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Calorie expenditure calculation in a gym environment

– Calorie expenditure calculation parameters and data visualization

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Bachelor’s Thesis | Abstract

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Calorie expenditure calculation in a gym environment

– Calorie expenditure calculation parameters and data visualization

Calorie expenditure calculation during exercise has become an important tool in gym environments. People are trying to improve their health every day and calculating calories accurately allows to give people an understanding of what they can do about their energy expenditure and general health. In Finland, we have seen a significant increase in obesity and many people have had their lifestyle choices degraded because of the pandemic and other factors.

The purpose of this thesis was to provide an exercise calorie calculation formula, user interface, and data visualization solution for David Health Solutions. David Health Solutions develops biomechanically optimized equipment for musculoskeletal rehabilitation and cardio exercise equipment. They are in the need of an accurate calorie calculation method that can be implemented into gym environments. The method needs to be feasible without excess work or devices but the calculation formula should be adequately accurate to provide their clients with quality service.

The solution was made from a medical environment perspective because the solution is also meant to be utilized in rehabilitation where the client will be using the system. In the data presentation suggestion, there are features and design solutions that help the client to navigate and read the data. Data presentation and user interface were designed using AdobeXD. The amount of data provided has been considered carefully to suit the client’s needs and what they can use to improve their health. A solution was created that met the requirements.

As a result, the suggested activity associated calorie calculation formula consists of heart rate, VO_2max, age, length, weight, and exercise duration. The solution uses an InBody770 bioimpedance measurement device to measure body composition, and an electrocardiography-based chest strap electrode to measure heart rate with Firstbeats beat-to-beat technology. In addition, the solution calculates an empirical estimation of VO_2max and measures the client’s length.

Keywords: Calorie calculation, energy expenditure, metabolic rate, kilocalories, weight, heart rate, oxygen uptake

Koulutus Tieto ja Viestintätekniikka

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Timo Kalaoja

Kalorikulutuslaskenta kuntosaliymäristössä

- Kalorikulutuksen laskentaparametrit ja tulosten esittäminen

Kalorikulutuksen laskennasta harjoituksen aikana on tullut tärkeä työkalu kuntosaliympäristöissä. Ihmiset yrittävät parantaa itseään päivittäin, ja kalorien laskeminen tarkasti antaa ihmisille käsityksen siitä, mitä he voivat tehdä energiankulutukselleen ja yleiselle terveydelleen. Suomessa lihavuus on lisääntynyt merkittävästi ja monien ihmisten elämäntapavalinnat ovat huonontuneet pandemian ja muiden tekijöiden vuoksi.

Tässä opinnäytetyössä ehdotettu liikunnan aikana kulutettujen kalorien laskentakaava ja datan esitysratkaisu on tehty David Health Solutionsille. David Health Solutions kehittää biomekaanisesti optimoituja kuntolaitteita tuki- ja liikuntaelimistön kuntouttamiseen ja cardiolaitteita. He tarvitsevat tarkan kalorien laskentamenetelmän, joka voidaan toteuttaa kuntosaliympäristössä. Menetelmän on oltava toteutettavissa ilman ylimääräistä työtä tai laitteita, mutta laskentakaavan on oltava riittävän tarkka, jotta voidaan tarjota asiakkaille laadukas palvelu.

Ratkaisu on valmistettu lääkinnällisten laitteiden näkökulmasta, koska ratkaisua käytetään myös kuntoutuksessa, jossa asiakas käyttää järjestelmää. Tietojen esityksessä on ominaisuuksia ja suunnitteluratkaisuja, jotka auttavat asiakasta navigoimaan ja lukemaan tietoja. Tietojen esitys ja käyttöliittymä suunniteltiin AdobeXD ohjelmaa hyödyntäen. Annettujen tietojen määrää on harkittu huolellisesti vastaamaan asiakkaiden tarpeita ja sitä, mitä he voivat käyttää itsensä parantamiseen. Ratkaisu luotiin, joka täytti nämä vaatimukset.

Ehdotettu aktiivisuuteen liittyvä kalorien laskentakaava koostuu sydämen sykkeestä, VO_2max, iästä, pituudesta, painosta ja liikunnan kestosta. Ratkaisu käyttää InBody770 bioimpedanssimittauslaitetta kehon koostumuksen mittaamiseen, elektrokardiografiaan perustuvaa sykevyöelektrodia sydämen sykkeen mittaamiseen Firstbeatin beat-to-beat -tekniikalla. Lisäksi ratkaisussa mitataan asiakkaiden pituus sekä arvioidaan empiirisesti asiakkaiden VO2max.

Asiasanat: Kalorilaskenta, energiankulutus, aineenvaihduntanopeus, kilokalorit, paino, syke, hapenottokyky

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List of Abbreviations

AEE	Physical activity-associated energy expenditure
BMI	Body mass index
BMR	Basal metabolic rate
bpm	Beats per minute
EE	Energy expenditure
Fat %	Fat percentage
HR	Heart rate
kcal	Kilocalories
LBM	Lean body mass
MET	Metabolic equivalents
PEEE	Post-exercise energy expenditure
REE	Resting energy expenditure
RR	Respiration rate
RRI	Respiration rate interval
TEF	Thermic effect of food
VO2	Oxygen consumption
VO2max	Maximal oxygen consumption

1 Introduction

Calculating calorie expenditure has been an important part of many people’s lives for some time now. It allows us to monitor how many calories we need for the amount we do physical work and what it requires from us to lose weight. In the last decade, there have been major developments in what technologies we can use to determine calorie expenditure and the actual well-being of the body.

The goal of this thesis was to search the literature for an accurate calorie expenditure calculation method and to develop a data presentation and user interface for the data. This thesis was commissioned by David Health Solutions. The suggested calculation formulas and the data gathering methods are designed for gym and rehabilitation environments. This affects how the data needs to be presented to the client and slightly restricts the method’s accuracy because not all methods that can be used to measure different information from the body are fit for such an environment. Also, some of the available information that we can obtain from the body does not benefit the accuracy of the calculation result enough for the extra work and devices required.

The thesis is structured as follows.

The introduction to the background and objectives of this thesis are introduced in Chapter 1.

The theory of calorie expenditure calculation is covered in Chapter 2. The accuracy of some different methods is compared, and the impact of variables has been examined.

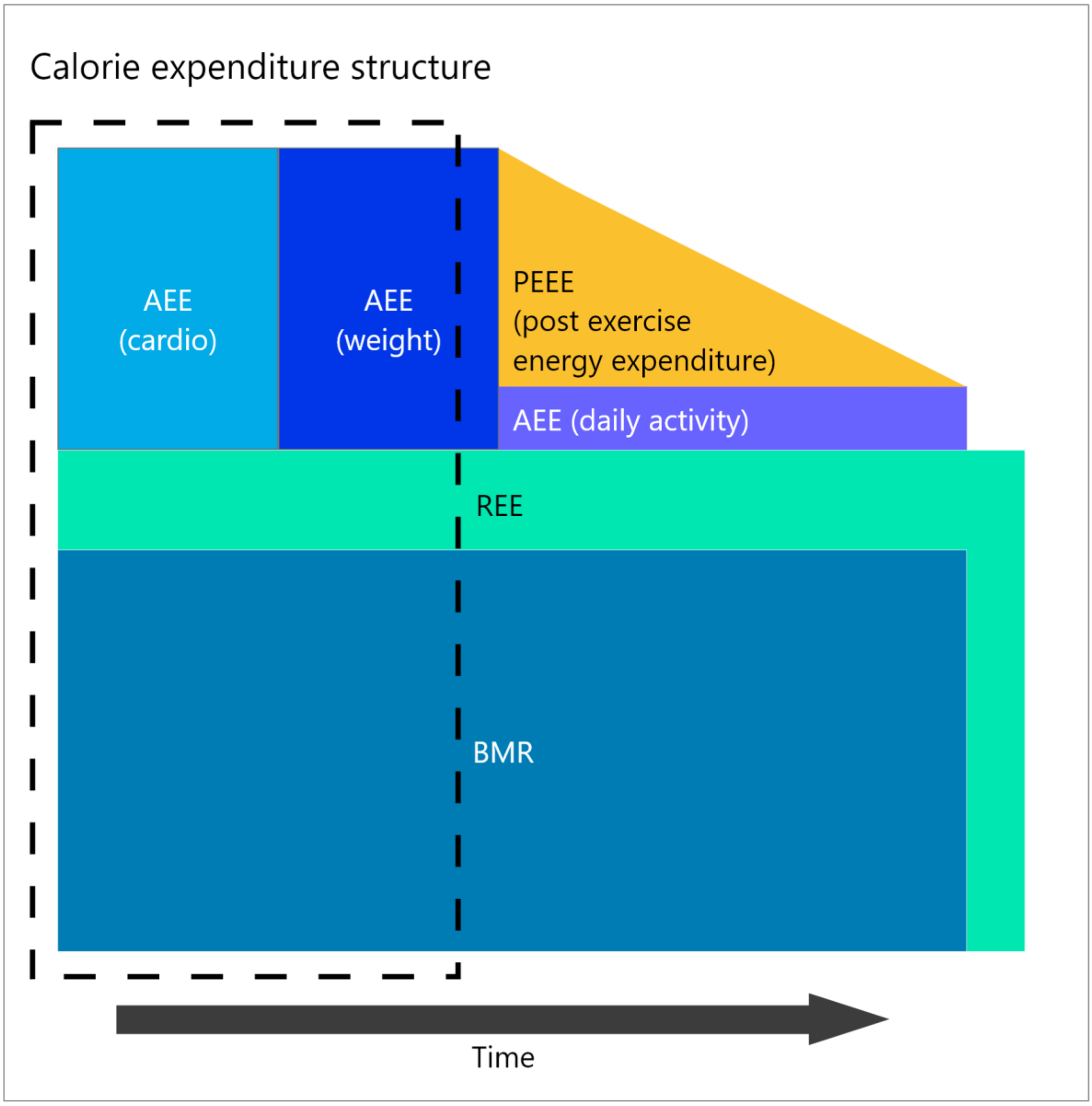
The methods and technologies required for the solution are covered in Chapter 3. This includes body composition measurement, heart rate measurement, and the technologies required for the calculation method and why these benefit the result considerably.

The calorie calculation formulas used in the solution of this thesis are discussed in Chapter 4.

Data presentation and user interface solutions are presented in Chapter 5. The chapter presents a suggestion on how to present the data efficiently and clearly to the client with all the necessary data which they can use to improve their health. It has been taken into consideration that the user interface can be used by any kind of individual.

2 Calorie expenditure theory

Consumed calories are quite a simple concept and quite self-explanatory. Calorie expenditure however consists of a few different components and it is much more complex. Resting energy expenditure (REE) or basal metabolic rate (BMR) is the majority of it, as presented in Picture 1. The REE is the energy requirement for basic daily tasks and body functions while the BMR is when the body is at rest in the absence of external work. The REE includes some everyday walking, body temperature fluctuation, eating, and other little factors that affect our energy expenditure. The BMR does not include these everyday actions, so it is the pure number of what the human body needs to function and stay alive. (Pavlidou et al., 2018; InBody methods., 2021) Usually, only one of these is presented, but both are important to understand for the solution and it potentially adds a layer of understanding of the subject for the client. The REE is dependent on the lean body, fat-free mass, and accounts for 50-75% of the total energy expenditure (TEE). This varies among different people considerably because of the size of external organs and differences in metabolic rates. Physical activity is a part of calorie expenditure and it includes exercising or any other physical activity we do on the daily basis. The smallest part is the thermic effect of food (TEF). The TEF is the energy associated with a postprandial rise in metabolic rate and covers energy expended to process food. This amounts to about 10% of ingested calories but it can vary greatly depending on the portions of different micronutrients in the body, thus being 5-30%. When lean body mass is lost over time it will lower the resting energy expenditure. (Pavlidou et al., 2018; InBody methods., 2021)



Picture 1. Calorie expenditure structure.

There are a few different formulas to calculate the REE but the most commonly used one is Weir's equation. This formula is used with indirect calorimetry that is not utilized in the solution of this thesis:

$$kREE(in\ kcal/day) = [(VO2 * 3.941) + (VCO2 * 1.11)] * 1440$$

Equation 1. Resting Energy Expenditure, Weir's equation. (Delsoglio *et al.*, 2019)

When calculating BMR, the Cunningham equation was found the most convenient for the solution based on the available literature, because we will be using the InBody 770 body composition measurement device and it directly provides us with the result. However, the device will calculate BMR using lean body mass (LBM) so BMR will react if the client gains LBM between sessions, leading to an increase in BMR. This is desired effect in any weight management program. Cunningham equation is more accurate on healthier subjects. (InBody 770, 570 Manual., 2020)

$$BMR(kcal/day) = (21.6 * LBM) + 370$$

Equation 2. Basal metabolic rate Cunningham equation when LBM is in kilograms. (InBody 770, 570 Manual., 2020)

Total energy expenditure (TEE) is the sum of the basal metabolic rate (BMR) and the basic daily activities and changes occurring in the body included in resting energy expenditure (REE), but after that, we need to take into account physical activity and or exercise which is usually 20-40% of the value. (Pavlidou *et al.*, 2018)

When looking at calorie expenditure when exercising, there are several factors to count in such as physical condition, heart rate, weight, exercise duration, and VO_2max. There are many other values that can be used to make the calculation more accurate, for example, body heat, corrective multipliers that are based on previous scientific research on exercise, or other factors such as body composition. The formula presented in this thesis consists of VO_2max, heart rate, and energy expenditure calculated by using the information on metabolic events occurring in the body. The most accurate method of calculating energy expenditure in a gym setting that was found for this thesis consisted of heart rate, weight, age, metabolic equivalent, exercise duration, and calculated VO_2max. Equation is the short version of the formula that is suggested for David Health Solutions gym devices. The formula will be explained in Section 2.1 and with more detail in Chapter 4. (Montgomery et al., 2009; Swain and Franklin, 2002; Rotariu et al., 2015)

$EE_{HR+VO2max}$

Equation 3. Short version of the physical activity-associated energy expenditure (AEE) formula (Montgomery et al., 2009; Swain and Franklin, 2002; Keytel et al., 2005; Firstbeat Technologies Ltd., 2007a.; Rotariu et al., 2015).

