Assessing Thermal Comfort in Nursing Home Using Heart Rate Measurement

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Abstract. The ratio of dementia amongst the residents in nursing homes makes it practically impossible to conduct traditional questionnaire-based comfort analyses. Besides, there are uncertainties in the residents' cognitive capabilities to respond to a questionnaire, since residents with dementia can be very sensitive to the smallest changes in their everyday life. Therefore, there is a need for alternative investigation methods when conducting comfort studies in nursing homes, such as indirect measurements or observational studies. Based on a pilot study in two Danish nursing homes, this paper demonstrates how thermal comfort can be estimated using the heat balance-based comfort equation of P.O. Fanger, using the metabolic rate of residents calculated from a simple heart rate measurement. This estimate is then compared to the Predicted Mean Vote (PMV), using standard metabolic rates to investigate how well the estimated thermal comfort fits the PMV theory.
The proposed method, based on heat rate measurements, has minimum impact on the test persons and requires no cognitive activity. Furthermore, it enables a more dynamic perspective on thermal comfort. The study results indicate that the metabolism of elderly people (+75 years of age) living in nursing homes can be at a lower level than what can be counterbalanced by a lower heat loss, as it is normally assumed.
The conclusion is that the proposed method is promising but needs further development and validation concerning the conversion of heart rate to metabolism and how to account for age-related physiological changes.

Keywords. Metabolism, Thermal comfort, Field study, Nursing home.
DOI: https://doi.org/10.34641/clima.2022.177

1. Introduction

Conducting thermal comfort analyses in nursing homes entails a number of challenges, from the impact of the residents' physical- and mental disabilities to the general differences between the typical users (residents and employees).

Despite national differences in age and degree of physical- and/or mental disabilities of persons who becomes a nursing home resident, dementia often plays a role. In western Europe 50-80% of nursing home residents suffer from dementia [1]. People with dementia belongs to a category of particularly vulnerable adults, who are unable to express the need for adjustments of the thermal environment or conduct the right correctional action [2]. This cognitive impairment often leads to an exclusion of dementia sufferers from environmental studies in nursing home. Simply because they do not have the cognitive abilities to complete the used questionnaire [3], [4].

This exclusion of dementia sufferers can question whether it, in practical terms, is possible to form a group of test subjects that is representative of the resident-population in a typical nursing home. Alternatively, comfort analyses must be altered in a way that allows dementia sufferers to participate.

An example of such an alteration is the 10-month behavior study of agitation among nursing home residents with dementia, which have shown a direct link between the average indoor temperatureand the occurrence of agitated behavior [5]. Observational studies running for several months will in many cases be too time consuming to be a realistic alternative, and the response time exclude the possibility of using the response to adjust the thermal indoor environment.

Another alternative way of conducting comfort studies that allows dementia sufferers to participate, is by measuring parameters related to the human thermoregulation. In other studies, infrared thermography (IRT) have been used for measuring skin temperature [6]. In relation to dementia sufferers, IRT could be challenged by placing the cameras correctly without introducing a forint object in the living space. A third alternative could be to use the relation between heart rate and metabolism, as done in [7]. The particular measuring devices used in this study could not be used for either onside measurements or test subjects with dementia. During the last decade there has been a great development in wearable devices capable of measuring heart rate. Simple devices intended for athletes, which means that measuring heart rate could be done with an impact of a test subject that is comparable to wearing a wristwatch.

When assessing thermal comfort in nursing homes, another question that is often raised [2] has to be taken into account:

- Is the age of the test subjects a factor of importance?

P.O. Fanger originally stated that age related reduction of the metabolic rate did not have a significant impact on the validity of the comfort equation, because the decrease in the metabolic rate is counterbalanced by a lower heat loss - provided that comfort analyses are based on tabular values of the metabolic rate. In other studies of this specific question, no consistent answer has been given, but in some field studies a significant age related difference have been detected [8].

It is also worth noticing, that in nearly all the conducted age related studies, the test subjects are described as healthy and often significantly younger than the average nursing home residents. A person moving into a nursing home in Denmark is in average 84 years old and suffers from one or more chronical illnesses [9].

2. Research Methods

A pilot study was conducted in November 2019 in two different Danish nursing homes. The scope was to determine if it is possible to evaluate thermal comfort, based on simple heart rate measurement, without consideration to dementia amongst the test subjects. The measuring period at each nursing home consisted of five consecutive weekdays.

The conceptual idea is to calculate the ideal operative temperature for each test subject. This is defined as the temperature that provide equilibrium in P.O. Fanger's Comfort equation, corresponding to a PMV scorer of 0 on the 7-point Ashrae scale according to DS/EN/ISO 7730 [10], by using a Metabolic rate calculated from measured heart rate (comparable with level 3 analysis DS/EN/ISO_8996 [11]).

Finally, the calculated temperature is compared to operative temperatures, defined from observed activity levels and measured room temperatures.

2.1 Test Subjects and Registrations

Test subjects are selected amongst both residents and employees to be able to detect age related deviations in the results.

Test subjects have been selected in two different ways, depending on the subject's status as resident or employee. Employees could volunteer, if they had one or more work shifts in the measuring period. Potential test subject amongst the residents have been pointed out by the General Manager.

Prior to volunteering, all test persons and legal guardians for persons suffering from dementia have received information of the study and signed a consent form to participate. As part of the consent, a test subject gives the following information:

Employees: age, sex and work function.

Residents: age, sex, if they are diagnosed with dementia or use beta blockers.

Height and weight gets registered for all test subjects. Height and weight of the employees got measured as part of the introduction to the measuring equipment. Measuring height and weight of the residents is part of the weekly routine, and is provided by the nursing homes.

The test subjects are anonymized and consists of 13 residents (see Tab. 1) and 17 employees (see Tab. 2)

Tab. 1 - Essential parameters of the resident test subjects, information on dementia and Beta-blogger not included.

ID	Sex	Age [year]	Height (h) [cm]	Weight (w) [kg]
R01	M	93	178	68
R02	F	81	153	53
R03	M	75	183	85
R04	M	87	183	91
R05	F	85	167	80,4
R06	M	86	182	65,5
R07	F	93	166	58,9
R08	M	91	175	72
R09	M	92	162	80,1
R10	F	67	169	91,5
R11	F	69	160	63
R12	M	88	163	66,4
R13	M	69	180	88,7

2.2 Observations

During day and evening hours, clothing- and activity level of the test subjects were registered based on visual observations. The observations were conducted by following the participating employees in the common area of the nursing home. The observer registered time of observation, description of the observed activity and estimated clothing level.

The registration was noted in predefined forms for each test subject.

To protect the integrity of the residents, the observer only enters private living spaces based on direct invitation from the resident. Activities in the private living spaces are therefore mainly based on observations trough open doors and the employees' descriptions of the work conducted in the private living spaces.

The observations were conducted in collaboration with engineering students, specialized in indoor environment.

Tab. 2 - Essential parameters of the employee test subject.

ID	Sex	Age [year]	Height (h) [cm]	Weight (w) [kg]
E01	F	57	161	69
E02	F	58	156	58
E03	F	25	164	57,7
E04	F	22	169	64,8
E05	F	22	189	95,5
E06	M	51	175	93,5
E07	F	64	169	63
E08	F	37	162	61,7
E09	F	39	160	54
E10	F	58	171	81,5
E11	F	20	167	58,7
E12	F	45	167	67,9
E13	F	42	176	75
E14	F	46	172	79,5
E15	F	55	167	75,6
E16	F	49	166	61,2
E17	F	37	177	131

2.3 Measuring Heart Rate and Room Temperature

For residents it is essential that the measuring equipment affect the subject's everyday life as little as possible. Therefore, measurements are conducted using Garmin vivosmart® 4 Fitness Activety tracker worn around the wrist, as a normal wristwatch (see Fig. 1).

Hygiene requirements states that employees are not allowed to wear anything on their arms below the elbow, beside clothing. This excludes the wrist worn measuring device. Instead, the heart rate of employee test subjects are measured using Garmin HRM-Dual, Heart Rate Monitor with Chest Strap, in combination with iPhone 5 (or newer) or IOS 8 (or newer) (see Fig. 1). The phones act as data loggers, because Garmin HRM-Dual do not have a build in memory.

Fig. 1-On the left, Garmin vivosmart 4 worn by a test subject beside the subject's own wristwatch. On the right, measurement equipment for the employee.

The residents carried the Garmin vivosmart activity tracker around the clock during the measuring period, while the employees carried the equipment during one or several work shifts.

Room temperatures were measured using Tinytags, placed out of sight and out of reach in both common areas and private living spaces of the nursing homes (see Fig. 2).

The Tinytags were set to log temperature every third minute during the measuring period.

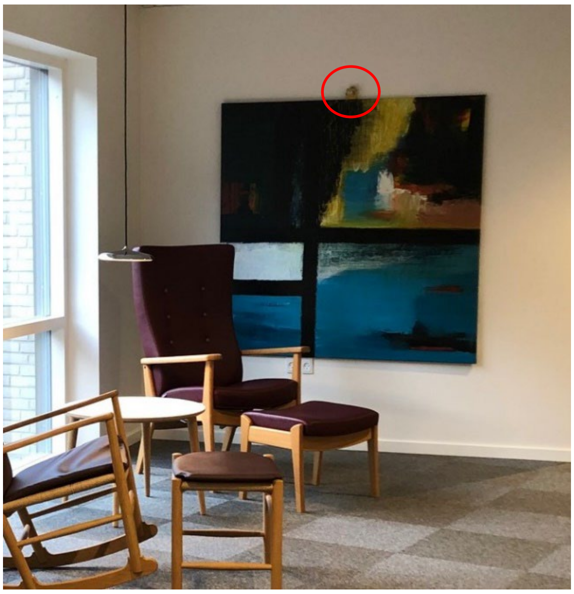
Fig. 2 – Example of placement of Tinytags in the common area.

2.4 Converting Heart Rate to Metabolic Rate

It is presumed that the relation between heart rate (HR) and metabolism (M) given in (DS/EN/ISO 8996) [11] can be used with a satisfactory accuracy, despite the potential effect of psychological factors with heart rates below 120 beats pr. minute (BPM). The relation between HR and M is defined as:

$$HR = HR_0 + RM \cdot (M - M_0) \qquad (1)$$

Where:

M_0 Metabolic rate at rest, defined from tabular values related to age (a) and weight (w), (Tab. 3).

HR_0 Heart rate at rest under neutral thermal condition.

RM Increase in heart rate per unit of metabolic rate.

Tab. 3 - Metabolic rate at rest based on age and weight (w), given in MJ/day [12].

Age	Female	Male
19-30	0,0615 w + 2,08	0,0640 w + 2,84
31-60	0,0364 w + 3,47	0,0485 w + 3,67
61-75	0,0386 w + 2,88	0,0499 w + 2,93
>75	0,0410 w + 2,61	0,0350 w + 3,43

Conversion from MJ/day given in Tab. 3, to W/m² in formula (1) is based on the body surface area of the test persons defined as:

$$A = 0{,}202 \cdot h^{0{,}725} \cdot w^{0{,}425} \qquad (2)$$

For residents HR_0 is defined as the average of the measured HR between midnight and 4 am. Whereas for employees, HR_0 is given as the mean value for persons with an average fitness and a fitness level above average(se Tab. 4). Notice that an exception has been made if the value is less than 8 BPM lower than the average measure heart rate. In these cases, HR_0 is defined as 90% of the average measure heart rate.

RM is found, as defined in (DS/EN/ISO 8996) [11], to:

$$RM = \frac{HR_{maks} - HR_0}{MWC - M_0} \qquad (3)$$

Where

HR_{maks} Maximum heart rate based on age (a) as given in equation (4)

MWC Maximum working capacity based on age (a) and weight (w) as given in equation (5)

$$HR_{maks} = 205 - 0{,}62 \cdot a \qquad (4)$$

$$MWC = \begin{cases} male = (41{,}7 - 0{,}22 \cdot a) \cdot w^{0{,}666} \left[\frac{W}{m^2}\right] \\ female = (35{,}0 - 0{,}22 \cdot a) \cdot w^{0{,}666} \left[\frac{W}{m^2}\right] \end{cases} \qquad (5)$$

2.5 Calculating Operative Temperature

Based on the general time factor involved in regulating the room temperature, the ideal operative temperature for each test subject is calculated based on the average metabolic rate of the test subject.

Tab. 4 - Heart rate at rest based on age, sex and general fitness [13], F=Female, M=Male, AF=Average fitness, AaF=Above average Fitness.

Age	F-AF	F-AaF	M-AF	M-AaF
18-25	74-78	70-73		
26-35	74-76	69-72		
36-45	75-78	70-73		
46-55	74-77	70-73	72-76	68-71
56-65	74-77	69-73	72-75	68-71
65+	74-76	69-72	70-73	66-69

The ideal operative temperature is defined as the temperature which provides equilibrium in P.O. Fanger's heat balance-based comfort equation:

$$(M - W) - 3{,}05 \cdot 10^{-3} \cdot (5733 - 6{,}99 \cdot (M - W) - p_{da}) - 0{,}42 \cdot \big((M - W) - 58{,}15\big) - 17 \cdot 10^{-6} \cdot M \cdot (5867 - p_{da}) - 1{,}4 \cdot 10^{-3} \cdot M \cdot (34 - t_a) = 39{,}6 \cdot 10^{-9} \cdot f_{cl} \cdot ((t_{cl} + 273)^4 - (t_r + 273)^4) + f_{cl} \cdot \alpha_k \cdot (t_{cl} - t_a) \qquad (6)$$

Where:

M The average calculated metabolic rate

W Effective mechanical power - Assumed from observing activities

I_{cl} Clothing insulation calculated from observed clothing levels, as described in [14].

t_r Mean radiation temperature

t_a Air temperature

t_{cl} Clothing temperature found from equation (7)

α_k Convective heat transfer coefficient given in equation (8)

f_{cl} Clothing area surface factor calculated in equation (9)

P_a Water vapour patial pressure set for a relative humidity at 50%, at the calculated air temperature

$$t_{cl} = 35{,}7 - 0{,}0275 \cdot (M - W) - \Big((M - W) - 3{,}05 \cdot 10^{-3} \cdot (5733 - 6{,}99 \cdot (M - W) - p_{da}) - 0{,}42 \cdot \big((M - W) - 58{,}15\big) - 17 \cdot 10^{-6} \cdot M \cdot (5867 - p_{da}) - 1{,}4 \cdot 10^{-3} \cdot M \cdot (34 - t_a)\Big) \qquad (7)$$

$$\alpha_k = \textit{Higest value of} \begin{cases} 2{,}38 \cdot (t_{cl} - t_a)^{0{,}25} \\ 12{,}1 \cdot {v_{ar}}^{0{,}5} \end{cases} \qquad (8)$$

Where:

v_{ar} is the relative air velocity found from equation (10)

$$f_{cl} = \begin{cases} 1{,}00 + 1{,}290 \cdot I_{cl} & for\ I_{cl} \leq 0{,}078 \\ 1{,}05 + 0{,}645 \cdot I_{cl} & for\ I_{cl} > 0{,}078 \end{cases} \quad (9)$$

$$v_{ar} = v_a + 0{,}005 \cdot (M - 58) \quad (10)$$

Where:

v_a Air velocity assumed to be equal to 0,15m/s.

The participating nursing homes are relatively new, well insulated and mechanically ventilated. It is therefore assumed, that the mean radiation temperature is equal to the air temperature, which makes the operative temperature equal to the air temperature.

3. Results

The given result is a condensed overview of conducted observations and calculations.

3.1 Observed Activity and Clothing

In general, the observed activity level of the residents is significantly lower than the activity level of the employees, in particular employees handling care tasks.

For the residents, a typical day consists of different sedentary activities in the private living spaces of the nursing home, e.g. watching TV, using a computer or doing needlework. These activities are estimated to be equal to the activity level "seated, relaxed", giving an expected metabolic rate of 58 W/m^2. During the day the general sedentary activity is replaced by short periods of physical activity consisting of walking (if capable of it) to the common room for the main meals, or participating in common activities, such as singing, church service or chair gymnastics.

From an activity point of view, the employees can be divided into two groups depending on work function.

Employees primarily conducting administrative tasks, are evaluated to have an activity level comparable to sedentary office work, with short brakes of walking around in the common areas. This gives an expected metabolic rate of 70 W/m^2. The activities of employees primarily providing care of the residents are described as active work without heavy lifting and no running. The observed activities primarily consist of standing and walking in both private living spaces and common areas. Due to a general focus on self-empowerment of the residents and prevention of injuries amongst the employees, heavy lifting is conducted using assistive devises. The observed work activities are estimated to be comparable with "walking on level ground 2-3 km/h", giving an expected metabolic rate of 125 w/m^2.

Based on the observed activities, the effective mechanical power for all test subjects are assumed to be negligible, whereby W=0.

Fig. 3 shows examples of typical clothing levels for both employees and residents.

Fig. 3 – Examples of typically observed clothing levels, left to right: Employee, female resident and male resident.

The observed clothing levels show big individual differences amongst the residents. Both from test subject to test subject, but also as variations during the day; from fully dressed to dressing gown and pyjamas. In general, the registered clothing levels of the residents arefound to vary from 0,63 clo to 1,18 clo, with an average of 0,83 clo.

The employees are wearing uniforms with some possibilities for adaptation to individual preferences. The uniform consists of either a shirt with short sleeves in combination with trousers or a dress with short sleeves. The employees have free choice of footwear, and it is possible to combine the general uniform with a light jacket. The chosen combinations are evaluated to give a combined clothing level of the employees that vary from 0,3 clo to 0,82 clo, with an average of 0,5 clo.

3.2 Measured Heart Rate

With the continuously logged heart rate, it becomes clear that the heart rate changes very rapidly during the day for both residents and employees. The measured heart rates also show significant differences from individual to individual, both in terms of the average heart rate and the deviation. These are differences that cannot be related to either age, sex, or group of test subject.

Deviding the test subjects into tree groups, some general differences can be detected. As shown in Fig. 4, the residents have the lowest average heart rate, while the caregiving employees have the highest. The employees that primarily conduct administrative work are more compareable to the residents based on the average heart rate.

Heart rates below 50 BPM are defined as low, but normal, and can be the result of a fitness level above average, heart disease or medication [15]. Therefore, the very low heart rates amongst the residents are not ruled out as measuring errors.

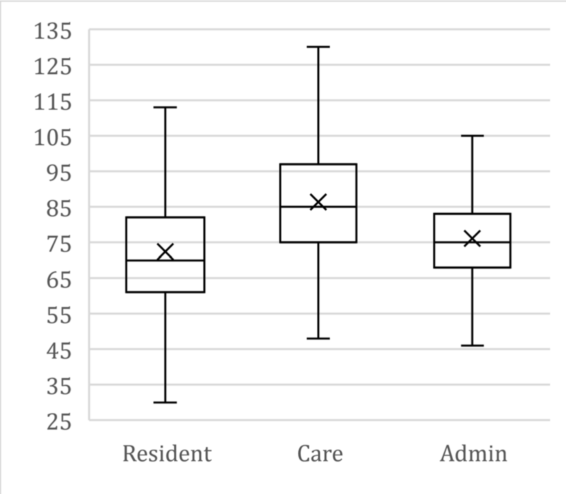

Fig. 4 – All measured heart rates (BPM) sorted according to groups of test subjects; Residents, Employees (care), