department and construction planners and also suggestions regarding what needs to be taken care of when planning a new MRI department.

2 Method and material

This section discusses in detail how the data for this research was collected, processed and analyzed. The study is divided into two parts, theoretical and practical. The theoretical part concentrates on giving background information about collecting data from MRI systems, technical specification, environmental needs and typical site planning. The practical part consists of actual data collection from real MRI systems in hospital and from R&D department of Philips Oy. Research design and approach is introduced next. Data for the study, its collection methods and necessary actions are introduced after design and approach.

Research design and approach

As shown in figure 1, the study started with a theoretical part, which was focused on collecting a systematic set of theory around the subject.

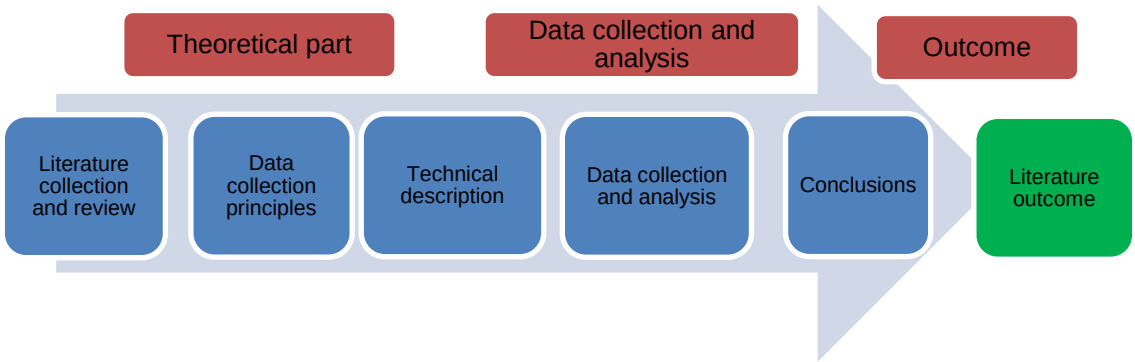


Figure 1. Design of research

The first two steps of the study are focused on collecting and reviewing literature for the theoretical part. The third step starts with a technical description, presents characteristics of typical MRI department planning, needed technical specifications and system installation. The fourth step introduces data collection, one of the main components of this research. The fifth step is for conclusions and the sixth and final step is comprised of the results of this thesis as an outcome.

The background data was collected from technical white papers, articles, literature, application notes and field test reports available in the internet and confidential company documents, the university library and databases. Data collecting principles is introduced next. Data was collected from five different MRI system log files.

A Log file is a file in a system which collects data on system processes. It contains all system events, incidents, warnings and errors. A modern MRI system can have hundreds of events every second. All these processes are divided according to their severity level. Events and incidents are for normal operation mode, warnings indicate that an error may occur and errors tell that something went wrong and needs user attention.

Log file size can be several hundreds of megabytes (MB) every day. The amount of data is huge and needs to be handled in a special way to separate the necessary information from all other log events. Data was anonymized by giving codes for the systems: A, B, C, D and E. Anonymizing means that data is not trackable and it is not possible to find out from what system it was collected. After anonymizing and separating, the necessary collected data was analyzed. Based on the analyzed data, an outcome was created. It contains a proposal on how to avoid and detect issues and how to plan an effective department for MR imaging.

Data collection from MRI system

Data for this thesis was collected from real MRI systems. Permission was asked and got to use anonymized log files from real systems and also log files from Philips Vantaa, R&D systems. These log files were collected, anonymized and then parsed to get data needed for this study. As mentioned earlier, log files are huge. At the same hundredth of a second, there can be dozens of events. An example of this is shown in Figure 2.

```
2018-01-27      00:00:00.39
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
2018-01-27      00:00:00.40
```

Figure 2 Events in a log file

The system writes a separate log file for each day. In Philips MRI systems the log files are then packed to save disk space, not deleted for the reason that they can be needed later on for troubleshooting purposes. Size, in bytes, of a log file depends on system events of the day. Typically, weekends are quieter than normal weekdays, basically hospitals and clinics have less patients on weekends than on weekdays. An example of a log file directory can be seen in Figure 3. The log file from Tuesday 16th of January 2018 is 115017 KB, which is ~115MB, and Sunday 21st of January 2018 is just 0,988MB. The difference is huge, the file from Tuesday is over 100 times bigger than the file from Sunday.

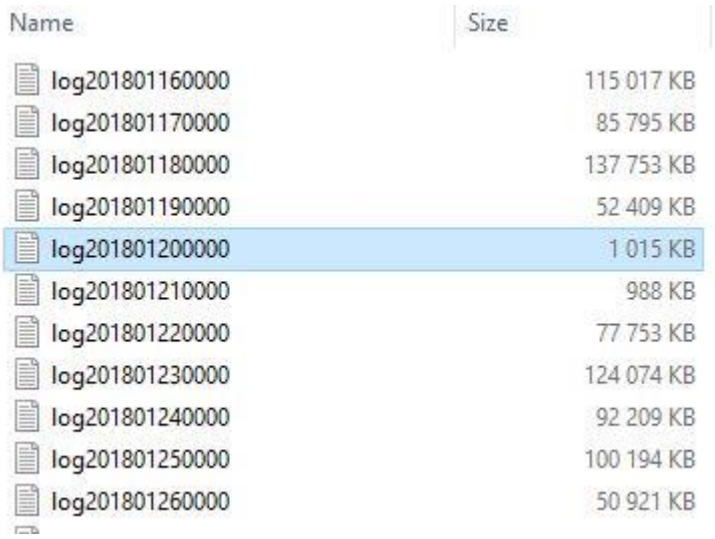


Figure 3 Log files in a system directory

As already told, files needed to be structured. This means that huge log files had to be separated to find just the log events needed. Differences between log files made this

separating difficult. There was not the same amount of needed data available in each of the files. Several methods were checked and tested, but the most effective way was to use Microsoft Windows Basic Command line (CMD) tool “findstr.exe”. For data handling it was chosen and used first. The Findstr tool searched and then echoed needed log file events from input files to a target data file. Typing “findstr -?” on Windows command line shows more information on the tool, print of the functions is on Appendix 1. Tool commands were written to a practical batch file to make it more usable. This batch file could then be copied to other directories to get data from other log files.

System Reference Number (SRN) was searched and echoed to get the analyzed MRI system serial number for researching purposes. This serial number was removed afterwards to ensure data protection. Strings from “findstr” batch file are shown in Figure 4.

```
findstr /c:"The SRN is" *.log >>humidity.txt
findstr /c:"Humidity of the examination room[%]:" *.log >>humidity.txt
```

Figure 4 findstr –batch file

In Figure 4 “findstr” searches the string “The SRN is” from all files in the directory with extension .log and echoed them to data file “humidity.txt”. Same command is given and looked for “Humidity of the examination room[%]:” from all files with extension .log and then echoed them to “humidity.txt”

The output data file with the needed, for example, humidity data line was then structured and imported to Microsoft Excel to create graphs from the data. Example of the data line in a data file is shown in Figure 5.

```
[log201XXXXXXXX.log:]14:27:03.25(log): Humidity of the examination room[%]: 61.9
```

Figure 5 Example of "Humidity info" in the log file

In this case the data shows “Humidity of the examination room 61.9%” of relative humidity in examination room on this particular date with timestamp 14.27:03.25.

Focus on temperature and humidity

Temperature and humidity have a correlation. In this study, these quantities are taken into account by using single quantity instead, namely relative humidity. It means how much moisture air can keep in a certain temperature. Manufacturers of MRI systems have specified levels of allowed humidity and temperature. To avoid problems, users need to keep in mind that these levels must be met by the hospital climate conditioning system. Temperature and humidity need to be maintained inside a certain range set in the manufacturer's specification also for patient comfort. The patient needs to be calm and still when imaging is ongoing, too high temperature and humidity levels makes patient feel uncomfortable and he/she could start to move. This could lead to unsuccessful imaging. An example of disturbance in image can be seen in figure 6 and as a reference, same scan shown without disturbance in figure 7. [6]

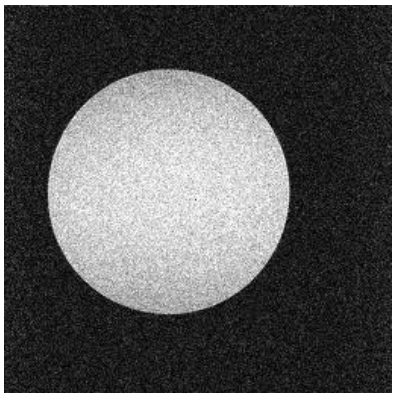


Figure 6 Disturbance on MR test image

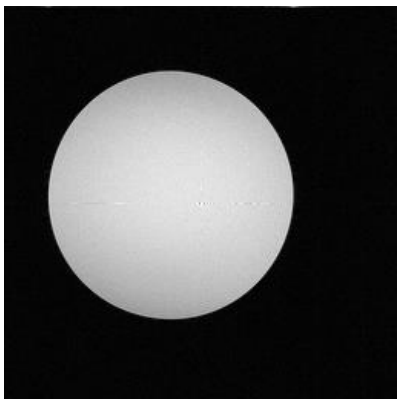


Figure 7.Normal reference MR test image

Figures 6 and 7 show MR images taken from a test phantom. Phantom is a test object, which gives good image signal for the MR system receiver. Phantom is a perfect circle and has homogenous liquid inside, normally cupric sulfate in a specific mixed ratio.

3 Existing knowledge of the MRI

This section starts with a discussion of the MRI market in Finland and introduces MRI manufacturers, who are selling their products in the European Union (EU). After that the MRI system components and principles on a basic level are introduced. It is important to know basic principles first to be able to understand the whole structure of an MRI system, all its components in their specific locations in different special built rooms. These rooms have requirements for the facility environment. The manufacturer has

done research and development (R&D) to establish correct “environmental condition” values for the system to make it work as the manufacturer has planned. [8]

3.1 Market overview

MRI users in Finland can be divided in at least two ways. The first is the public healthcare sector versus the private healthcare sector. Second way would be to divide the users by their level, for example university hospital and sport injuries specialized high level private clinic versus regional hospital and regular private imaging clinic. MRI manufacturers have systems for all needs. Figure 8 shows an example of Philips Ingenia 1.5T systems which were analyzed in this study.

Figure 8: Philips MRI Ingenia 1.5T

This Philips Ingenia 1.5T system is modern and powerful for advanced users and equipped for university hospital use.

Basic principles are same in all brands MRI systems; the solutions just differ a little. For example there are at least three other brands than Philips who are selling their MRI systems in the EU. The information below is based on the manufacturers´ websites. [10, 11, 12, 13]

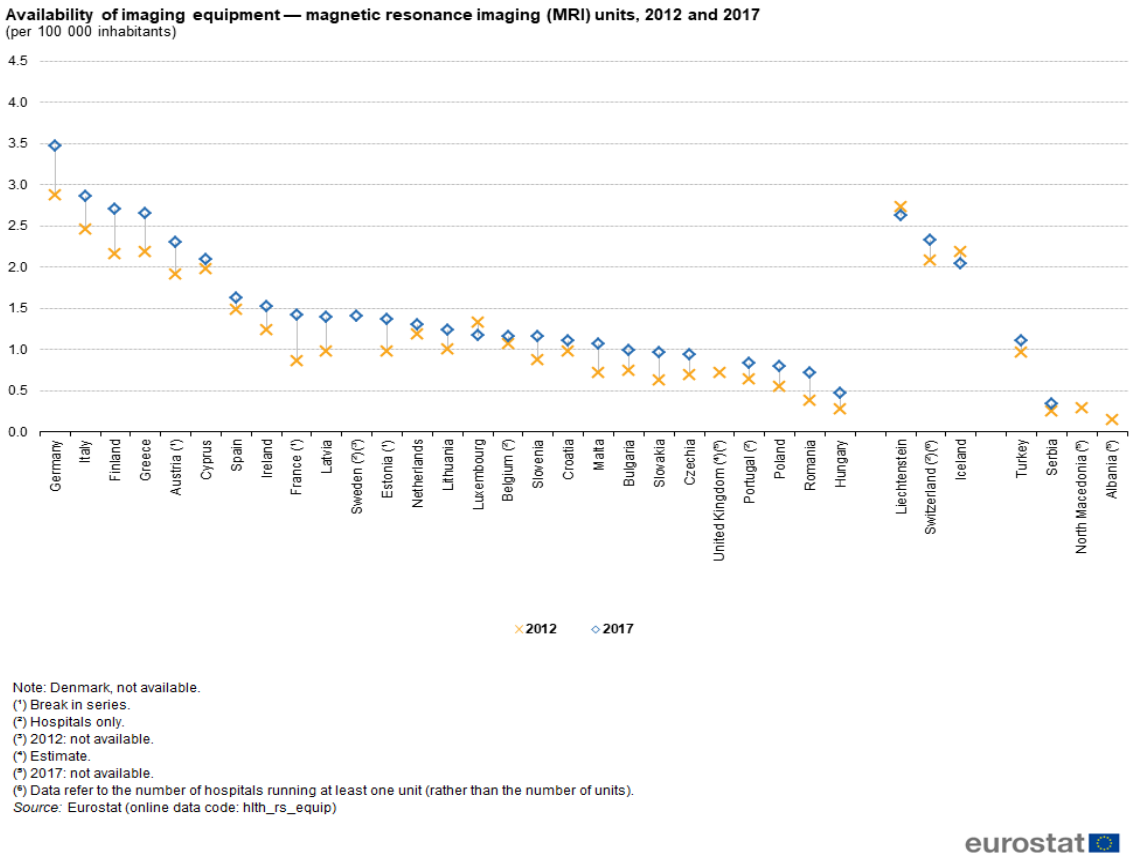
- Philips Medical Systems
  - Elition 3.0T
  - Ingenia 3.0T
  - Ambition 1.5T
  - Ingenia 1.5T

- Siemens Healthineers
    - Magnetom Vida 3.0T
    - Magnetom Lumina 3.0T
    - Magnetom Sola 1.5T
    - Magnetom Altea 1.5T

- GE Medical systems
    - Signa Premier 3.0T
    - Signa Artist 1.5T

- Canon Medical
    - Vantage Galan 3.0T
    - Vantage Orian 1.5T
    - Vantage Elan 1.5T

Across the European countries, the amount of MRI systems (per 100 000 inhabitants) has increased rapidly between 2012 and 2017. This is shown in Figure 9. [4]



Note: Denmark, not available.
(1) Break in series.
(2) Hospitals only.
(3) 2012: not available.
(4) Estimate.
(5) 2017: not available.
(6) Data refer to the number of hospitals running at least one unit (rather than the number of units).
Source: Eurostat (online data code: hlth_rs_equip)

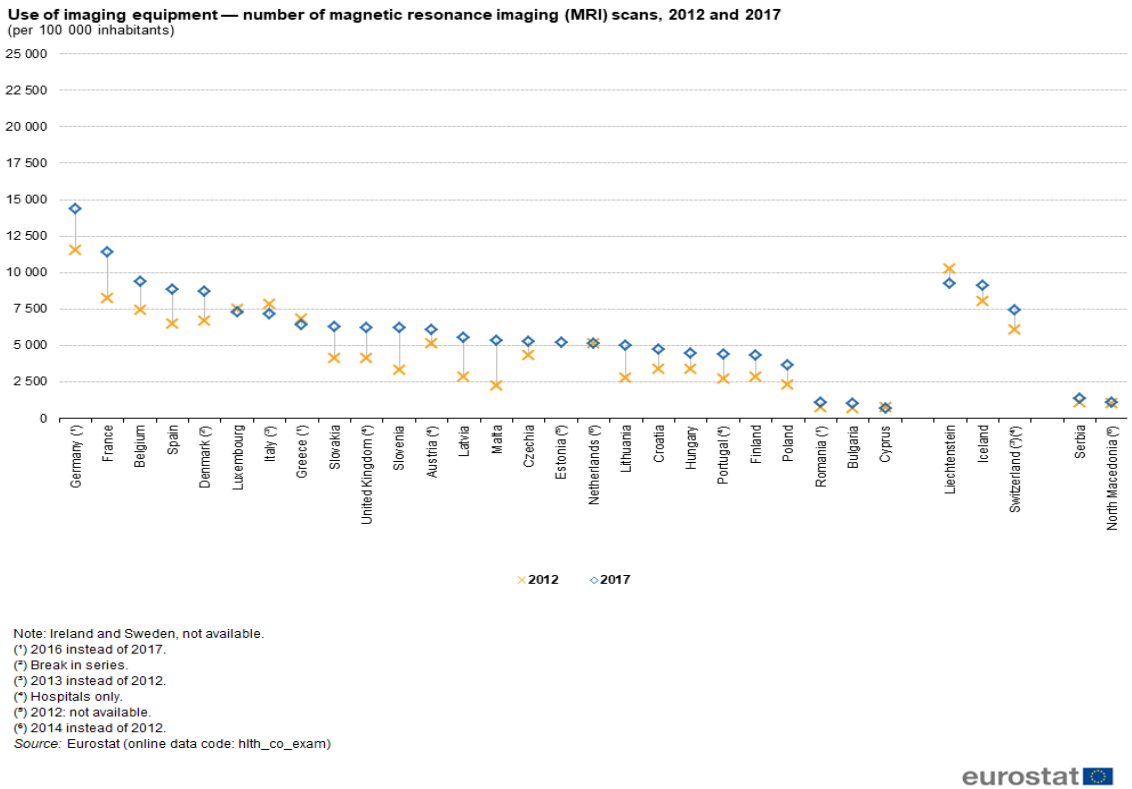
eurostat

Figure 9. MRI-units in the EU 2012-2017

As shown in Figure 9, the amount of MRI units (per 100 000 inhabitants) in Finland has increased from 2.15 to 2.75 between 2012 and 2017. Total amount of inhabitants in 2012 was 5,401M and 2017 5,503M. Total amount of MRI units in 2012 was 116 and in 2017 151. Total growth was 35 units, and if these 35 units are divide by 5 (years), it gives 7 units per year. In Finland there should currently be 14 units more if this speed of growth has continued until the end of 2019. The estimated total amount of MRI units in Finland is therefore approximately 165. [20]

For example university hospitals have many systems for advanced studies, for everyday imaging and for special use like cancer treatment planning and labor planning. This leads to huge amount of patient studies and makes usability and uptime more important than earlier.

Finland has the third most MRI systems in Europe but is in among the last in using the systems per 100 000 inhabitants, as presented in Figure 10 [4]. The amount of MRI systems and their utilization have grown, so the number of MRI examinations has grown as well. The low density of population in Finland could be a major reason for the relatively low utilization. A minor factor could be a malfunction in the system.



Note: Ireland and Sweden, not available.
(1) 2016 instead of 2017.
(2) Break in series.
(3) 2013 instead of 2012.
(4) Hospitals only.
(5) 2012: not available.
(6) 2014 instead of 2012.
Source: Eurostat (online data code: hlth_co_exam)

eurostat

Figure 10 Number of MRI scans in the EU 2012-2017 [4]

As shown in Figure 10, the number of MRI scans in Finland has grown from 2600 to 4900 (per 100k inhabitants) between 2012 and 2017. Effectiveness in patient flow has a big value. [21] One of biggest factors in effectiveness in patient flow is to get diagnostically valid images of the patient at their first time visit. This means that the patient does not need to go back for a new examination or have more imaging sequences than planned. When a patient visit takes longer than planned, it disturbs the hospital´s or clinic´s work-flow. [3, 4]

The private sector in Finland is mainly focused on basic level MR imaging. This means ankles, knees, neck and spine examinations. These examinations can be carried out fast and simple and there is no need for a doctor (as would be the case of a contrast agent or anesthesia were used).

There are at least four private healthcare providers who have MRI systems in different locations around Finland and a few smaller local providers. The biggest ones are listed below:

- Mehiläinen Oy
- Terveystalo Oy
- Aava Oy
- Pihlajalinna Oy (may became a part of Mehiläinen Oy after a while, merger is in progress)

The providers listed above also provide comprehensive healthcare services. Imaging is just a part of those. In Finnish private sector there are also companies that provide just imaging (Unilabs Mediscan), a company focused on cancer treatments (Docrates Oy) and a company that only has MRI trucks in order to get MR imaging where there is no permanent MRI location (Etelä-Pohjanmaan Magneetti Oy).

3.2 Characteristics of the MRI system

MRI is based on the magnetization properties of hydrogen atom nuclei. A strong, uniform, external magnetic field is used to align the protons that are normally randomly oriented within the water nuclei of the tissue being examined. This is called “net magnetization”. This phenomena is shown in Figure 11. [7]

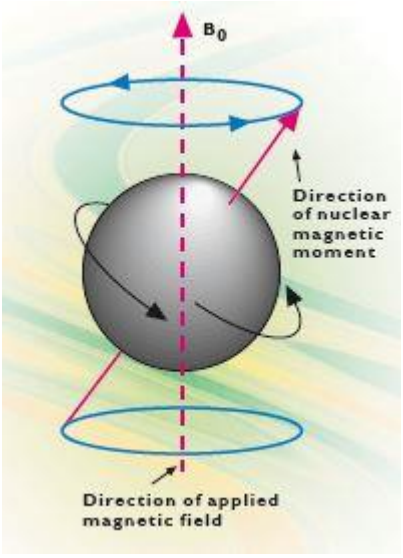


Figure 11. Atomic nuclei on external magnetic field [1]

This net magnetization is then interfered by transmitting an external Radio Frequency (RF) energy. The nuclei returns to their resting alignment through several relaxation processes. Doing so it emits RF energy. After a particular session following the first RF, the emitted signals are received and measured. Fourier transformation is employed to convert the frequency information, contained in the signal from each location in the imaged plane to corresponding intensity levels. They are then shown as shades of gray in a matrix arrangement of pixels. By modifying RF pulse sequences applied and collected, creation of different image types is established. Repetition Time (TR) is the time between consecutive pulse sequences applied to the same slice of the object. Time to Echo (TE) is the time between transmit of the RF pulse and receiving of the echo signal. [7]

These emitted and measured RF signals have really low intensity and therefore technique for receiving them must be really fine-tuned and sophisticated. This leads to the fact that an MRI system is sensitive against external RF disturbance. The MRI system´s main components are listed below.

1. Magnet for generating the static magnetic field
2. Magnetic field gradient system, consisting of gradient amplifier and gradient coils. The gradient system is required for spatial selection and spatial encoding.
3. RF amplifier and RF transmit coil for production of measurement pulses to excite the nuclei
4. RF receive coil and amplifier to detect the re-emitted signal from nuclei (Transmit, and receiver coil may electrically and physically be integrated)

5. Acquisition and control system for digital signal processing, image processing, and data acquisition control.
6. Physiological hardware to measure a patient´s electrocardiogram (ECG) and respiratory cycle, necessary for some types of examinations (optional)
7. Reconstruction system for image calculating, producing and reconstruction
8. An operation and viewing console for display of the images and for operator input of control parameters
9. Archiving system for image data archiving (user responsibility)
10. Magnetic shielding to minimize the effect of the fringe magnetic field on the areas surrounding the MR scanner.
11. RF shielding to protect the system from external RF interferences and vice versa
12. Patient table for positioning of the patient in the magnet during an exam.
13. Patient monitoring equipment to monitor the patient during the exam. [1]

A magnetic resonance imaging study uses a combination of a static magnetic field, local variations of this magnetic field (magnetic field gradients) to encode spatial information on the nuclei within a tissue sample and RF pulses, applied through a radio frequency pulse generation system, to generate a signal. An RF receiver system then detects re-emitted RF energy and transports this signal to a computer system for digital processing and image display. [1]

An RF room is working like a Faraday cage. No RF signals are passed from outside and RF signals produced by the MRI system are not passed outside. An MRI system uses specific RF signals, RX and TX, to make an image and if an external signal disturbs system signal receiving, image data can be useless. External signal is every signal, which is not produced by the MRI system, also inside of RF cage. It is possible that in very dry (humidity level <35%) conditions, every single “metal against metal” surface can produce “spikes”. In Philips terminology term “spike” is understood as an “Electrostatic Discharge (ESD) -spark” in examination room. [15] Other manufacturers use, for example, the term “popcorn” to describe the same phenomena. Spikes generate RF signals on a very wide spectrum in high density. This is then received by the system and if the spike is big, it will be shown in the patient image. MRI system tries to correct these by special image correcting algorithms but if they are big, correcting is not possible. Spike issues could lead to a situation where the image is useless and the object has to be rescanned. An MRI system collects logs all the time, so that all things happened including errors and environmental data are written to log files.

3.2.1 Basic principles by system component level

This section introduces MRI system´s field of use, system components and typical layout. All of these are needed to understand the system´s requirements regarding its environment.

Field strength and purposes

MRI systems are available for research and diagnostic purposes in different field strengths. Field strength means MRI system´s main magnetic field. In theory, higher field strength in MRI enhances the image resolution and reduces the scanning time. In reality, this is not fully true, but with certain anatomy types there are advantages in scanning with stronger field MRI. Earlier, in 1980s and 1990s there were MRI systems available with field strength from 0.15T to 1.5T, where weaker MRI was developed with permanent magnets and from 0.5T to 1.5T with superconductive magnets. For comparison, the Earth´s magnetic field varies between 0.2 and 0.7 gauss (1 gauss is 0,0001 tesla). Therefore 1.5T system´s magnetic field is ~21 429 times Earth´s magnetic field.

For research purposes, 7.0T systems are available. The nearest 7.0T Philips MRI system is located in Sweden. 7.0T systems are mostly for research purposes, but Siemens Magnetom Terra 7.0T is accepted also for diagnostic imaging in the European Union and in the United States of America. [11] For diagnostic imaging purposes, all new MRI systems in Finland are 1.5T or 3.0T with different options.

MR system components and typical layout

A typical layout of MRI department is shown in Figure 12. Typically, MRI system room division is aimed to form a structure like in this layout.

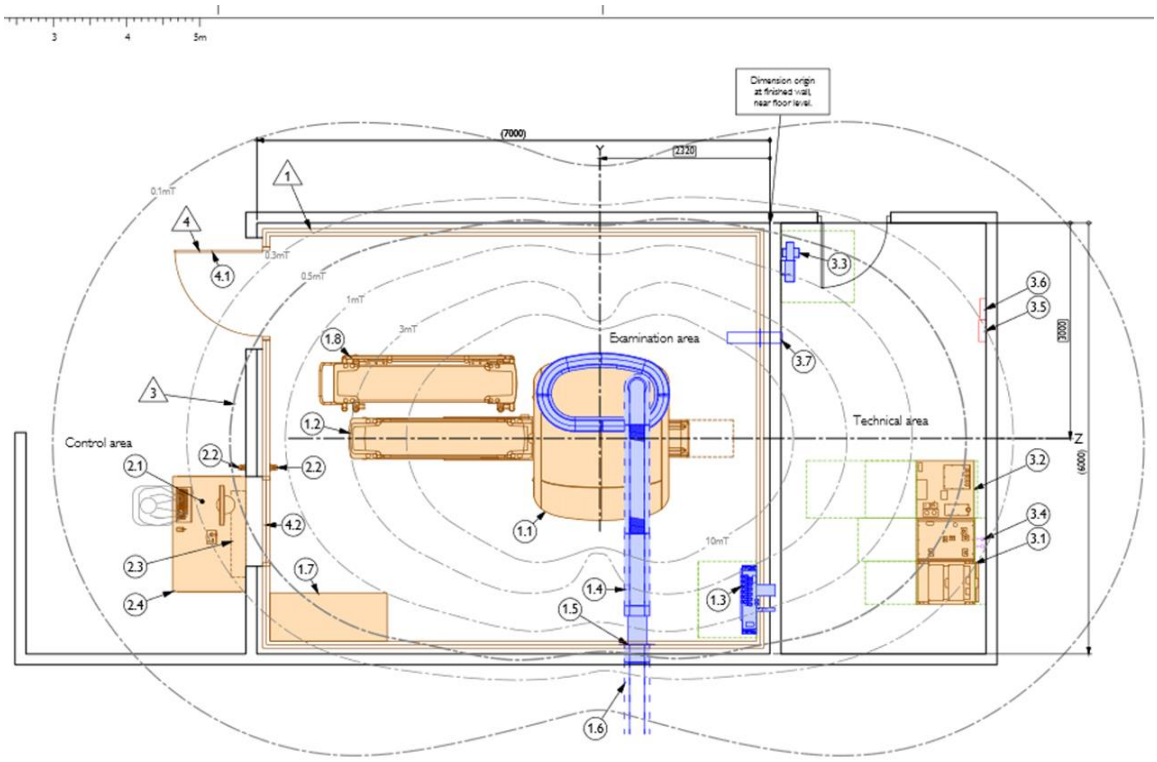


Figure 12 MRI facility room layout

The user side is on the left in the drawing and door to the examination room is near so that users have easy access to the room. The technical room is on the far right due to cable lengths: MRI systems have a lot of cables that need to get from examination room to technical room via the shortest route.

Basically, all new MRI system installations have the same functional components and all have these three different rooms:

- Examination room, for imaging
    - Superconductive magnet, receiving coils, patient table
- Technical room, for technical cabinets
    - Gradient amplifiers
    - RF amplifier(s)
    - Reconstruction computer
    - System cooling cabinet
- Operator room, where users are and operate the system
    - Operator console
    - Intercom for patient-nurse communication

3.2.2 A typical examination

This section introduces a typical MRI examination. Phases from the patient preparation to the examination are introduced systematically.

Patient preparation

The patient comes to the clinic or hospital and registers himself/herself at the registration desk. After registration the patient goes to the imaging department´s waiting room. An MRI nurse asks the patient to enter the MRI facility and takes info sheet that the patient should have filled in. Normally the patient fills up an info sheet in advance to make sure that he/she do not have any restrictions for an MR examination. For example, HUS-kuvantaminen “Preinfo sheet for MR examination” can be seen in Appendix 2. Restrictions would be for example claustrophobia or ferromagnetic objects inside the patient´s body such as a pacemaker, artificial joints or metal pieces from ammunition or welding, grinding, etc.

Usually, the patient changes his/her clothes to hospital ones to avoid any incompatible objects on own clothes, such as metal zippers, buttons or very sweaty fabric. The referral from the patient´s doctor is on the hospital system and the patient registration is transferred to the Hospital Information System (HIS) and Radiology Information System (RIS). HIS and RIS are connected to the imaging system so a nurse can choose this particular patient from the RIS list. Nurses get all the necessary information for examination from the RIS. The patient is now ready for the examination room. The patient lies down on the table in front of the magnet and the nurse arranges suitable RF coil on the anatomy area that is going to be scanned as well as puts hear protection on the patient because the very loud noise from the system can affect damage for ears and lead to hearing loss. A nurse call button is also given to the patient so that he/she can call the nurse if needed. This is also a safety issue. Reasons for a need to call the nurse can be inconvenience, extraneous heating or claustrophobia. Patient cannot come out of the MRI system by him/herself. A nurse is needed to take the table out of the magnet bore.

MRI examination

The anatomical area to be examined makes the difference between MRI examinations. The scanning time can vary from 10 minutes to several hours. Patient needs to be calm

and stay in place to establish good image data. Scans can also be chained as an examination. This is a common method to get enough image data from the anatomy area to make the diagnosis. Commonly scans of the anatomy area are taken at least from different directions.

3.3 Typical requirements for environment

An MRI system is big and heavy equipment. The system has special requirements and these are shown in this section by introducing following terms:

- Recommended room size
- Climate condition specification
- Airflow specification
- Vibration specification
- RF interference
- Disturbance of moving heavy metal objects
- Magnetic field disturbance for nearby systems and for humans

There are differences between manufacturers, models and field strength, but a few main points are the same for all. The weight of a superconductive magnet can range from 3000kg to 7000kg and the physical size is approximately 2,5m x 2,5m x 2,0m. That leads to the fact that an MRI department has to be easily accessible from outside the building. An MRI system needs a powerful electricity connection as well as liquid cooling. The system is very loud when scanning, so the examination room needs to be carefully soundproofed.

Recommended room size

Examination rooms are typically smaller, but the recommended room size is 7 times 6 meters, so totally approximately 42 m^2. The recommended height is more than 2,5m. The technical room needs approximately 10m^2 and the operator room 8m^2. A recommended MRI facility needs altogether 60 m^2 area for a comfortable working environment. Neither the patient preparation area nor patient waiting area are included in this calculation. There is also a need for some back office space for tasks supporting the actual imaging work.

Beside hospitals, useful and fully workable MRI systems are installed on truck trailers and permanent containers. The maximum allowed trailer size in Finland is: height 4,4 meters, length 23 meters (including the whole truck length) and width 2,6 meters [26]. In this case the recommended room size is not fulfilled. However, MRI trailers are practical way to get MRI scanners to places where there is no permanent MRI location.

Climate conditions

The climate conditions are important in the examination room, but it is useful if conditions are the same for the whole department section. This helps the air condition system to keep conditions stable taking into account door openings, outside weather, etc. For example, Philips MRI system specification for climate conditions in examination room are shown in Table 1.

Table 1 Philips MRI requirements for climate conditions

Requirement	Specification
Examination	room
Temperature	+18 to 22 ºC
Maximum temperature change	5ºC / 10 min
Relative humidity	40 – 70% (non condensing)

Quality performance index (QPI) in Philips terminology means a value that tells if the system has image quality issues. When the value goes over 1.0, the user may notice an issue. The theory and the calculation behind the QPI specification (value=1.0) is confidential information.

An example of measured climate conditions and quality performance index from the MRI system environment that meets the specifications can be seen in Figure 13.

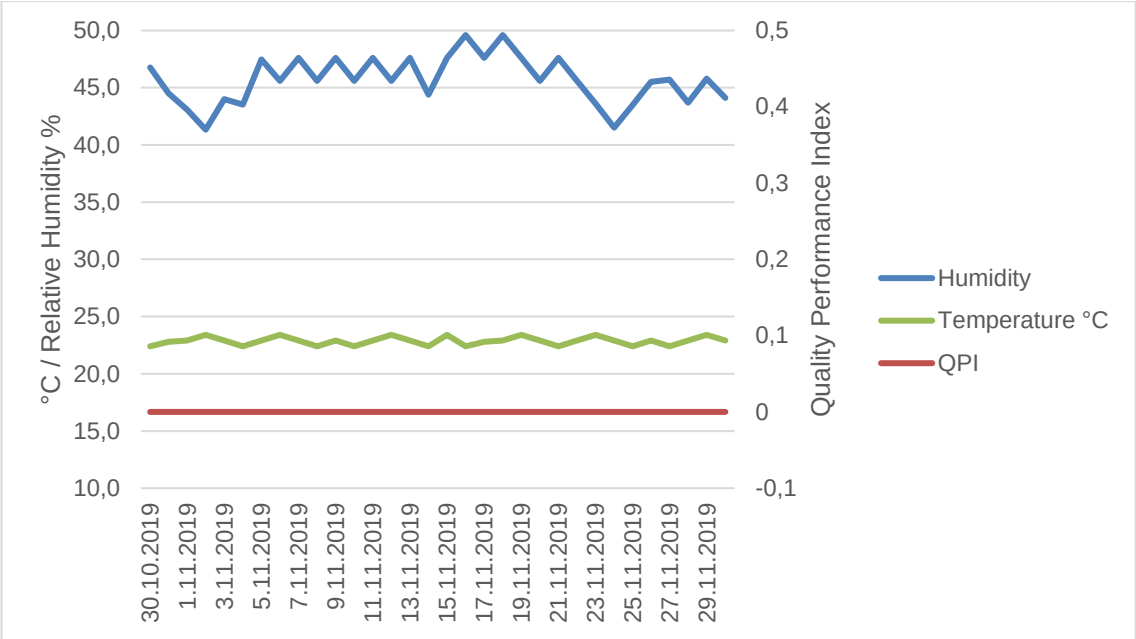


Figure 13 Example of an environment corresponding to specification

Relative humidity and temperature in examination room are within the values set in the specification (40-70% and 18-22 °C). QPI is zero all the time, no reported image quality issues and errors from the users.

Airflow specification

Airflow is important for the system and for the patient comfort. Manufacturers have defined specifications for airflow in the examination room. A Philips MRI system needs several hundred cubic meters of air per hour, where half is routed via inside ducts through the system to ensure enough air cooling for the system. The other half is routed through the examination room, circulated and then routed to air out. Typically, liquid cooling is used for the cooling system itself, but there are components, Printed Circuit Boards (PCB), etc, which need air cooling in the examination room.

Vibration specification

An MRI system is sensitive for vibrations coming from outside. This needs to be taken care of when planning an MRI facility. A “vibration specification curve” example is shown in Figure 14 for Philips Achieva system.

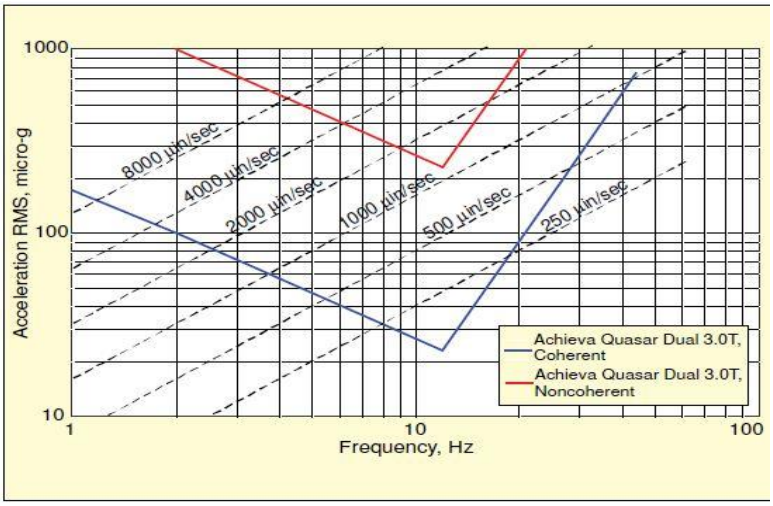


Figure 14 Vibration specification for Philips MRI

Allowed vibration levels can be seen from the given specification chart. On the horizontal axis is vibration Frequency in Hertz (Hz), and on the vertical axis Acceleration root mean square (RMS) in µG. Typically, vibrations are measured before installing the system by special equipment on exactly the same place where the MRI system is going to be installed. [24]

When the vibration level is too high, the installation cannot continue or, in special cases, special supports below the magnet are needed in order to eliminate vibration and movements of the building. The vibration can be too high near a railway, tram or subway. Trucks and lorries can also cause vibration if a road is near or the building frame is made using a steel beam structure and vibration was not taken care of when the building was planned. A motion artifact on MR image when vibration occurred is shown in Figure 15.

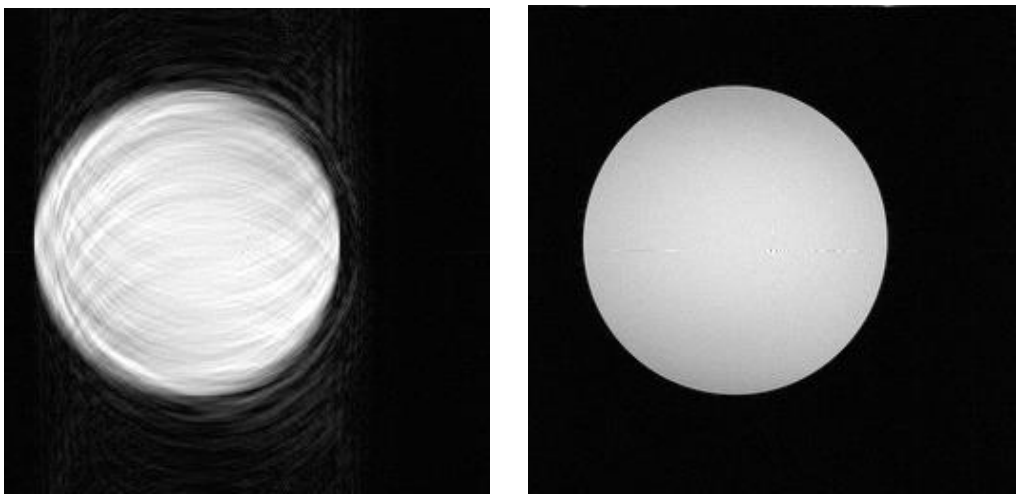


Figure 15 Motion artifact MR image and MR reference image [22]

On the left side of Figure 15, a demonstrative movement artifact can be seen, a lot of blurred echoes from moving fluid inside the phantom are well visible. A reference image is on the right.

RF interference specification

An MRI system superconductive coil is tuned for a specific frequency depending of its magnetic field. Due to the MRI system working method, this frequency also defines the frequency where system can receive a signal from target. A signal from target is really weak and on a very specific frequency. This leads to the fact that an MRI system is sensitive for high energy Radio Frequency, RF bursts. RF bursts are high energy and wide band RF transmits, so this disturbance more or less goes on the specific MRI system tuning frequency. The worst case scenario would be a dedicated radio transmitter, which is transmitting on this specific frequency and there is a leak on the RF cage. Field strength versus tuning frequency of MR System is seen on Table 2.

Table 2.Field strength vs tuning frequency

Field strength	Tuning Frequency
1.0Tesla	42,6 MHz
1.5Tesla	63,9 MHz
3.0Tesla	127,8 MHz
7.0Tesla	300,0 MHz

Table 2 shows that the field strength is directly proportional to the tuning frequency. A stronger magnet field needs a higher tuning frequency.

The sensitivity of the MRI system can also be an issue when high voltage cables or for example tram electric lines are very near the MRI system. Especially in wintertime, those lines are sparking and producing high energy RF bursts. Normally the RF cage can block those, but strong RF bursts can get through and demolish scans when the system receives those bursts and not the RF signal from the imaging object. Attenuation of 100dB for the RF shield is typically enough. Attenuation of 100dB is strong attenuation; on every 3dB step the attenuation is doubled. Therefore, if 0dB is 1, 100dB is $1*10^{-10}$. Still, on a certain point high disturbances need to be taken care of with active shielding of the RF cage. [25] Maximum allowed external RF signal is shown on Table 3.

Table 3 3.0T Maximum allowed external RF signal

3.0T magnet	
System frequency	127,8MHz
Bandwidth	~±300kHz
Maximum allowed external RF signal	*xx* dBµV/m or *y* mV/m

Table 3 shows the maximum allowed external RF signal for a 3.0Tesla system (system frequency 127,8 MHz). Exact values are confidential information. It is described in dBµV/m when bandwidth is around ±300kHz. Decibel microvolt per meter (dBµV/m) describes the transmit strength at certain distance.

Disturbance from moving heavy metal objects

An MRI system needs to have a homogenous magnetic field to get good image quality. This is done by shimming the magnet unit during installation. Magnet shimming means searching and plotting magnet field homogeneity by a special tool called “magnet field camera”. This tool is used by MR service engineer and it takes typically one day of installation time. The system gives deviation on magnetic field, this deviation is then calculated and given grams of ferromagnetic metal pieces, typically iron. With this calculation an MR service engineer can put these iron pieces precisely on the magnet as instructed. After this magnet is homogenous and gives the best image quality. Then static metal objects nearby are matching with the magnet system. Therefore, moving big metal objects can disturb the homogenous magnet field, because moving objects cannot be calculated off. They are appearing on the magnetic field´s sphere of influence randomly. A moving metal object causes bad image quality. The minimum distance to moving objects depends on the direction. The magnet is more sensitive on its Z-axis than X-, and Y-axes. MRI system planes (axes) are shown in Figure 16.

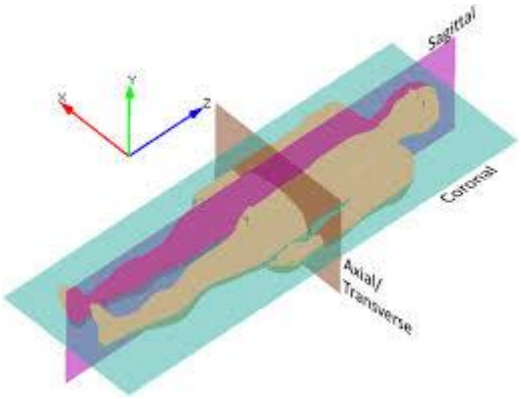


Figure 16 MRI system coordinate system [27]

Axes are visualized in Figure 16. The most sensitive Z-axis is through the magnet bore, X is for horizontal and Y is for vertical axis. The manufacturer specifies the mass of the moving object and distance from the magnet origo. For example, normal passenger car (weight 1,5t) needs 6,5 meters distance from magnet origo along Z-axis. Along the X and Y –axes 4,5 meter distance is enough. Safe distance for a passenger car is shown in Figure 17.

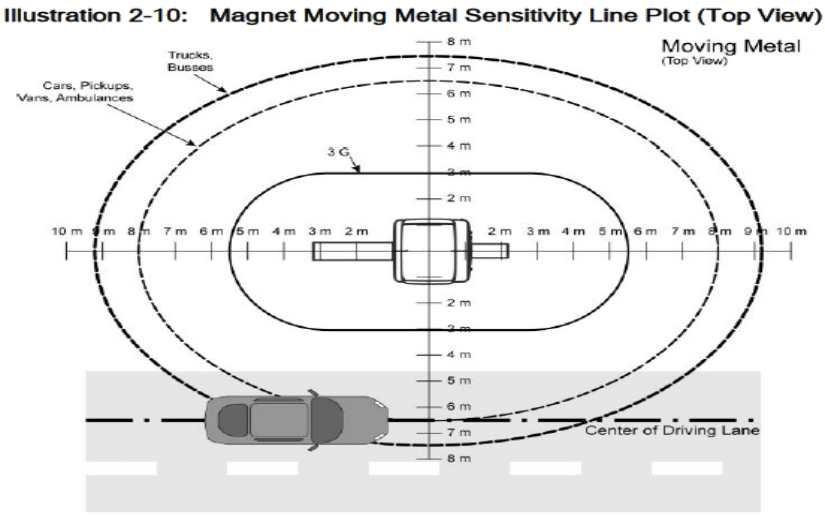


Figure 17 Distance to moving passenger car along Z-axis [28]

A highway near an MRI facility can cause issues. Facility planning needs to take care of safe distance to a road. In Figure 17 it can be seen that a 6,5 meter distance is enough for a passenger car (1,5t), but much more heavier trucks and buses (10-40t) need a 7,5 meter distance.

Magnetic field disturbance for nearby systems and humans

A magnetic field of the MRI system can affect or influence nearby systems and equipment such as CT scanners, X-Ray systems and lifts. This possibility needs to be addressed when planning a new MRI facility. Magnetic field goes the same way in any direction 360° (when looking from the front of the magnet). Facility planning can run into a problem if the magnetic field is spreading to a wrong area. Special magnet shielding can be used in this situation. The reach of the field can be limited with the shielding. The shield consists of special made metal sheets. Metal volume, place and distance from magnet have to be carefully calculated. This procedure confirms that magnet shielding is in the correct place and strong enough to ensure safety area where it is needed. A magnetic field is fatal for persons who have a non-magnet compatible pacemaker. There

is a specification for safety zone, where all people can come. This safety zone is marked on MRI planning drawings as “5 Gauss line”, in Europe term “0.5mT” is used. {1 Gauss (G) = 1 x 10^{-4} Tesla (0.0001T); 5G=0.0005 T = 0.5mT}. Examples of 0.5mT line and a Warning sign are shown on figure 18.

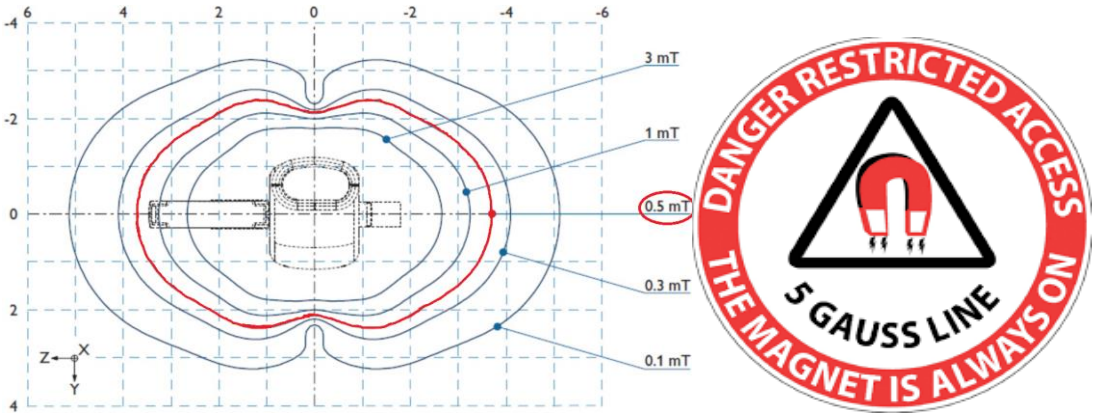


Figure 18. 5 Gauss line (0,5mT) and warning sign [19]

Figure 18 shows this 0.5mT magnetic field line. The line runs near the magnet itself. Usually this line does not reach out of the examination room at all, on the left-right side it is ~2 meters from magnet and on front-back side 3,5 meters from the magnet origo. In some cases the examination room is so small, that 0.5mT field needs to be limited as mentioned earlier.

American College of Radiology (ACR), has defined four safety zones within MRI facilities. These are denoted Zones I through IV and correspond to levels of increasing magnetic field exposure (and hence potential safety concern) [18] These zones are shown on Figure 19.

- Zone 1, freely accessible
- Zone 2, public area, patient dressing and screening. Under nurse supervision
- Zone 3, near MRI system. Can be fatal for human who is using pacemaker
- Zone 4, high magnetic field, no ferromagnetic objects can be inside

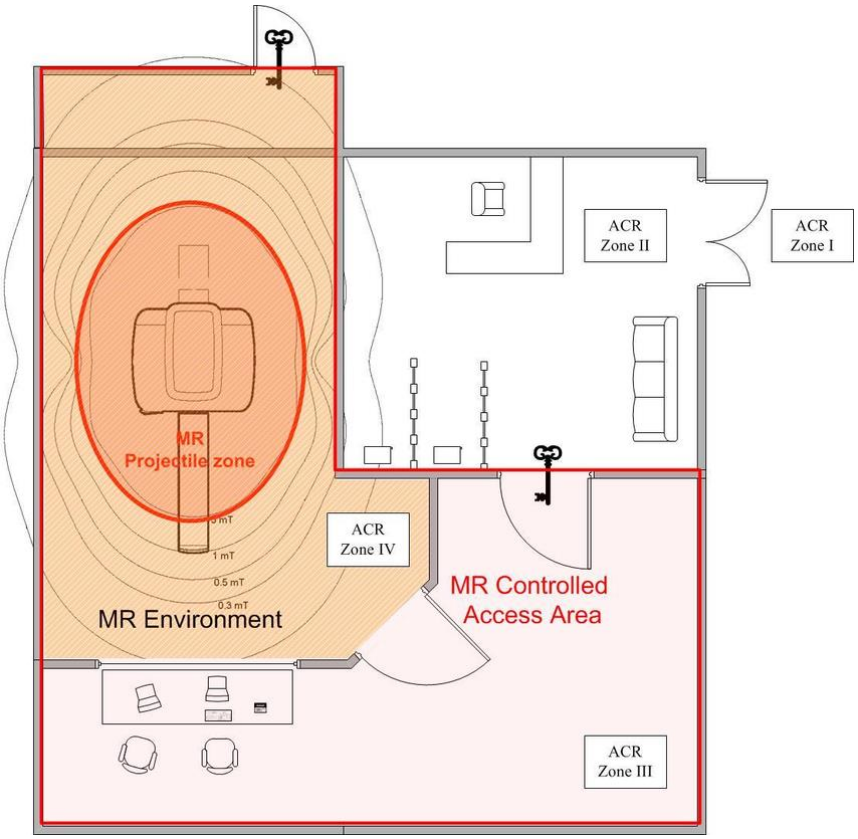


Figure 19 MRI department zones [18]

Figure 19 shows 0.5mT magnetic field on the examination room, and a small pass through to the technical room. Therefore examination and technical rooms are “zone IV” areas. Zones I, II and III are safe, but entering to II and III zones just under nurses´ supervision. The key symbol illustrates lockable doors. Doors to the technical room (backside of the magnet) and the operator room are controlled areas and therefore need to be lockable. On zone II the nurse will check the patient safety for the MRI examination. Zone III (the operator room) belongs to the controlled areas. Access to the MRI is in this room and a nurse always escorts the patient to the MRI room. [17]

3.4 Installation site challenges

As already told, an MRI system has environment specifications. Unfortunately, it is seen many times that climate conditions on existing sites are not permanent. This may cause massive image quality issues and reduce patient flow a lot. The biggest issue is humidity, especially in Northern countries. In wintertime air humidity drops outside. When fresh air is taken from the outside and warmed up, relative humidity sinks. Before using fresh air it needs to be humidified to get it to the recommended level. Challenges in heating and

humidifying incoming air in wintertime can be seen with Mollier chart, the chart is presented in Figure 20. When the air outside is -30ºC with relative humidity 100% and then it is warmed to +25ºC, relative humidity drops down to below 10%. [16]

In Philips MRI specification, relative humidity needs to be 40-70%. In this example (Figure 20), the incoming air needs to be humidified to a specific level.

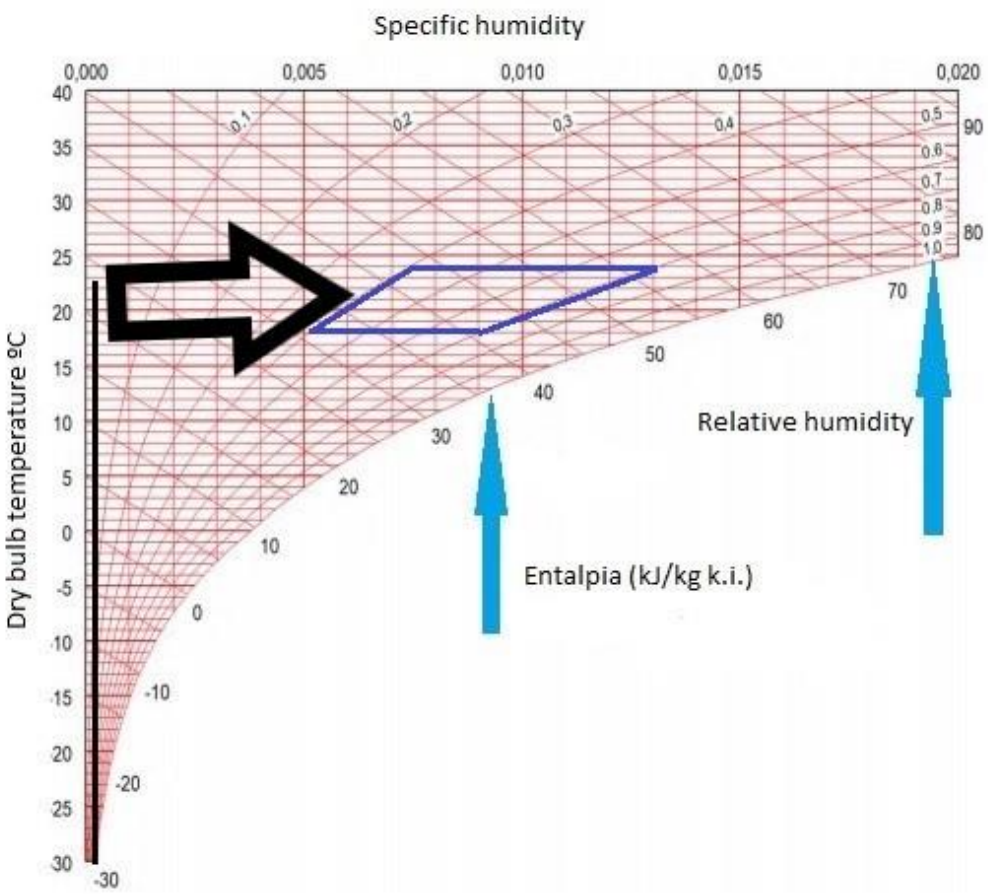


Figure 20 Mollier chart [16]

Figure 20 shows challenges when cold air (-30°C, relative humidity 100%) needs to be warmed up to +22°C, relative humidity drops below 10% (black line). Then the air needs to humidify (black arrow) to the specified level (blue diamond).

An MRI system can log its climatic conditions itself, reasons are mentioned above. Example cases of relative humidity and Image Quality Performance Index, (QPI) charts are on Figures 21 and 22.

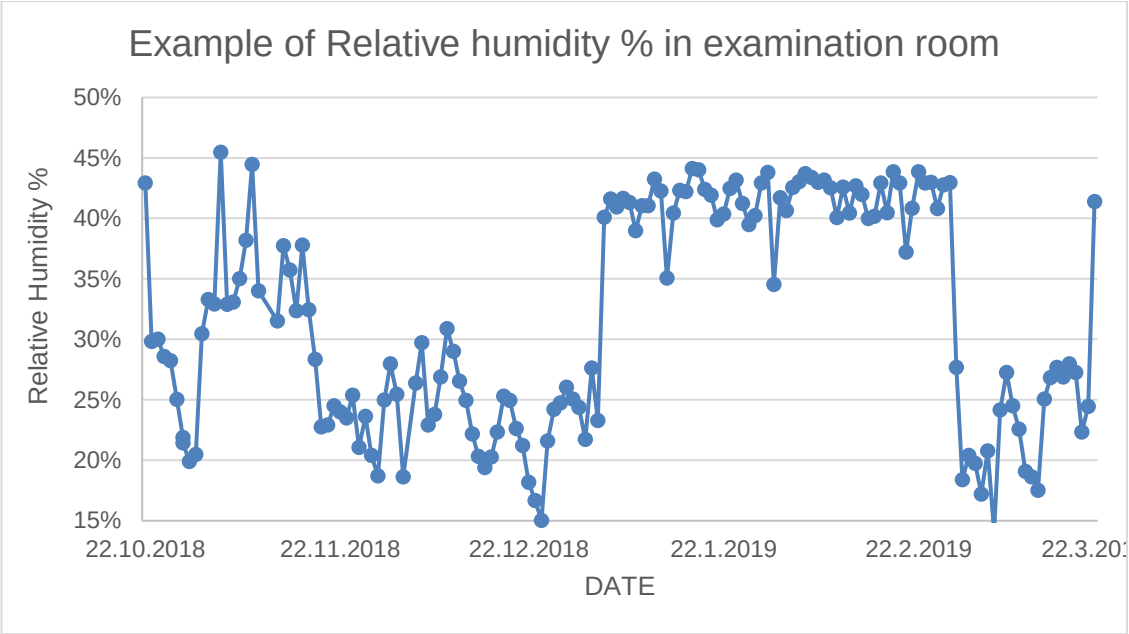


Figure 21 Example of "Relative humidity %" in examination room

From Figure 21, it can be seen that "Relative Humidity %" -value changes a lot. 22-Dec it has been just 15%, which is a really low value. On 3-Jan it jumps just above specification to 40%. This causes system major Image Quality issues. This is easily seen in Figure 22. On this particular system, QPI values are almost all the time more than 50, which means 50 times more than specification.

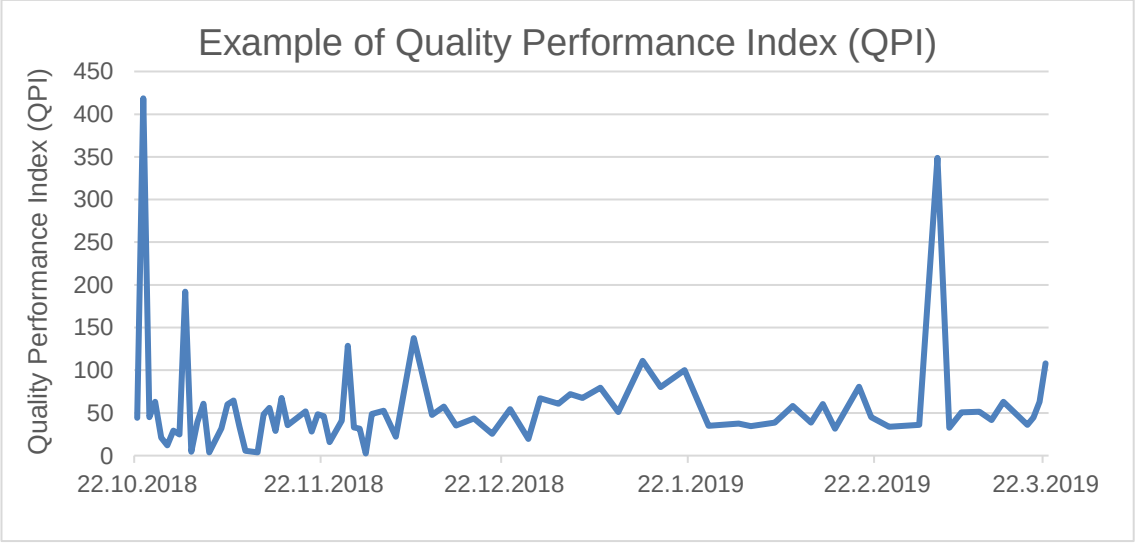


Figure 22. Example of "Quality Performance Index (QPI)" –curve

The chart in Figure 22 shows so high QPI values that the system clearly suffers bad image quality issues all the time.

Humidifying can be taken care of when planning a new department or facility but in old buildings and small private clinics, this is not easy and may cost a lot. One example for an easily adjustable humidifying system can be like this:

- Hospital main climate condition system makes rough adjustment for air to get relative humidity level near specification.
- Near the imaging system air can be fine humidified with local climatic system
- The whole system is connected to the facility automation system. This is important in order to get alarms if, for example, a humidifying fault occurs.

4 Data collection and analysis

This section introduces data collection and analysis for the study. Data collection was a multi-phased task. Collection needed to be implemented and tuned to every system. After collection, the analysis part of the study can start. Analysis was a linear task when collected and handled data was similar. Data collecting and handling is described first and then comes the “analysis of the data” section.

4.1 Description of data collecting and handling

MRI system can produce hundreds of thousands of events during normal daily-based use to the system log file. Interesting data needs to be found and then processed in order to make it usable for analysis. Ten different systems were analysed and then five systems of these ten were chosen to get good examples and self-explanatory graphs. Data was anonymized to ensure that the data origin could not be detected. This was done because of the company confidential data handling rules, but also due to the user data handling rules. In fact, origin of data would not add any value for the study. Interesting data in this context are relative humidity percentage and Quality Performance Index (QPI). Beside the above mentioned data, of interest for the data collection are the system´s installation year and its field strength. Installation year is interesting because manufacturer´s specification commonly changes during the years. The installation year and location are not shown in the study, they are for company use only. In one case the examination room temperature is included in the collected dataset.

Analysed time-window differs between systems because the available log files were not from the same time or period. The systems had differences in their software versions

and this influenced the log file writing. Older systems do not have such at deep log file reporting as the newer system versions. Version differences did not influence this study. All systems logged all the needed information, even though the older ones did so less frequently. Older systems can log temperature and humidity just once a day, whereas newer systems can do it right before each scan.

In Philips MRI systems QPI value is an index for detected disturbances during scanning in an examination room. Ideal situation is when QPI value is 0.000. This means that no errors were detected by the system during scanning. QPI value below 1.000 means that image quality is still good, and normally system can fix these problems by itself on the fly. In this situation the user does not notice any image quality issues. All QPI values over 1.000 mean that there are problems in the system or examination room.

Every MRI system manufacturer shows and handles this kind of issues with their own method. In this study, it was not possible to compare other brands´ MRI systems to Philips MRI systems.

The collected data is handled system by system in their own sections. Excel charts illustrate specific things which can be seen from the data. Table 4 introduces the list of analysed Philips MRI systems.

Table 4 Analyzed systems

System code	System type
A	Achieva 3.0T
B	Achieva 1.5T
C	Achieva 1.5T
D	Ingenia 1.5T
E	Ingenia 1.5T

Table 4 lists the system types. For marketing purposes, “system type” or “marketing name” has been same for a long time, technically systems have changed over the years. Medical device development process is ongoing in the background. Therefore, System B does not have the same setup as System C; there were a few years between their installation.

4.2 Analysis of the data

This section introduces the data analysis. The analysis of the systems are divided by the system codes A, B, C, D and E. The analysis consists these listed phases:

- A problem or an issue with the system
- Solving the problem or the issue
- Solution for the problem
- Chart and clarification about the problem

System A

System A has faced several image quality issue periods during its service time. On that time when System A was installed, it was the top model on Philips MRI fleet. This is a good example of an MRI facility where the environmental specifications were not taken seriously in construction planning and implementation phases. This has been causing severe problems for the image quality and therefore not even such a high end MRI system has not reached its potential. Problems are easily seen in the Figure 23 chart. During this period of time QPI is all the time over 1, which means major issues with image quality. The highest peaks of the index went over 400, which means that the scanned images were not usable. At the same time humidity is below specification (40-70%). The MRI system installation site and climate conditions are like in a regular office building. The MRI department does not have its own extra humidifying device on “air in” ducts, which means that the climate conditions are almost impossible to adjust to MRI needs.

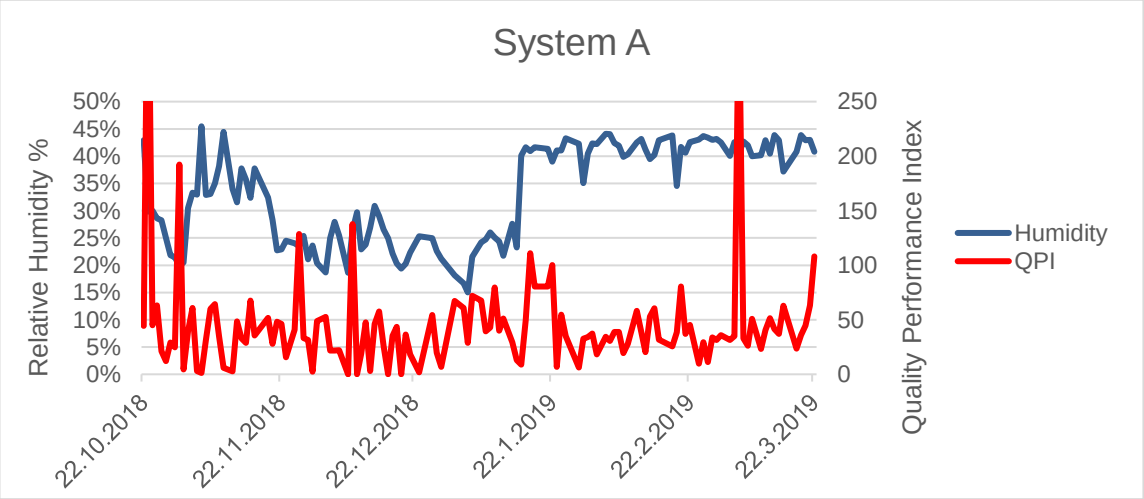


Figure 23. System A. Lot of IQ issues, humidity below specification most of the time

System B

This MRI system was inspected because users had reported about image quality issues with the system. The system log file was inspected and analysed. The log file showed a lot of high level QPI events during that specific period. The humidity was also below specification values. These factors can be seen in the System B chart in Figure 24. There are high QPI peaks on 25-Oct, 27-Oct and so on. The facility service inspected the facility´s climate conditioning system and noticed that the main humidifier was broken. The humidifier device was fixed and the image quality reverted to normal after a few working weeks. This correction cannot be seen in this chart because data from that time was not available. It is really important that also hospital facility devices are working as they should.

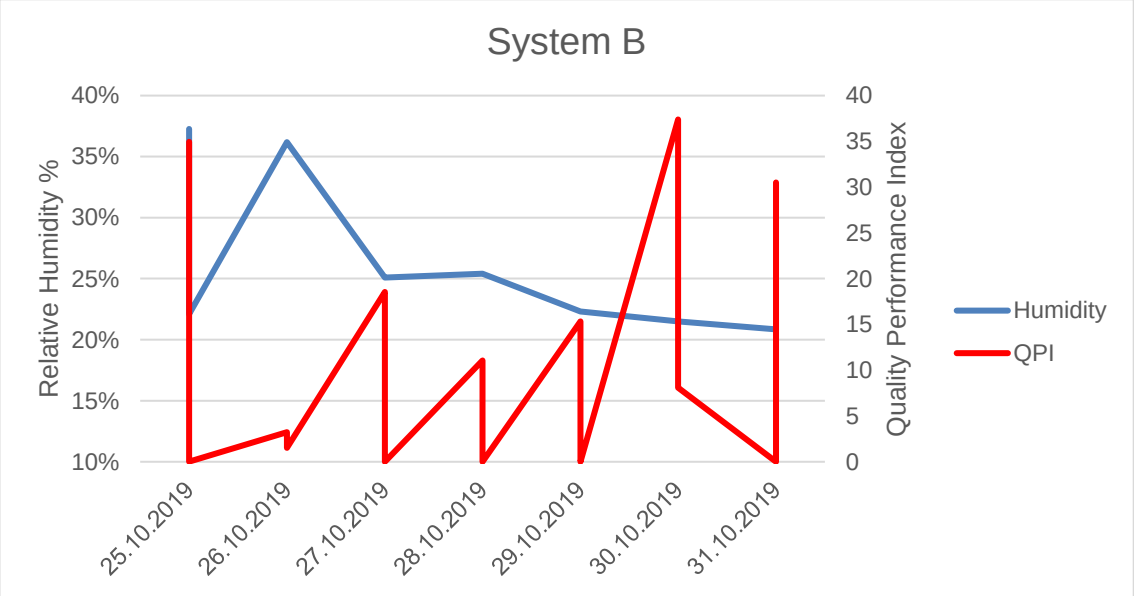


Figure 24. System B Humidity below specification, major image quality issues

System C

The Philips remote service team noticed that the relative humidity % in the system´s examination room was not maintained on the specification levels. The system is highly used, and must be on working condition all the time as a high priority. The humidity problems were caused by an issue with the climate condition system and this was fixed in time before major image quality issues occurred. Analyzed data is shown in Figure 25. Humidity starts to go down on 14-Feb and drops below specification on 15-Feb. The data also tells that, low, still below 1.0, QPI values occurred already. Values below 1.0 normally do not cause any issues for images. In this case, the climate conditioning system malfunction had not influenced neither the MRI system nor the department workflow before the malfunction was fixed.

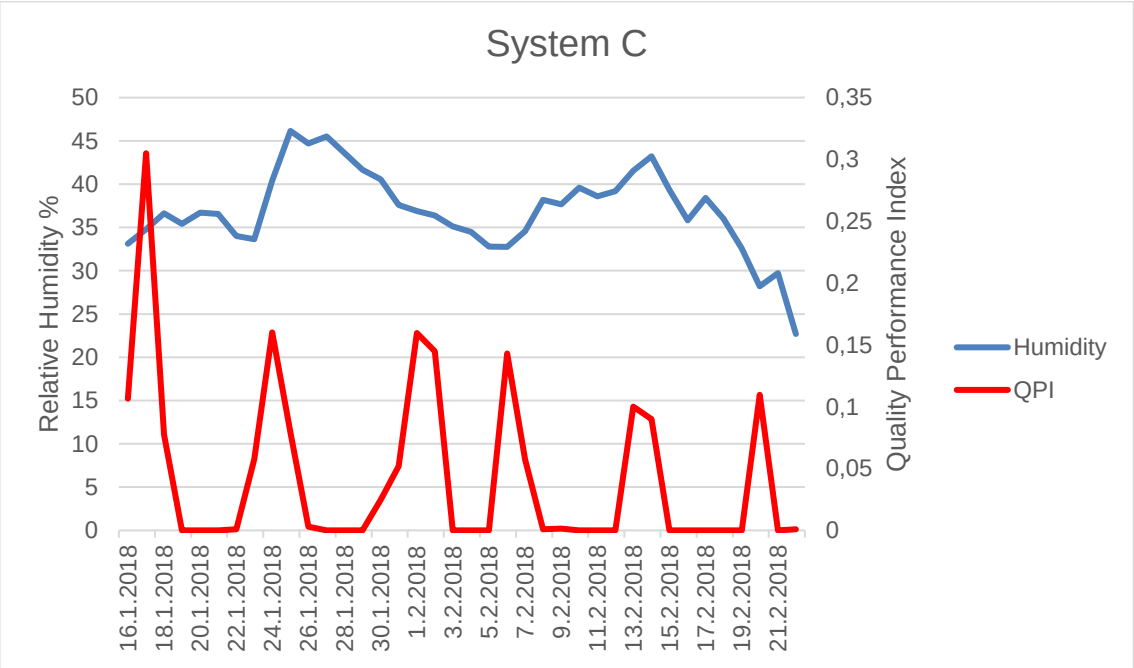


Figure 25.System C. Humidity changes, no IQ issues, still below 1.

System D

The system is working according to specification. No errors are reported. During planned maintenance it was noted that relative humidity varied too much during the days. If the fluctuation in humidity is too high, it can lead to moisture condensing on surfaces. This is a risk for electrical equipment in the room. The facility service department was asked to re-adjust the climate conditioning system. The cause of the problem was found to be a broken extra humidifying device on the MRI department air inlet. The facility´s main air-conditioning system tried to keep conditions right and this caused massive fluctuating; this can be seen in Figure 26. On 1-Nov humidity was 39% and on 2-Nov 48%. The local humidifying equipment was replaced and the humidity control returned to normal on 9-Nov. In this case no abnormal behavior with the MRI system happened, nor was the system affected by condensing moisture on surfaces.

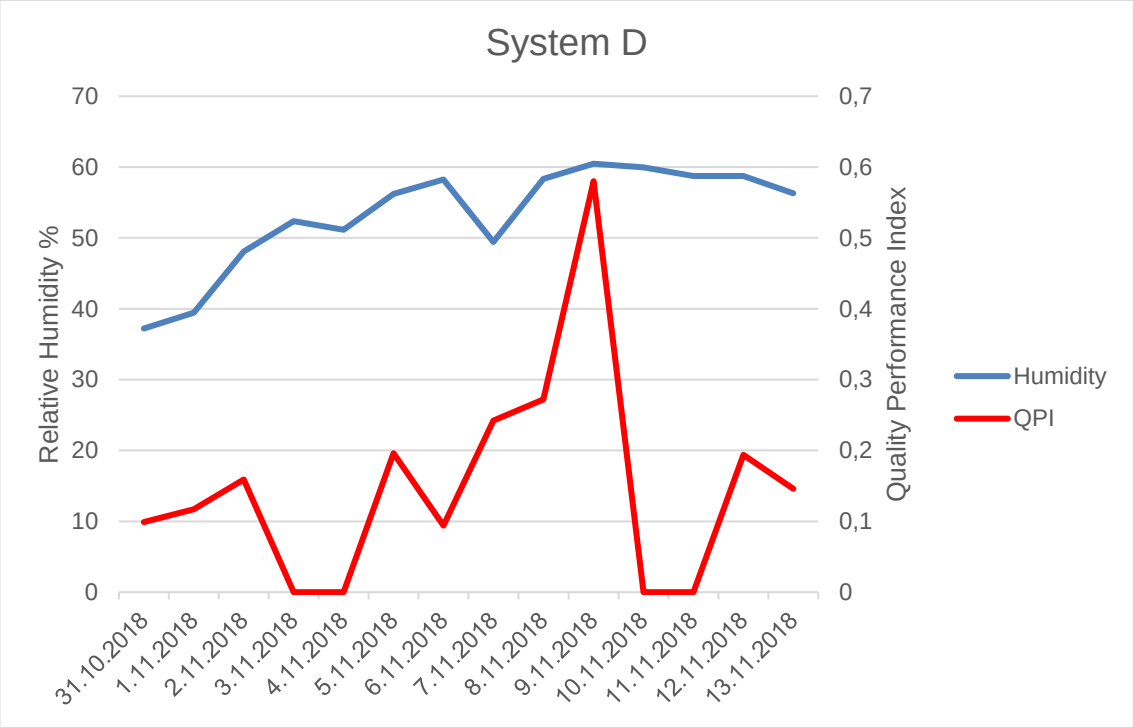


Figure 26. System D. Humidity fluctuating.

System E

Users had reported an intermittent issue: the images were sometimes unclear. Images looked like as if they had been shifted or vibrated. This caused rescans on particular examinations. The system was inspected and found to be working according to specification. Image quality errors were not detected by the system. Problem solving was continued and then the users reported that some patients had complained about uncomfortable examinations due to warming up and sweating, “feeling like in a sauna”. This behavior was investigated more and it was noticed that the temperature in the examination room was a little over specification (18-20 °C). High temperature combined with high relative humidity (see Figure 27) made the patients feel uncomfortable. This combination causes patients to move and leads to unsuccessful and non-diagnostically valid scans. Unsuccessful scans lead to longer examination periods and to facility workflow peaks. Image quality is on a good level, QPI values are very low, the highest value is 0.005, a way below specification 1.0. The temperature curve together with humidity and QPI values brings more clarity to this case. The facility services was asked to adjust the climate condition system. Temperature and humidity was adjusted little bit lower and this solved the issue, no more complaints from patients or reports from users regarding unclear images.

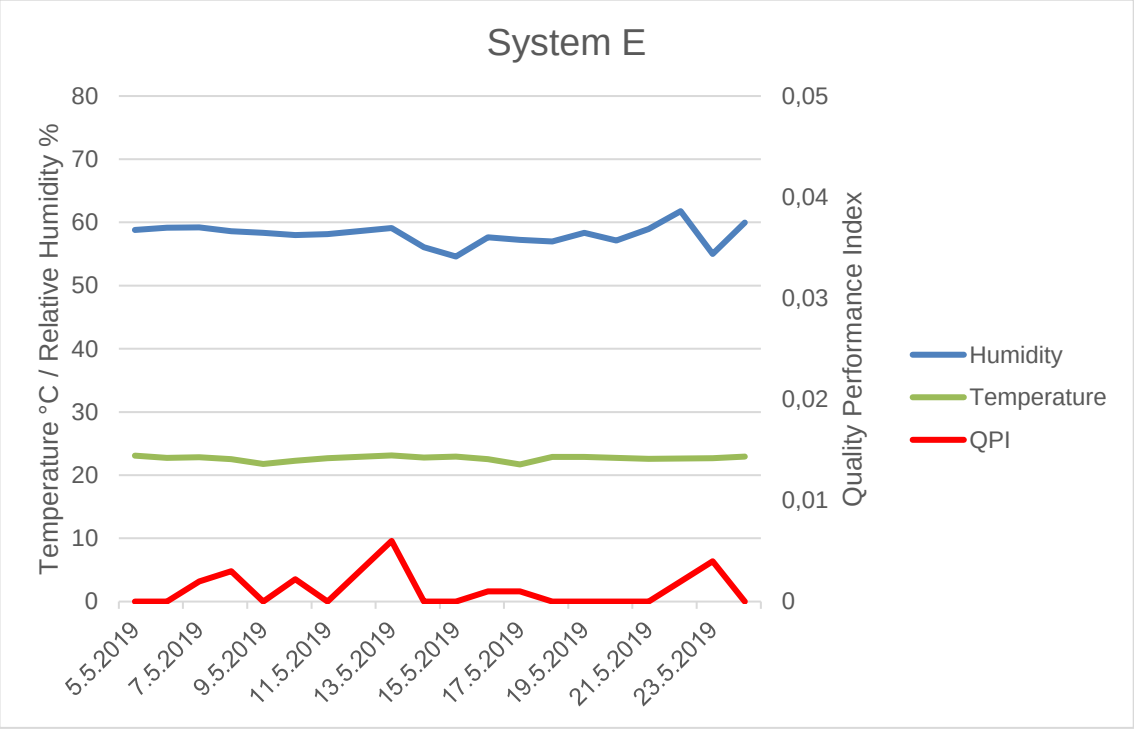


Figure 27 System E. Small QPI values, with high temperature and humidity

5 Conclusion and summary

Reading and understanding manufacturers´ specification in the planning phase is very important and sounds simple. Manufacturers are assisting their customers with planning on an early stage. Both manufacturer and user will get benefits when working conditions are planned and implemented in a way that meets the MRI system specification. The user gets a well working system, lower downtimes because of system failures, and good image quality. The manufacturer can have benefit for sales it has a good reputation on market. Knowledge is available for planners also from specialized hospital consultants and construction planning offices. It is highly recommended to use these professionals when starting to plan new or renewing old MRI facilities. An MRI facility needs to meet all the supplier´s (MRI manufacturer´s) specifications to get the best performance that the chosen MRI system can offer and keep it in working condition at all times necessary.

Climate conditions can differ between hospital departments and this causes issues when doors are open and more humidified air gets mixed with dry air. This will cause fluctuation in important quantities, humidity and temperature. It is suggested to use the same climate condition adjustments in nearby rooms than in an MRI department. A common solution is to add an extra humidifier onto the MRI department air inlet, so that dry air can have extra humidifying when it flows into the MRI section. Specific climate conditions are most important in the MRI examination room, but if the whole MRI department has the same conditions, it is easier to keep them within specifications. Climate condition automation is a good way to keep the MRI facility within the climatic specification. Automation helps to get alarms if needed specifications are not met, for example, when a humidifier device gets broken.

The purpose of this study was to help customers make useful facilities for MRI together with their construction planners and consultants. To get the focus to the main points of the MRI facility planning, this study adds information and knowledge of the main failing points; MR image quality versus relative humidity and what this phenomenon can cause if not taken seriously. Investment into good working climatic system is not too high versus its lifetime benefits for the imaging system. The mentioned phenomenon is noticed by companies who manufacture and service MRI systems. Nowadays these quantities are monitored remotely and therefore service engineers can interfere before the issue become too bad and causes serious problems for clinic workflow.

Measured values from five different MRI system´s log file data were searched and analyzed. This phase of the study was a challenge due to different software versions on the MRI systems. All systems had all the needed data for this study, but older systems had the data in a specific format, which meant that the data was not so easily found. Newer systems got log data on more understandable format and it was easier to process it further.

The correlation between the relative humidity percent below the manufacturer´s specification and high QPI values was clearly seen from the data. Image data was not used for this study, so based on the data, it is impossible to say exactly how many scans had to be retaken.

The humidity and temperature specifications have also a high limit, a patient can feel him/herself uncomfortable which makes the patient nervous and to move a little. This also leads to unsuccessful scans. Climate condition fine tuning near the MRI system is the easiest way to have stable conditions in an MRI department. Climate conditioning system needs to be able to adjust to wintertime conditions when moisture needs to be added to the air, but also to be able to dry the air if it is getting too moist. Temperature is also important to be kept within given limits, because with high moisture and too warm conditions will make the patient uncomfortable.

All this data can be measured by facility automation services. Instruments need to be added to airducts to get the same information as measured by an MRI system. Facility service can interfere when the issue grows too big and affects imaging department workflow. The facility will get this investment back due to faster patient turnaround times, lower service part expenses and less downtime for the MRI system. They can also get added value for it with energy savings when adjustments are faster, easier and more automatized. [9, 23]

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```
                          findstr
Searches for strings in files.

FINDSTR [/B] [/E] [/L] [/R] [/S] [/I] [/X] [/V] [/N] [/M]
[/O] [/P] [/F:file]
        [/C:string] [/G:file] [/D:dir list] [/A:color
attributes] [/OFF[LINE]]
        strings [[drive:][path]filename[ ...]]

  /B         Matches pattern if at the beginning of a line.
  /E         Matches pattern if at the end of a line.
  /L         Uses search strings literally.
  /R         Uses search strings as regular expressions.
  /S         Searches for matching files in the current
directory and all
             subdirectories.
  /I         Specifies that the search is not to be
case-sensitive.
  /X         Prints lines that match exactly.
  /V         Prints only lines that do not contain a match.
  /N         Prints the line number before each line that
matches.
  /M         Prints only the filename if a file contains a
match.
  /O         Prints character offset before each matching
line.
  /P         Skip files with non-printable characters.
  /OFF[LINE] Do not skip files with offline attribute set.
  /A:attr    Specifies color attribute with two hex digits.
See "color /?"
  /F:file    Reads file list from the specified file(/ stands
for console).
  /C:string  Uses specified string as a literal search
string.
  /G:file    Gets search strings from the specified file(/
stands for console).
  /D:dir     Search a semicolon delimited list of directories
  strings    Text to be searched for.
  [drive:][path]filename
             Specifies a file or files to search.
```

HUS

Potilasohje
HUS Kuvantaminen
Radiologia

www.hus-kuvantaminen.fi
www.tutkimukseen.fi

Magneettitutkimuksen esitietolomake

Täytä esitietolomake huolellisesti ja ota se mukaan tutkimukseen.

Nimi _____ **Henkilötunnus**_____

Puhelinnumero _____ **Pituus** _____ cm **Paino** _____ kg

Turvallisuutesi tutkimuksessa on meille tärkeä. Vastaa alla oleviin kysymyksiin.

	Kyllä	Ei
Onko sinulle tehty leikkauksia?		
Onko sinulla kehossa vierasesineitä?		
Kysymys naisille: Oletko raskaana?		
Onko sinulla jokin seuraavista? Jos vastaat johonkin alla olevaan "KYLLÄ", soita saapumisohjeessa olevaan puhelinnumeroon.		
Sydämentahdistin tai tahdistinjohdot		
Hermostimulaattori tai stimulaattorijohdot		
Valtimopullistuma(aneurysma)- tai leikkausklipsit tai koilit		
Sisä- tai välikorvaproteesi		
Sydämen keinoläppä		
Lääkeainepumppu		
Metallisirpaleita kehossa		
Aivokammiosuntti		
Rinnan laajenninproteesi (expander)		

Glukoosisensori, lääkelaastari ja/tai kuulolaite on poistettava kuvausta varten.

Keinonivel, sterilisaatioklipsit, hammasproteesit tai -raudat eivät yleensä estä kuvauksen tekemistä. Jos sinulla on implanttikortti, ota se mukaasi.

_____

Päiväys ja allekirjoitus

Voimaantulopäivä: 18.9.2019
Tunniste: 2450