2.1 Calculation formula

This section is about the formula for calculating calorie expenditure during exercise that was found the most efficient and accurate for the solution of this thesis based on previous studies. The formula is built on corrective multipliers and the relationship between heart rate and VO_2max. (Montgomery et al., 2009; Pulkkinen et al., 2005; Spurr et al., 1988; Ceesay et al., 1989; K. Rennie et al., 2001; Swain and Franklin, 2002; Hiilloskorpi et al., 2003; Keytel et al., 2005b; Firstbeat Technologies Ltd., 2007a; Rotariu et al., 2015)

Here is the solution for physical activity-associated energy expenditure (AEE) calculation:

$$AEE_M = ((-95.7735 + (0.634 * HR) + (0.404 * VO2max) + (0.394 * W) + (0.271 * A))/4.184) * 60\, x\, T$$

Equation 4. Male physical activity-associated energy expenditure (AEE) (Rotariu *et al.*, 2015).

$$AEE_F = ((-59.3954 + (0.45 * HR) + (0.380 * VO2max) + (0.103 * W) + (0.274 * A))/4.184) * 60\, x\, T$$

Equation 5. Female physical activity-associated energy expenditure (AEE) (Rotariu *et al.*, 2015).

Where VO_2max is calculated: $VO2max = 1.5472 * (208 - (0.7 * A))$

Equation 6. Empirical estimation of VO_{2max} (Swain and Franklin, 2002).

A = age, HR = heart rate(bpm), W = weight(kg), T = exercise length in hours

The mean absolute error (MAE) and mean absolute error percentage (MAPE) in Table 1 for the suggested method $EE_{HR+VO2max}$ is based on the results of referenced studies and is a theoretical estimate. The validation of the methods was similar but not exactly the same so there can be some variance. $EE_{HR+Resp+ON/OFF}$ is estimation method developed by Firstbeat Technologies that uses respiration rate intervals and beat-by-beat heart rate measurement to provide accurate AEE estimates (Pulkkinen et al., 2005; Firstbeat Technologies Ltd., 2007). The solution of this thesis $EE_{HR+VO2max}$ uses an empirical estimation of VO_{2max} and its linear relationship to heart rate during moderate physical activity to give an accurate estimate of AEE (Rennie et al., 2001; Keytel et al., 2005; Firstbeat Technologies Ltd, 2007a; Rotariu et al., 2015). EE_{KEY} uses the same principles as $EE_{HR+VO2max}$, but it is not as accurate because of the values used with VO_{2max} and gender (Keytel *et al.*, 2005b). $FLEX_{IND}$ and $FLEX_{GEN}$ were developed using flex heart rate theory when doing light exercise using the relationship between heart rate and energy expenditure (Spurr et al., 1988; Ceesay et al., 1989; Rennie et al., 2001). EE_{RENN} was also developed using the relationship between heart rate and energy expenditure without individual calibration (Rennie et al., 2001). EE_{HIIL} uses the relationship between heart rate and oxygen uptake to estimate EE from low to high physical activity (Hiilloskorpi *et al.*, 2003). Chapter 4 presents in-depth information on AEE calculation and background details of the suggested formula.

Table 1. Mean absolute error (MAE) and mean absolute error percentage (MAPE) of different calculation formulas and methods. (Rennie et al., 2001; Keytel et al., 2005; Firstbeat Technologies Ltd, 2007a; Rotariu et al., 2015)

Method	MAE (kcal)	MAPE
$EE_{HR+Resp+ON/OFF}$	73	10.90%
$EE_{HR+VO2max}$	86	12.30%
EE_{KEY}	92	13.30%
$FLEX_{IND}$	93	13.50%
$FLEX_{GEN}$	101	14.40%
EE_{RENN}	181	22.00%
EE_{HIIL}	180	27.60%

2.2 Accuracy

The calculation accuracy is dependent on the variables used, the method used to acquire the information, possible corrective multipliers, and the impact of the variable. The impact of the variables is very dependent on the environment where the measurements are performed and what the client has eaten, how much liquid is in their body, have they performed physical activity, how well they have rested and if they have consumed caffeine or other drugs that affect the body and generally what is their physical condition as a whole. (Keytel *et al.*, 2005b; Shaughnessy, 2019)

In a gym environment, many of these values may vary between visits if you do not have an exact schedule to do everything. This is why it is important to measure the values for the calculation preferably every time the client visits if they want the optimal results, but it is not a necessity. Therefore, in the suggestion bioimpedance measurement results were avoided to be used too much in the calculation, because it would have made it a necessary step for every visit. However, for measuring basal metabolic rate it is not necessary to do the measurement every time for it to be reliable because our lean body mass is not changing so drastically in a short period of time. (Keytel *et al.*, 2005b; Shaughnessy, 2019)

The most important variables in the calculation formula for calorie calculation during exercise are heart rate and oxygen intake. These variables tell us how the exercise is going, how much the client's body is doing work, and how much they are burning calories. These variables can however be disturbed by multiple factors. There are some troubling factors such as stress, caffeine consumption, smoking, and hydration. All of these can affect the client's breathing and heart rate, and it will affect the calculation result in a negative way. (Keytel *et al.*, 2005b; Shaughnessy, 2019)

3 Methods and technologies

There have been major developments in what methods we can use to gather information about the human body and some technologies that have enhanced both new and old methods. In the solution of this thesis, there are a few of these that have been taken to use. The main factors that make the AEE calculation formula so accurate are that the heart rate data used is accurate and the body mass of the client is known. Body composition is also important for the solution in data presentation because it allows to provide an idea of how healthy the body really is. (Montgomery et al., 2009; Swain and Franklin, 2002; Firstbeat Technologies Ltd., 2007a; InBody., 2021; Rotariu et al., 2015)

3.1 Methods

Body composition measurement is used to determine for example how much there are liquids, minerals, proteins, and fat in the human body. In the solution of this thesis, bioimpedance measurement is used. With this data, we can determine how much there is muscle mass and fat mass in the different parts of the body. Before body composition measurements became generalized the accuracy of calorie expenditure calculation and presentation of body mass data were done by measuring weight or body mass index. These methods can improve the result, but they mostly give information about the size of the body and not enough about the well-being of the body and the changes occurring in it. The method of measuring liquids, minerals, proteins, and fat (4-component model) is considered the most accurate modeling of body composition, and it takes into account the quality of the skimmed mass. (Ling et al., 2011; InBody., 2021)

Body composition data can be utilized in the suggested formula to improve the outcome accuracy, but it will not make enough of an impact to make the extra work worth the effort. However, it is suggested for the solution that body composition data be used in the data presentation as an indicator of the well-being of the body and for calculating BMR. (Ling et al., 2011; InBody., 2021)

There are many ways to measure body composition, but some are difficult to use in certain environments such as gyms or physical therapy premises. Here are some methods to measure body composition: bioimpedance measurement, computed tomography (CT imaging), DEXA (X-ray measurement), water weighing and body densitometry, and skin action measurement. Out of these methods, bioimpedance measurement is the easiest to perform. It is also versatile, it provides the whole 4-component model and it gives accurate results. The other ones have some negative properties in them: some require more and larger devices, some of them require certain environmental conditions, some of them can not get all the 4 components and some of them can have side effects. (Ling et al., 2011; InBody., 2021)

Different tissues react differently when electricity runs through them. Liquid alone without other tissue conducts electricity and fat acts almost like an insulator. This conductivity of different tissues is measured by bioimpedance. When different frequencies are used it is possible to get more data and more accurate data that we can use to determine the ratio of intracellular and external fluid in different parts of the body, as well as information about the condition of cells. (Ling et al., 2011; InBody., 2021)

The device measures the amount of fluid and after that skimmed mass. Previous validation studies show that it is very important to get an accurate result of the skimmed mass. When the fat-free mass is correctly determined, the fat mass and fat percentage are also correctly determined. (Ling et al., 2011; InBody., 2021)

Through the electrodes, the device measures resistance and reactance, and these values form an impedance. Resistance is a measurement variable for the amount of water in the body. When the amount of water increases as the length remains the same, the resistance decreases. Reactance is caused by cell walls and is a measurement variable of cell mass. Healthy cell walls act as insulation and cause reactance. As the cell mass increases with the same length, reactance also increases. (Ling et al., 2011; InBody., 2021)

When multiple different frequencies are used the results can be made a lot more accurate, for example, 1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz, and 1000 kHz for each of the body segments. Different frequencies move through the body differently. High frequencies penetrate cell walls and measure all water in the body and low frequencies do not penetrate cell walls and only measure the cell's external water. With the different body mass data gathered and the liquid data, the quality of fat tissue can be determined. Some devices are able to measure fluid balance as an average of the whole body and some can measure fluid balance in addition to broken down from different parts of the body. However, when breaking down the value to different parts of the body there needs to be additional electrodes. The measurement of the midbody is the most difficult task but also the most important. Midbody covers about 50% of the body weight and most important parts that affect our health. The slightest change in impedance will contribute a lot to the kilogram results, the accuracy affecting parts must be really well implemented. (Ling et al., 2011; InBody., 2021)

It should be noted that bioimpedance measurement cannot be performed on subjects with implanted electronic devices, metallic prostheses, or missing limbs. The measurement is also inaccurate for subjects with extreme body weight and/or abnormal hydration status. (Ling et al., 2011; InBody., 2021)

3.2 Technologies

Body composition – Bioimpedance – InBody770

InBody770 is a bioimpedance measuring device that is able to make a full 4 component (fat, body water, minerals, protein) model of body composition. The basic steps to perform a body composition measurement with the device starts with pre-measurement values, weight, and length that are used to determine body volume. Then the client steps on the device that has an electrode surface, and the other electrodes are placed on the body. When the device is started it sends safe small electrical impulses from the electrodes between all the other electrodes and measures the changes caused by the body to the electric current. The measurement duration depends on the device and what information they are trying to gather and how accurate they want the data to be. The duration of measurement can be for example 10 to 180 seconds. After this, the device gives immediate and extensive quantitative values of various body composition parameters. (Ling et al., 2011; InBody., 2021)

These parameters are separated into nine different groups. The first group is body composition which is divided into the moisture of the body, protein, minerals, and fat. The second group is the diagnosis of body fat, which is divided into weight, muscle mass, and fat mass. The other seven groups are as follows, weight diagnosis which includes BMI and fat percentage, muscle balance between different body parts, the fluid balance which is the ratio of extracellular water to total body water, measurement history, fat segments, weight control suggestions, and body impedance values when using different frequencies on different body parts. (Ling et al., 2011; InBody., 2021)

More information can be found in Attachment 1 which, is a bioimpedance report created by the device. (InBody., 2021)

Maximal oxygen uptake

For this solution, VO_{2max} is calculated with prediction equations but the measurement is possible with a portable indirect calorimetry device if necessary. VO_2max can be calculated with the client's age and a few different multipliers as follows:

$VO_2max = 1.5472*(208-(0.7*A))$ (Swain and Franklin, 2002)

Heart rate – Firstbeat – beat-by-beat technology

Beat-by-beat is a HR analysis method developed by Firstbeat that provides more accurate results on heart rate data. More accurate heart rate data makes the results for calculating energy expenditure more accurate in most conditions. (Pulkkinen et al., 2005; Firstbeat Technologies Ltd., 2007)

Firstbeat also has their own way of calculating energy expenditure where $EE_{HR+Resp+ON/OFF}$ was derived from respiration rate interval (RRI) using a specialized neural network method that uses information of heart rate, RRI-derived respiration rate and on- and off-dynamics (Firstbeat Technologies Oy, Jyväskylä, Finland). No individual fit for HR to EE equation. Parameters include maximal metabolic equivalent (MET), maximal heart rate, and maximal respiration rate. Comparable accuracy to the method suggested, (error 7- 10%), and it does not require laboratory calibration. The method provides a second-by-second estimation of EE. (Pulkkinen et al., 2005; Firstbeat Technologies Ltd., 2007)

4 Calorie calculation

The suggested calculation formula in this thesis for AEE calculation has been developed by a few different parties. First, it was introduced in a study, by Keytel et al., 2005 where the aim of the study was to further characterize the factors that influence the relationship between energy expenditure and heart rate. They developed prediction equations leaning on their study and a previous study, Rennie et al., 2001. (Montgomery et al., 2009; K. Rennie et al., 2001; Swain and Franklin, 2002; Keytel et al., 2005b; Rotariu et al., 2015)

The equations were as follows:

$$EE = -59.3954 + gender * (-36.3781 + 0.271 * A + 0.394 * W + 0.404 * VO_{2max} + 0.634 * HR) + (1 - gender) * (0.274 * age + 0.103 * W + 0.380 * VO_{2max} + 0.450 * HR)$$

Equation 7. AEE calculation (Keytel *et al.*, 2005a).

And a second model, which contained no measure of fitness:

$$EE = gender * (-55.0969 + 0.6309 + HR + 0.1988 * W + 0.2017 * A) + (1 - gender) * (-20.4022 + 0.4472 * HR - 0.1263 * W + 0.074 * A)$$

Equation 8. EE calculation (Keytel *et al.*, 2005a).

Where gender is 1 for males and 0 for females.

The equations were proven quite accurate in predicting AEE and EE. The AEE formulas are included in Table 1 as EE_{KEY} and the previous study that they utilized is included as EE_{RENN}. (K. Rennie *et al.*, 2001; Keytel *et al.*, 2005b)

The equation was developed further in a study, by Rotariu et al., 2015 where genders and maximal oxygen consumption were taken more deeply into consideration referring to, Montgomery et al., 2009 and empirical estimation of VO_{2max}, Swain and Franklin, 2002. These factors made the formula more accurate in most environments. (Montgomery et al., 2009; K. Rennie et al., 2001; Swain and Franklin, 2002; Keytel et al., 2005b; Rotariu et al., 2015)

Equations for physical activity-associated energy expenditure (AEE) calculation:

$$AEE_M = ((-95.7735 + (0.634 * HR) + (0.404 * VO_{2max}) + (0.394 * W) + (0.271 * A))/4.184) * 60\, x\, T$$

Equation 9. Male AEE (Rotariu *et al.*, 2015).

$$AEE_F = ((-59.3954 + (0.45 * HR) + (0.380 * VO_{2max}) + (0.103 * W) + (0.274 * A))/4.184) * 60\, x\, T$$

Equation 10. Female AEE (Rotariu *et al.*, 2015).

Where VO_2max is calculated: $VO_{2max} = 1.5472 * (208 - (0.7 * A))$

Equation 11. Empirical estimation of VO_{2max} (Swain and Franklin, 2002).

A = age, HR = heart rate(bpm), W = weight(kg), T = exercise length in hours

This calculation formula was chosen for the solution because it uses heart rate and VO_{2max} to accurately define the exercise performance and how it impacts energy expenditure depending on the client's body weight and age. Heart rate and oxygen consumption have a linear relationship during moderate physical activity and this calculation formula gives accurate estimates as long as the data is accurate. (Swain and Franklin, 2002; Rotariu *et al.*, 2015) However, when calculating energy expenditure during weight training and the PEEE of any form of exercise it gets more tricky. Then there are more factors to consider such as the physical condition of the client that can be estimated in a gym environment with weight, LBM, respiration rate, VO_2 dynamics, and heart rate. These parameters can be very difficult to measure in a gym environment without at least a portable indirect calorimetry device. This can also be estimated with different blood pressure data, but it is not a suitable method for the environment. (Haddock and Wilkin, 2006; Adeel *et al.*, 2021) The value can be estimated with MET values in a gym environment, but then the result will be tied to the exercise estimated MET value and its correlation with weight and age of the client. This does not take into account the actual physical condition of the client. (Ainsworth *et al.*, 2000, 2011; Adeel *et al.*, 2021)

REE is calculated in the solution with Harris-Benedict equation adjusted by Tanita:

$$REE_F = 655.10 + (9.56\, x\, W) + (1.85\, x\, H) - (4.68\, x\, A)$$

Equation 12. Female REE, Harris-Benedict equation adjusted by Tanita. (Stubelj, Teraž and Poklar Vatovec, 2020)

$$REE_M = 66.47 + (13.75\, x\, W) + (5\, x\, H) - (6.76\, x\, A)$$

Equation 13. Male REE, Harris-Benedict equation adjusted by Tanita. (Stubelj, Teraž and Poklar Vatovec, 2020)

This equation has been proven accurate, especially with healthy people. If the client is noticeably overweight there is a second formula for the solution:

$$REE_F = (7.18 * W) + 795$$

Equation 14. Female REE for overweight adults, (Owen *et al.*, 1986, 1987).

$$REE_M = (10.2 * W) + 879$$

Equation 15. Male REE for overweight adults, (Owen *et al.*, 1986, 1987).

Two different equations are suggested in this solution because while Harris-Benedict equation adjusted by Tanita gives an accurate estimation of REE for most people, but the equations in studies, Owen et al., 1986, 1987 give noticeably more accurate estimation when it comes to overweight adults. (Stubelj, Teraž and Poklar Vatovec, 2020)

BMR is calculated with Cunningham equation (Equation 16.) because it is the most convenient for the solution. This is because we will be using the InBody 770 body composition measurement device which can directly give us the result using this equation. However, the device will calculate BMR using lean body mass (LBM) so BMR will react to changes in LBM. For example, if the client gains LBM between sessions the BMR increases. This is desired effect in any weight management program. (InBody 770 Manual., 2020)

$BMR(kcal/day) = (21.6 * LBM") + 370$

Equation 16. BMR Cunningham equation. (LBM = Lean Body Mass, kg) (InBody 770, 570 Manual., 2020)

Calorie calculation without heart rate data

Calorie calculation without heart rate data requires the use of the client’s measured parameters, and empirical calculated estimates based on the data from scientific experimentations or calculated with MET values that can be used with the pre-measured data to give an estimate. These methods are not accurate most of the time because the physical condition, body composition, and organ sizes of the client can be very different from the average. The result of the calculation can be altered with multipliers that define the physical condition of the client to make it more accurate, but this would need physiotherapists’ attention to give the estimate. (Ainsworth *et al.*, 2000, 2011)

Here is an example of a basic equation for calculating AEE without heart rate using MET values:

$AEE = MET * W * T$

Equation 17. AEE, using metabolic equivalent values. When, AEE = kcal, MET = reference value of 3.5 ml O2/kg/min, W = weight(kg), T = exercise length in hours. (Ainsworth *et al.*, 2000, 2011)

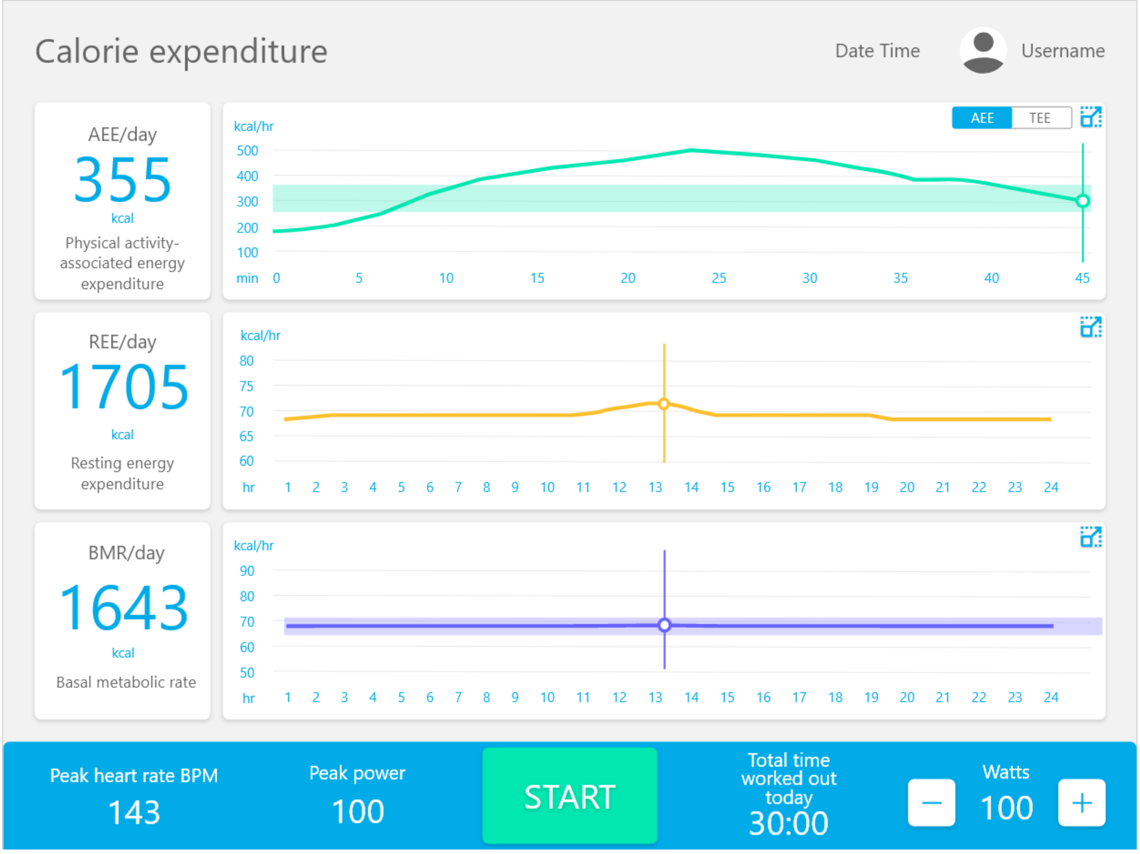
5 Data presentation

When designing a user interface for a medical environment where the client will be using the system there are many factors to consider. The solution in this thesis is used in a gym environment designed for rehabilitation purposes and regular gym purposes. This means that all kinds of people may be using the device no matter their gender, physical condition, age, race, disability, and so on. In creating this user environment many of these factors have been taken into consideration with the features and visualization. Some features are however designed in a way that may need some instruction from a physiotherapist or other staff. This is because of the amount of data that is necessary to present to give a whole picture of the well-being of the body and how the physical activities have affected the body.

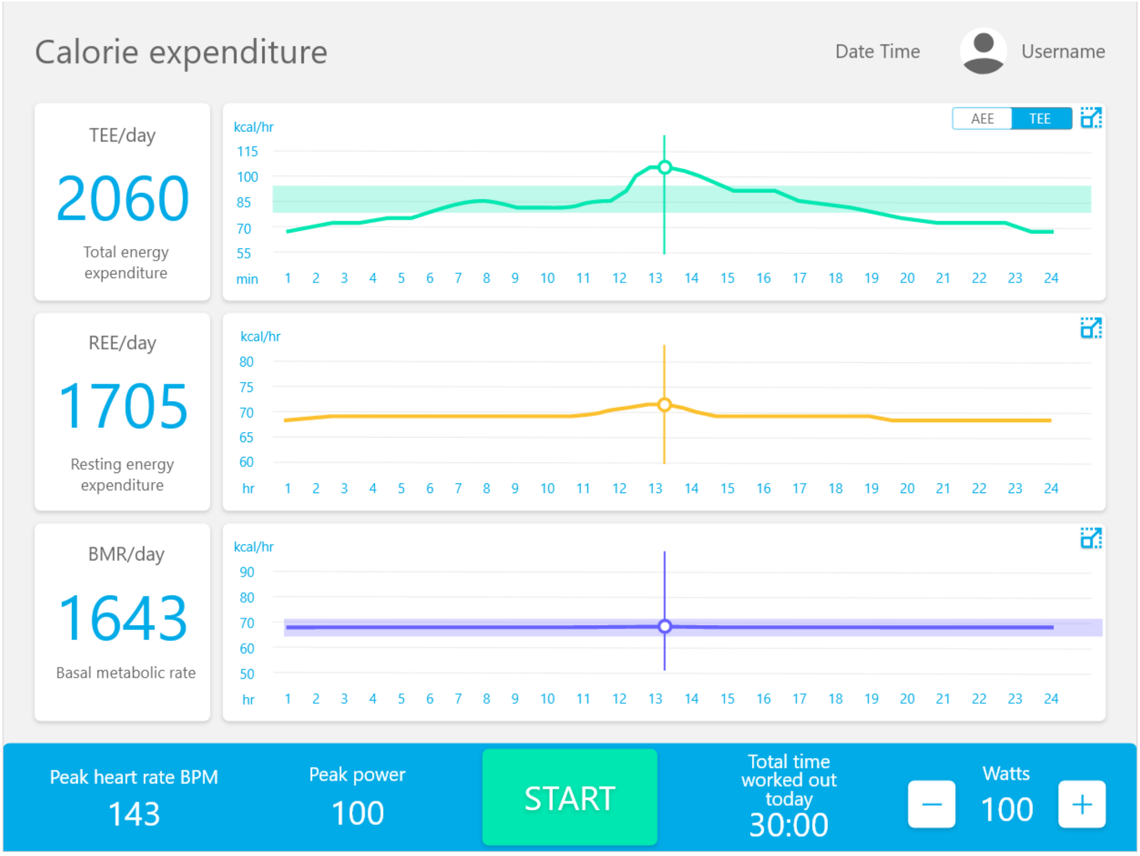
The user interfaces solutions that were taken into consideration were, for example, the font size, colors used, where the objects take the user’s attention, button placement to the sides and bottom of the touchscreen for easy access, and clear indicators on buttons that are active or inactive, abbreviation annotations, indicator lines for numbers, easily readable areas that indicate what values are on the recommendable range of values, info button for more instructions, easily accessible filters and so on. The company color palette was utilized. In the user interface descriptions, there is more information about where these solutions have been taken into consideration and why.

5.1 User interface descriptions

The simplest visualization of calorie expenditure data can be presented in two different ways when AEE, REE, and BMR are all required. As stated in the introduction calorie expenditure can be divided into a few different parts, physical activity-associated energy expenditure, resting energy expenditure, and basal metabolic rate. There is also the usually minor part of calorie expenditure, TEF, but in this solution, this is considered only in the calculation of REE. There are the three parts mentioned previously or you can switch the physical activity associated energy expenditure for total energy expenditure that technically gives the same information but in a format that gives the final value from that day. Picture 1 and Picture 2 user interface windows are meant for presenting the calorie expenditure of one day. In these line graphs, it has been taken into consideration that the values are in a logical order. The colors and position of the value and graph on the page are representing the importance of the said value (from top to bottom). Excess numbers were avoided, font size, button position, and visual changes in buttons. Every line graph has the option to make the graph larger for easier reading if you press the button on the top right corner.

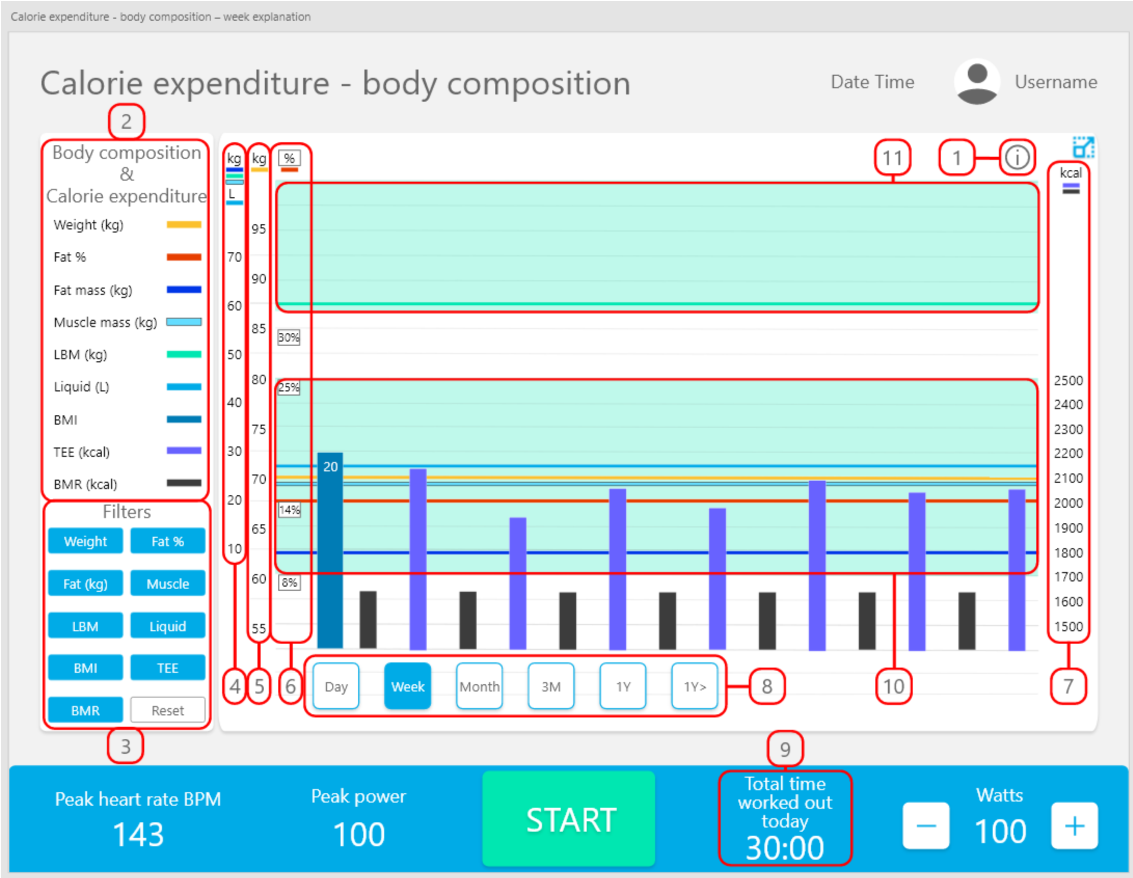


Picture 2. Calorie expenditure, AEE, REE, BMR.



Picture 3. Calorie expenditure, TEE, REE, BMR.

The Picture 4 visualization format has been made so calorie expenditure data is presented with body composition data to give the client a better understanding of their body's wellbeing and its correlation to their physical activities over time. This data can be presented with different filters and different time frames depending on how many times and how long the client is utilizing the gym's services. The basic format is used for the time frame presented and it goes as follows: one day, week, month, three months, one year, and more than a year. These are presented in Picture 4,5 , Picture 13,14 , Picture 15,16 , Picture 17,18 and Picture 19,20. This allows the client to follow their progress very closely and see the changes in their body composition and general health. Parameters presented are weight (kg), fat %, fat (kg), muscle mass (kg), LBM (kg), liquid (L), BMI, TEE (kcal) and BMR (kcal). The correlation between different parameters is shown again with how the values are positioned in the graph and highlighted areas show the recommended range of values. When only one parameter is presented in a highlighted area it only belongs to that value. If the graph is hard to read it is advisable to turn off the LBM parameter because it takes up considerable space in the graph. When reading this graph, it is important to pay attention to the colors presented with the axis as presented in Picture 4. When two parameters overlap in the graph there will be two different visual indicators, one with the color codes on the left and the second in the graph as presented in Picture 5.



Picture 4. Calorie expenditure data with body composition data, window contents 1-11.

The graph and the functionalities that come with it can be divided into 12 parts. One of the parts is settings that you can find in the right-hand corner below the profile that is not included in Picture 4. In the solution, there is an option to switch the colors and invert the window so the buttons are on the other side. Numbers and graph objects scale up in size when other parameters are turned off from the filters and there is a reset button that turns everything on and off.

Number 1 in Picture 4 is the info button where you can find the contents of Pictures 7 to 11 that include the info table of contents, data reading instructions, abbreviations, data analysis, and some theory behind the parameters.

Number 2 contains the parameters, their assigned colors, and the feature to bring up the parameters' numerical value on top of the graph.

Number 3 contains the filters that control what parameters are presented on the graph.

Number 4 is the first y-axis that contains fat mass (kg), muscle mass (kg), LBM (kg), and liquid (L).

Number 5 which is the second y-axis contains the scale for total body weight (kg).

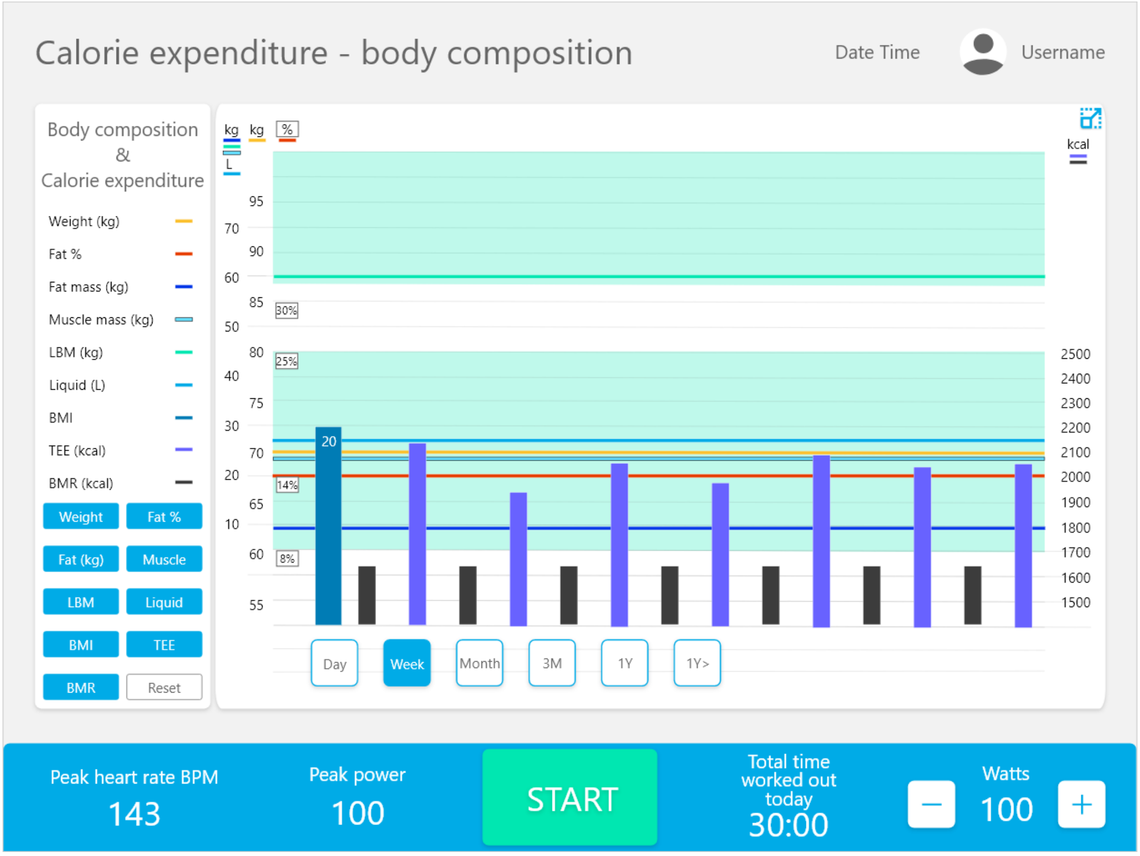
Number 6, third y-axis is the fat percentage.

Number 7, the fourth y-axis is for the kilocalories, and this changes to time averages when the timeframe is wider.

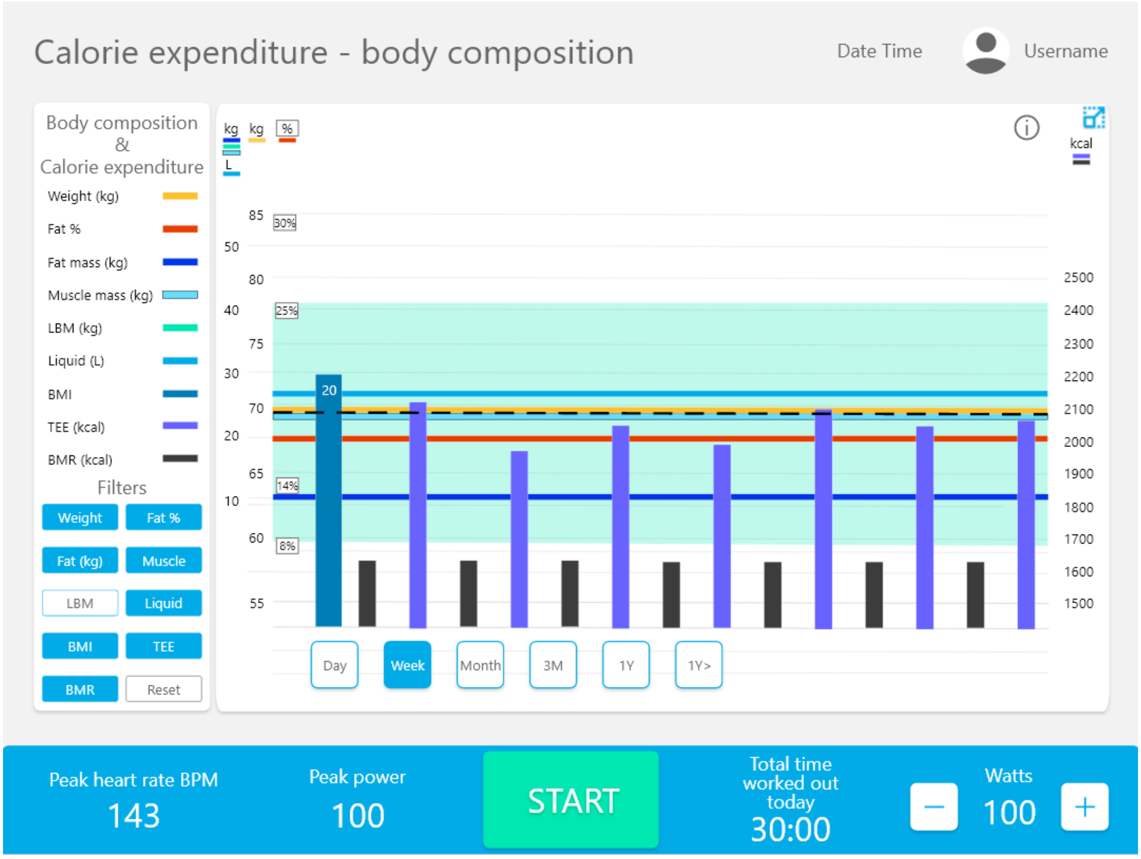
Number 8 are the buttons to change what kind of timeframe is presented in the graph.

Number 9 tells the time the client has worked out in the current day and in this solution, there is a feature to press this when you are inspecting a certain timeframe to switch the value to that timeframe.

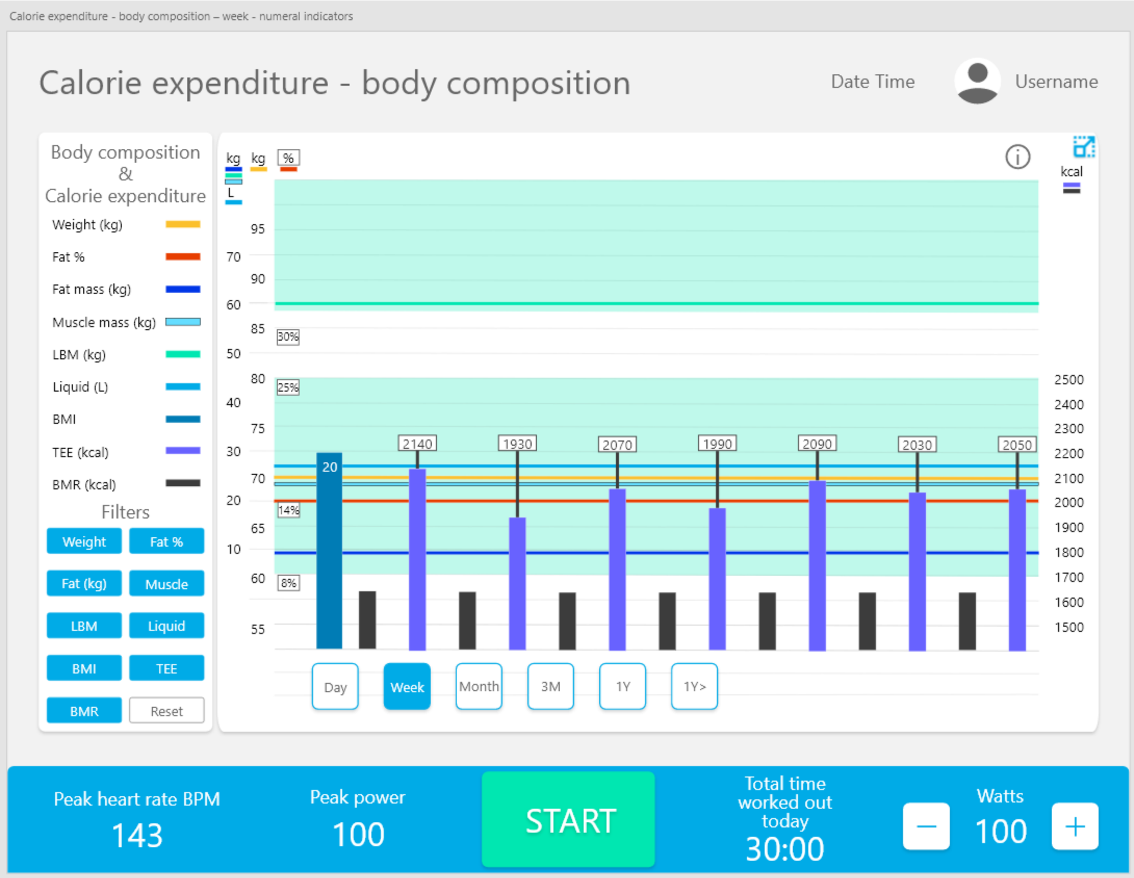
Numbers 10 and 11 are the visual representation of the recommended range of values for the parameters that are inside of it. This does not include basal metabolic rate because we can not affect it positively nor negatively.



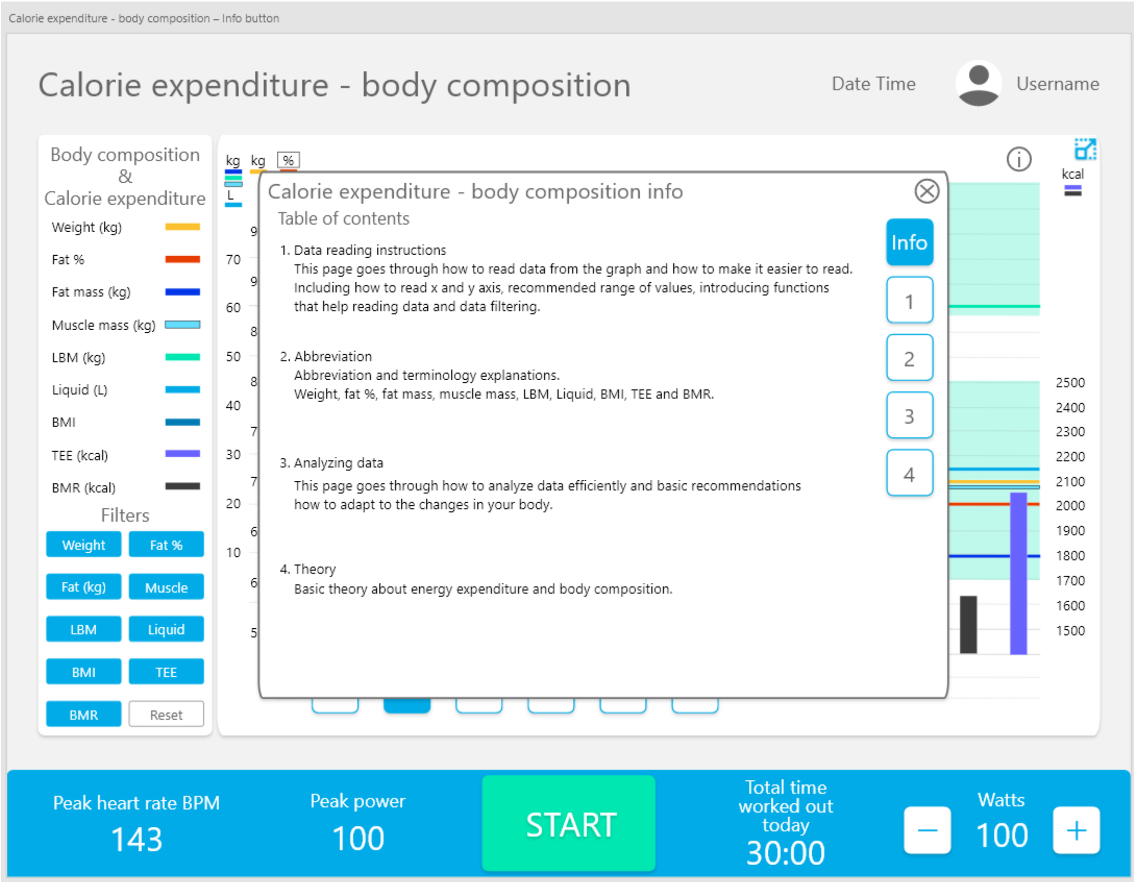
Picture 5. Calorie expenditure presented with body composition data.



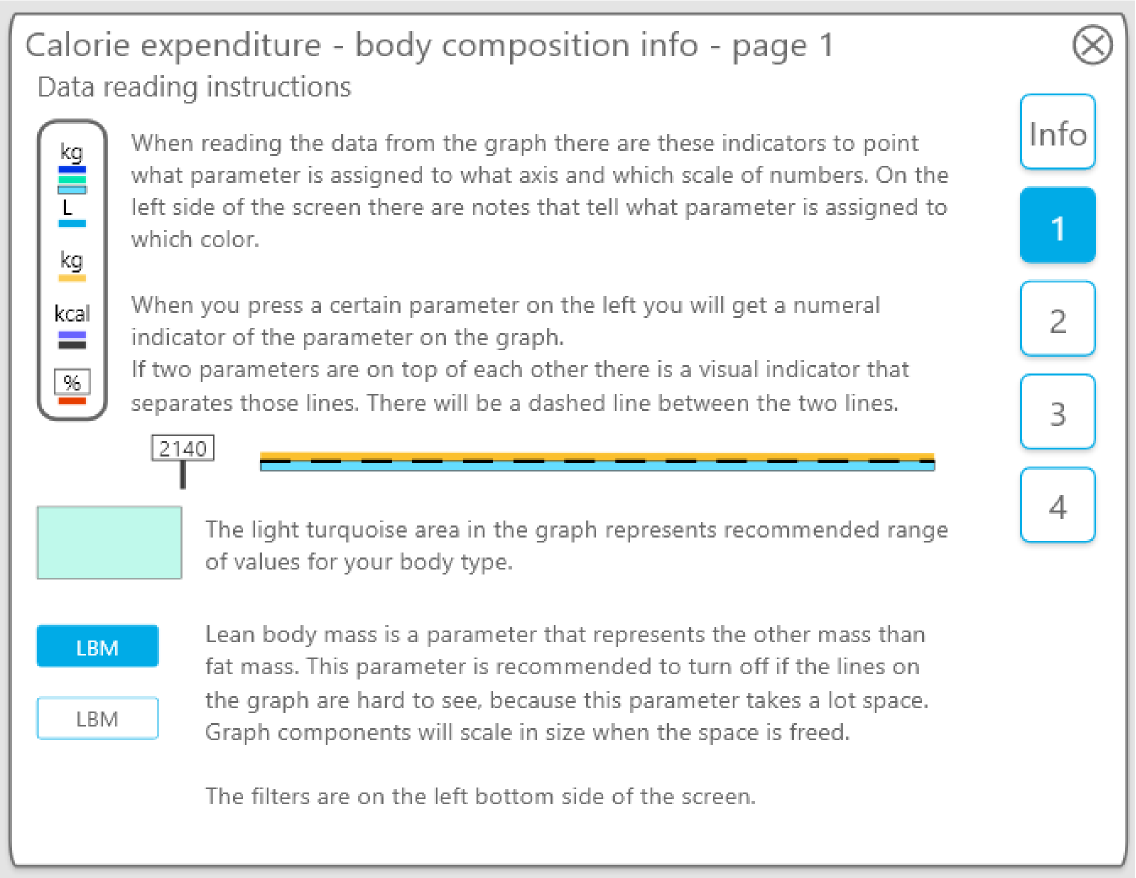
Picture 6. Calorie expenditure data presented with body composition data. Overlapping data and LBM turned off for easier reading.



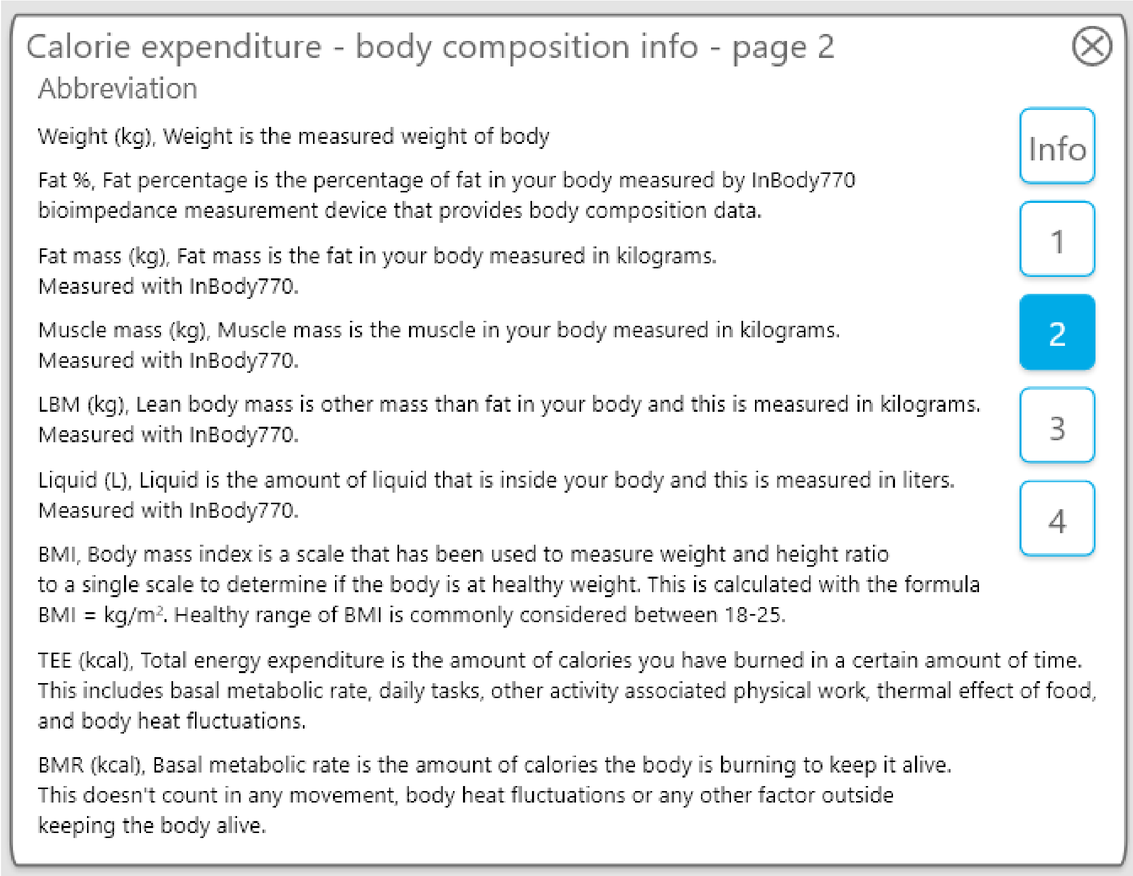
Picture 7. Total calorie expenditure data when numeral values are active for the parameter.



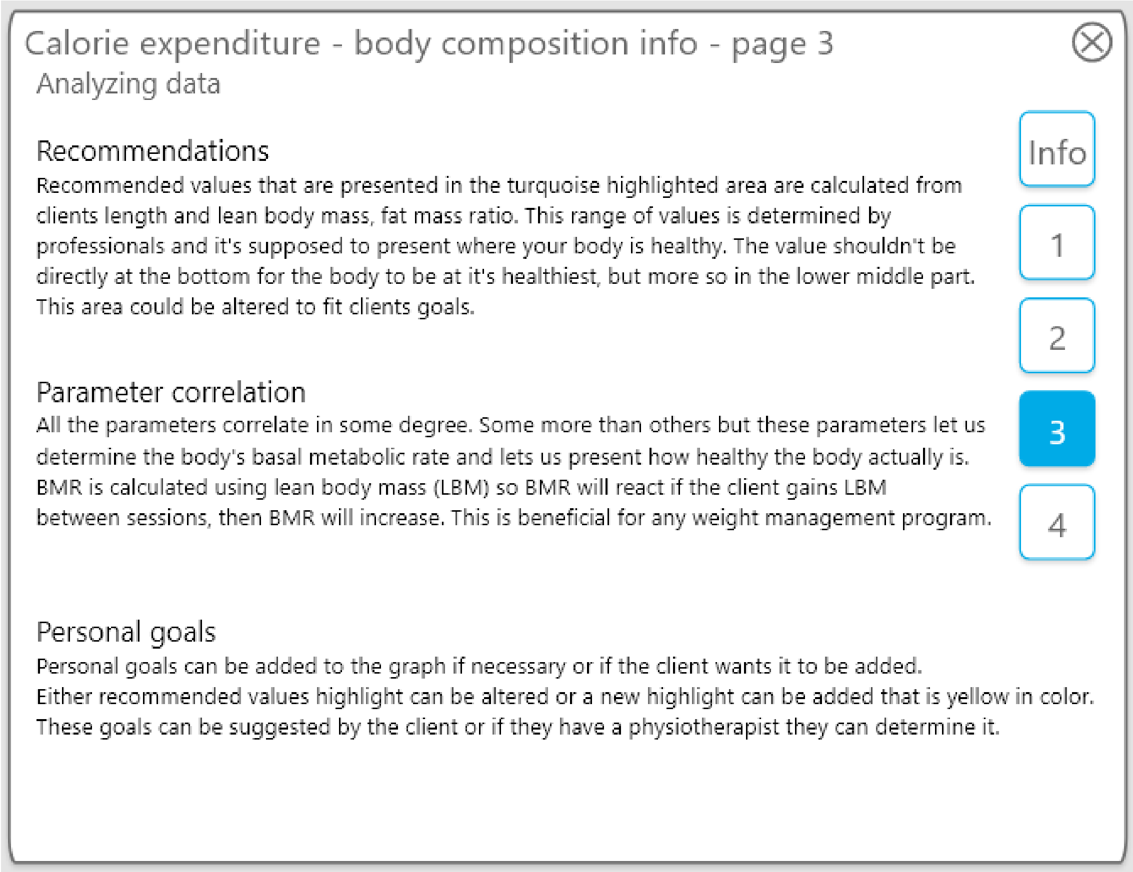
Picture 8. Info table of contents, how to read the data and analyze it correctly.



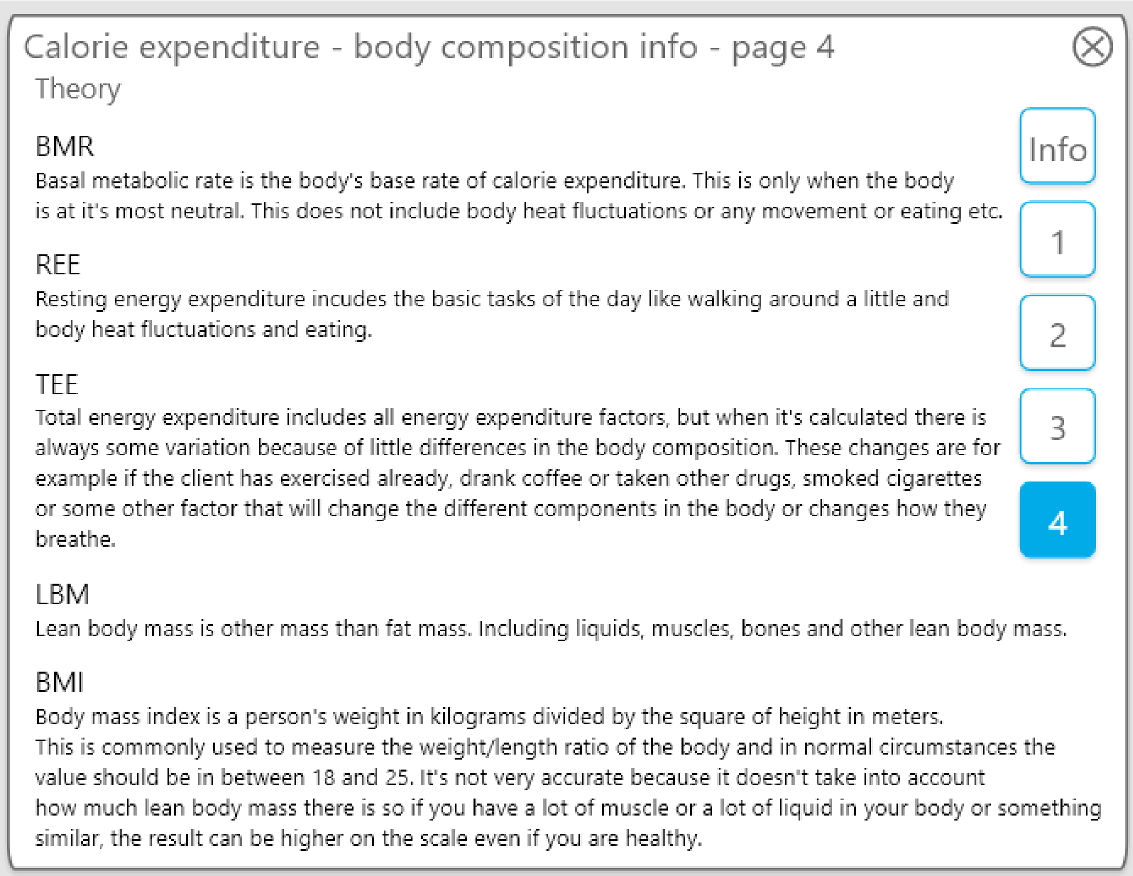
Picture 9. Info page 1, data reading instructions.



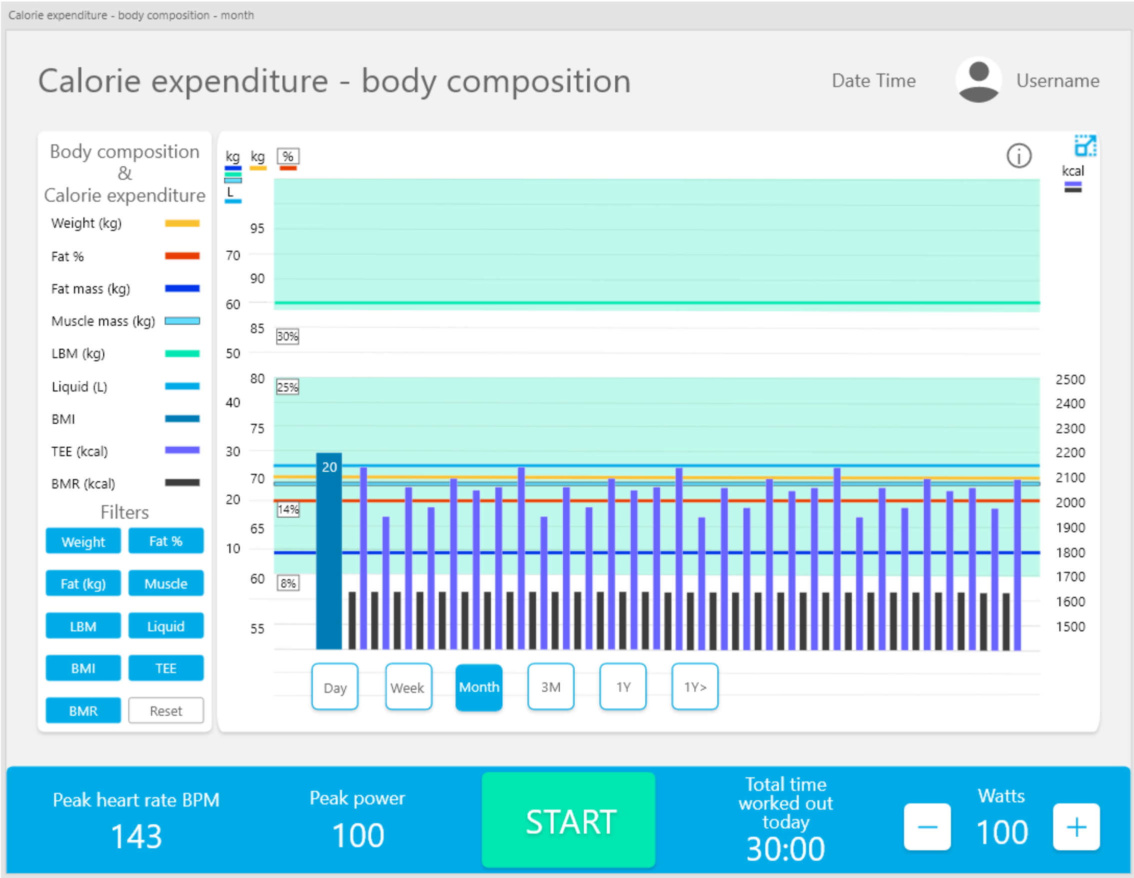
Picture 10. Info page 2, abbreviation.



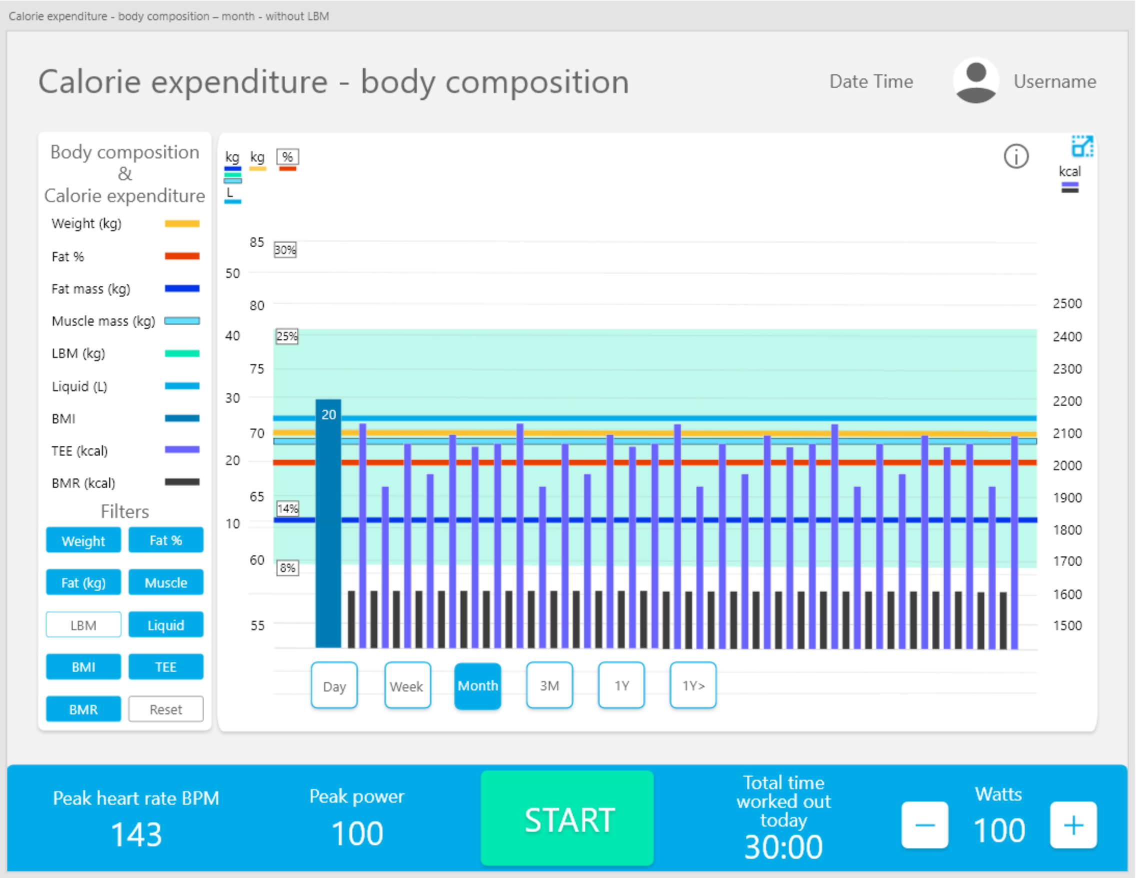
Picture 11. Info page 3, analyzing data.



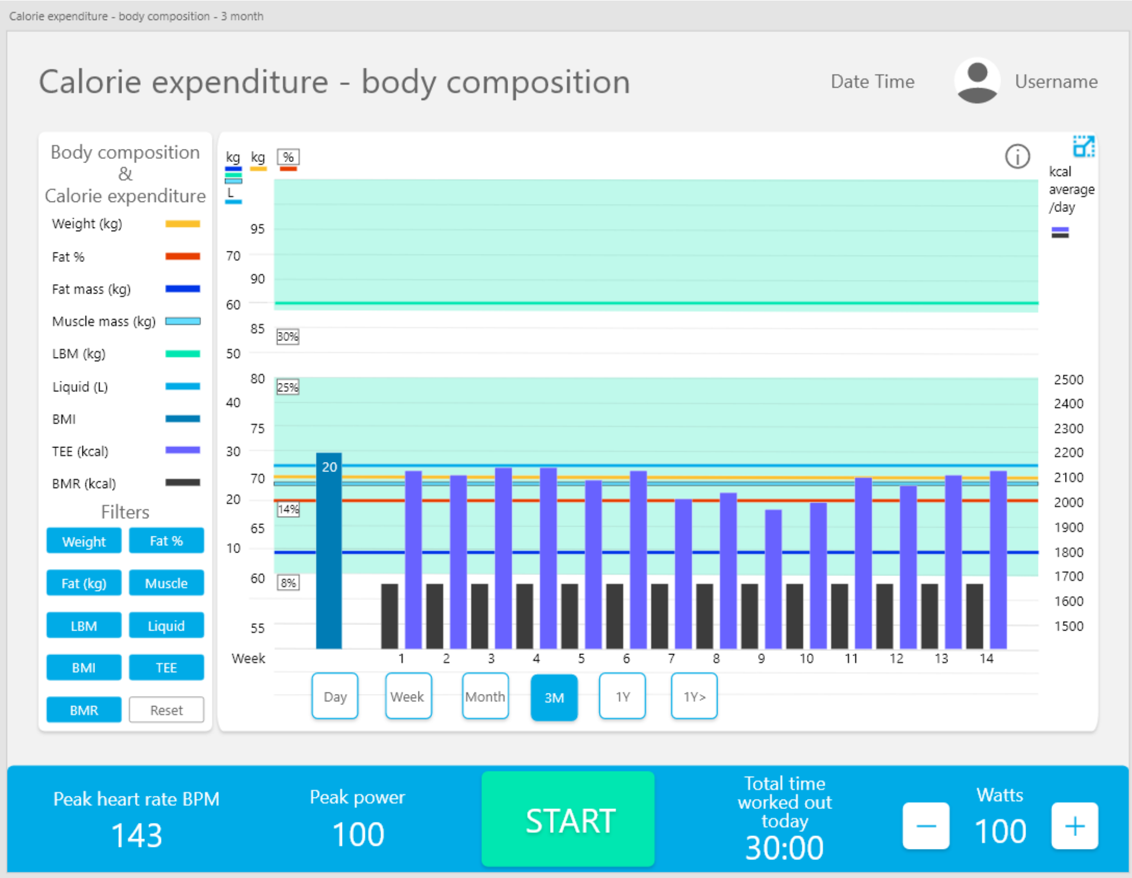
Picture 12. Info page 4, theory.



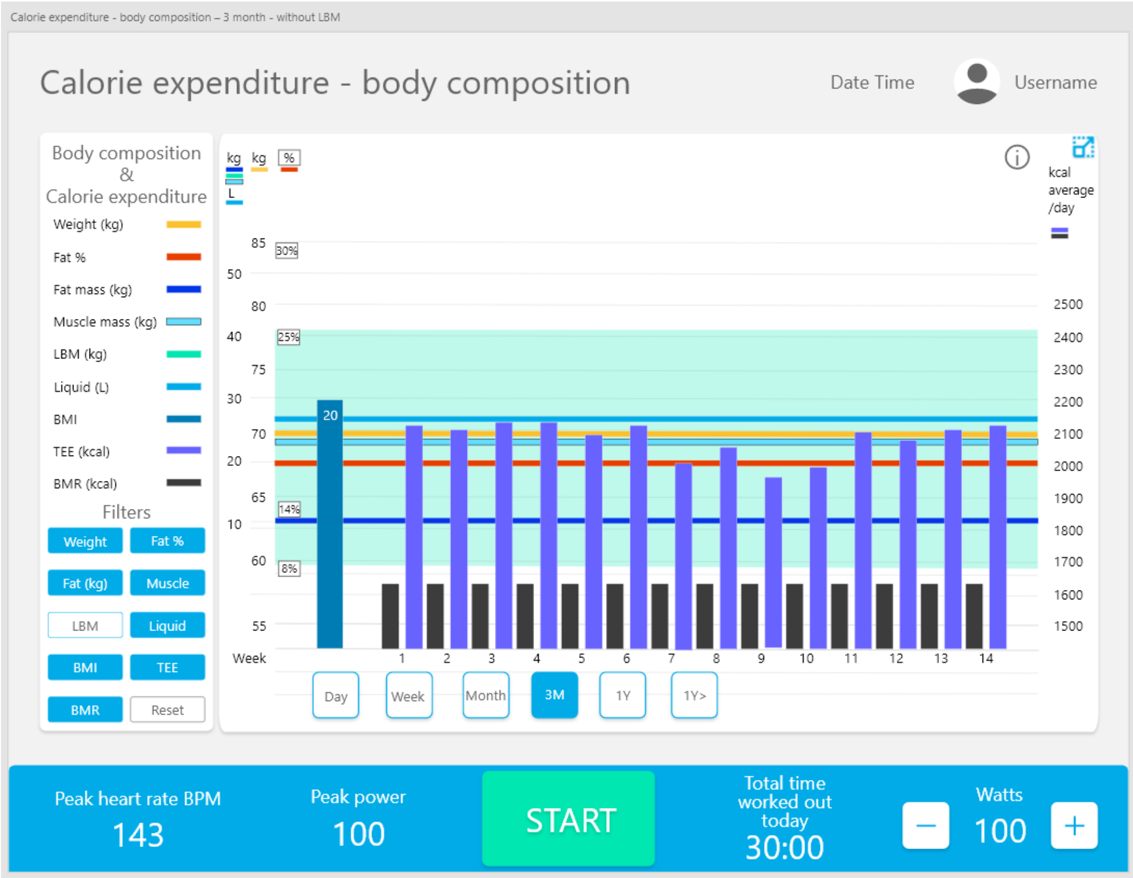
Picture 13. Calorie expenditure with body composition data, month.



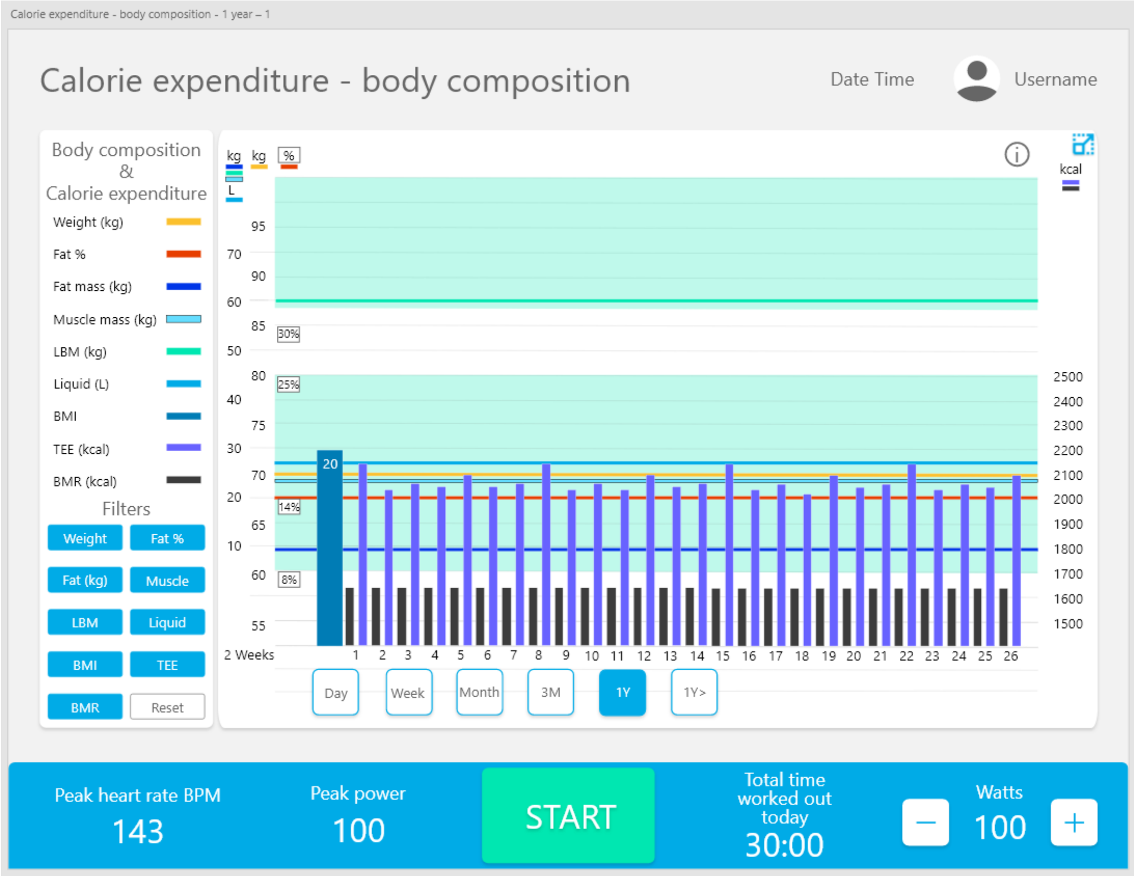
Picture 14. Calorie expenditure with body composition data, month, without LBM.



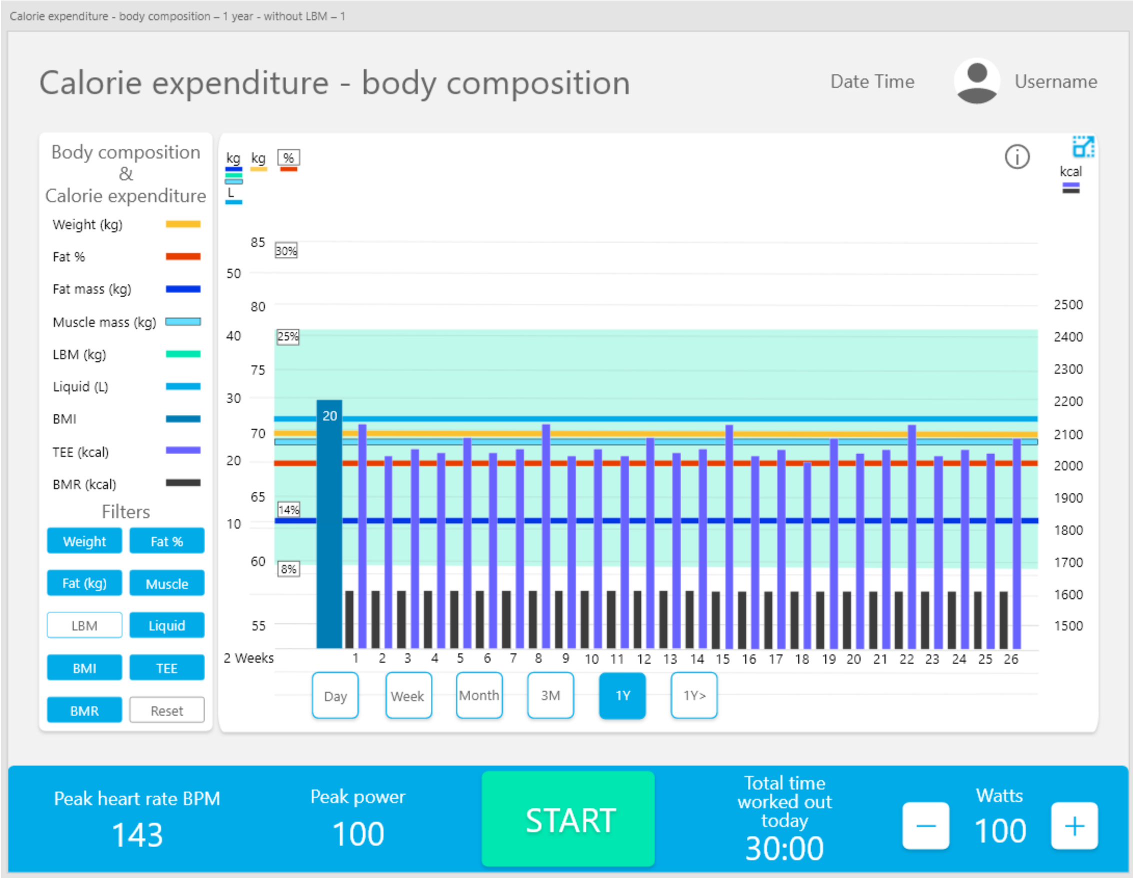
Picture 15. Calorie expenditure with body composition data, 3 months.



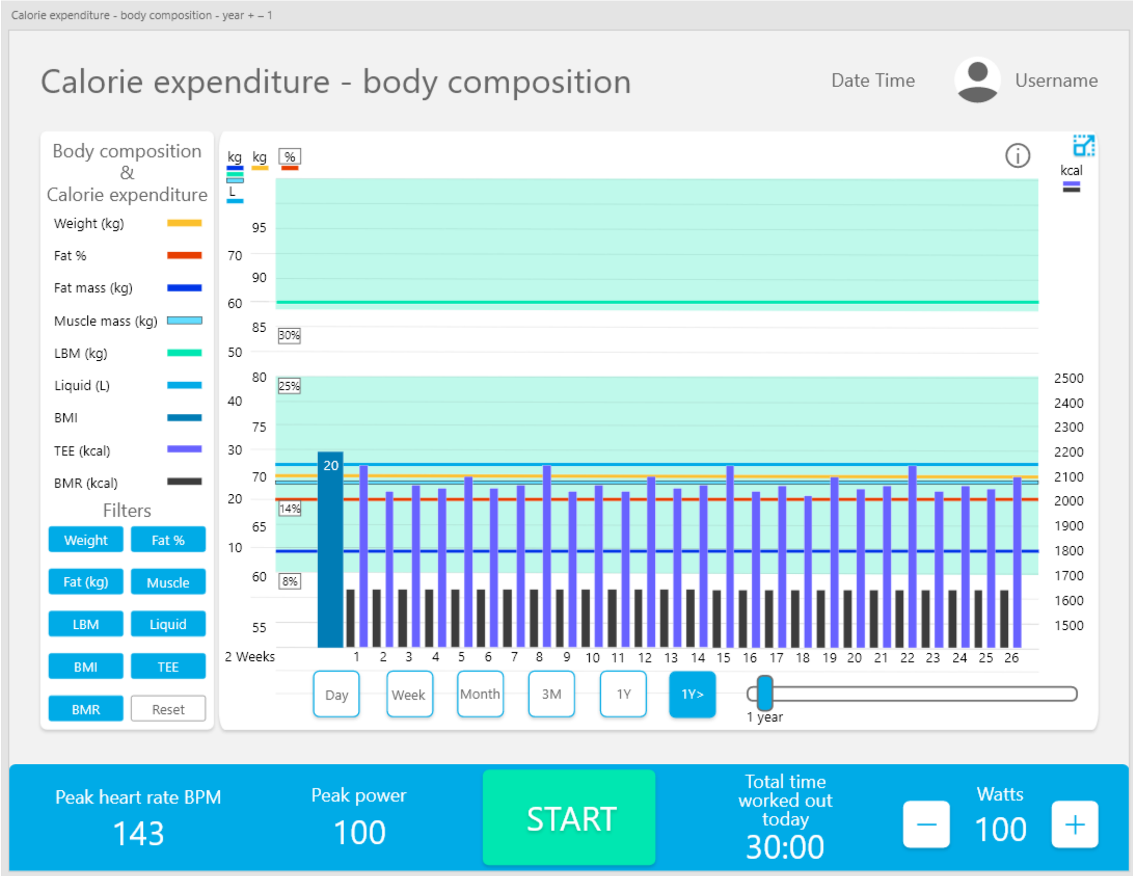
Picture 16. Calorie expenditure with body composition data, 3 months, without LBM.



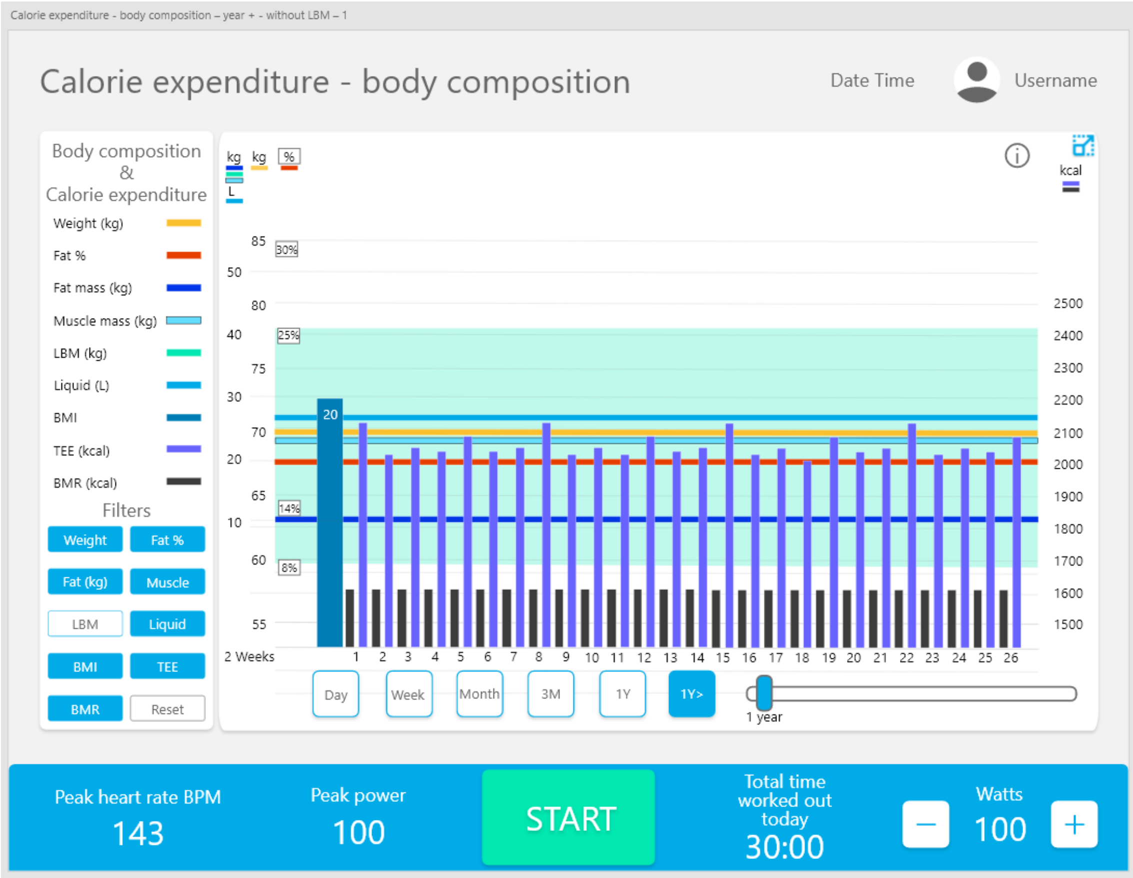
Picture 17. Calorie expenditure with body composition data, year.



Picture 18. Calorie expenditure with body composition data, year, without LBM.



Picture 19. Calorie expenditure with body composition data, year +.



Picture 20. Calorie expenditure with body composition data, year +, without LBM.

6 Conclusion

The goal of this thesis was to search the literature for an available accurate calorie expenditure calculation method suitable for a gym environment with medical device requirements and to develop a data presentation and user interface for the data. The calorie expenditure calculation formulas suggested can live up to the expectations of such an environment, but still, there is some room for improvement. There is a method to use a nonlinear model to predict AEE from heart rate that is very accurate but it needs to be trained with each client individually. This solution requires much more work and it needs multiple workout sessions from the client to train the model. (Montgomery et al., 2009; Swain and Franklin, 2002; Rotariu et al., 2015; Kortelainen et al., 2021)

Calculating weight exercise calorie expenditure estimation in a gym environment was found to be very challenging with the methods and technologies available and therefore not included in the solution suggested in this thesis. (Adeel *et al.*, 2021)

Efficiently calculating PEEE was also found to be challenging to perform in a gym environment for the same reasons and therefore not included in the solution suggested in this thesis. (Haddock and Wilkin, 2006)

Depending on what devices are used, what the client has done affecting their body composition before the test, and the exercise environment, the mean absolute percentage error of the suggested AEE calculation formula can be as low as 9% with the method presented without indirect calorimetry. Under normal circumstances, the mean absolute percentage error should be around 12-15% depending on how frequently the client goes through bioimpedance measurement and other harder to control variables that depend on the environment and the actions of the client. (Rennie et al., 2001; Keytel et al., 2005; Firstbeat Technologies Ltd, 2007a; Rotariu et al., 2015)

To provide the client a better view of the well-being of the body when displaying energy expenditure data, body composition data is used, but at this time, there are no publications available about a method to utilize this data in the calculation formula efficiently. There is, however, a method to obtain energy expenditure estimates for different physical activities solely based on the results, but that does not take into consideration the clients' physical condition, exercise form, and performance. (Ling et al., 2011; InBody., 2021)

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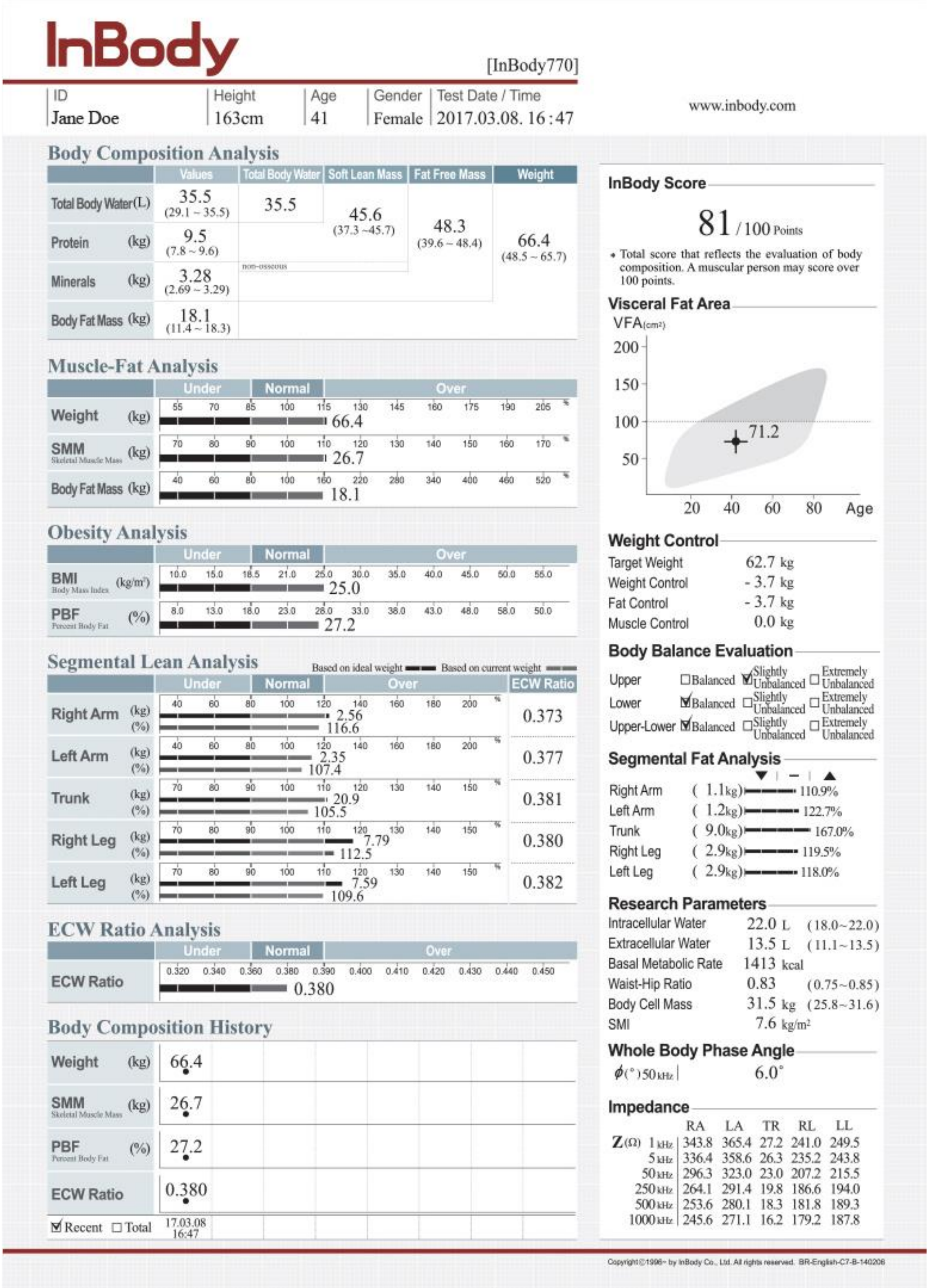
Bioimpedance report



InBody [InBody770]

ID	Height	Age	Gender	Test Date / Time
Jane Doe	163cm	41	Female	2017.03.08. 16:47

www.inbody.com

Body Composition Analysis

	Values	Total Body Water	Soft Lean Mass	Fat Free Mass	Weight
Total Body Water (L)	35.5 (29.1 ~ 35.5)	35.5	45.6 (37.3 ~45.7)	48.3 (39.6 ~ 48.4)	66.4 (48.5 ~ 65.7)
Protein (kg)	9.5 (7.8 ~ 9.6)				
Minerals (kg)	3.28 (2.69 ~ 3.29)	non-osseous			
Body Fat Mass (kg)	18.1 (11.4 ~ 18.3)				

Muscle-Fat Analysis

	Under / Normal / Over
Weight (kg)	66.4
SMM Skeletal Muscle Mass (kg)	26.7
Body Fat Mass (kg)	18.1

Obesity Analysis

	Under / Normal / Over
BMI Body Mass Index (kg/m²)	25.0
PBF Percent Body Fat (%)	27.2

Segmental Lean Analysis (Based on ideal weight / Based on current weight)

	(kg)	(%)	ECW Ratio
Right Arm	2.56	116.6	0.373
Left Arm	2.35	107.4	0.377
Trunk	20.9	105.5	0.381
Right Leg	7.79	112.5	0.380
Left Leg	7.59	109.6	0.382

ECW Ratio Analysis

ECW Ratio 0.380

Body Composition History

Weight (kg)	66.4
SMM Skeletal Muscle Mass (kg)	26.7
PBF Percent Body Fat (%)	27.2
ECW Ratio	0.380
☑Recent ☐Total	17.03.08 16:47

InBody Score

81 / 100 Points

* Total score that reflects the evaluation of body composition. A muscular person may score over 100 points.

Visceral Fat Area

VFA (cm²) 71.2

Weight Control

Target Weight	62.7 kg
Weight Control	- 3.7 kg
Fat Control	- 3.7 kg
Muscle Control	0.0 kg

Body Balance Evaluation

Upper	☑ Slightly Unbalanced
Lower	☑ Balanced
Upper-Lower	☑ Balanced

Segmental Fat Analysis

Right Arm	(1.1kg)	110.9%
Left Arm	(1.2kg)	122.7%
Trunk	(9.0kg)	167.0%
Right Leg	(2.9kg)	119.5%
Left Leg	(2.9kg)	118.0%

Research Parameters

Intracellular Water	22.0 L	(18.0~22.0)
Extracellular Water	13.5 L	(11.1~13.5)
Basal Metabolic Rate	1413 kcal	
Waist-Hip Ratio	0.83	(0.75~0.85)
Body Cell Mass	31.5 kg	(25.8~31.6)
SMI	7.6 kg/m²	

Whole Body Phase Angle

ϕ(°) 50 kHz 6.0°

Impedance

Z(Ω)	RA	LA	TR	RL	LL
1 kHz	343.8	365.4	27.2	241.0	249.5
5 kHz	336.4	358.6	26.3	235.2	243.8
50 kHz	296.3	323.0	23.0	207.2	215.5
250 kHz	264.1	291.4	19.8	186.6	194.0
500 kHz	253.6	280.1	18.3	181.8	189.3
1000 kHz	245.6	271.1	16.2	179.2	187.8

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Appendice 1. Bioimpedance report (InBody., 2022).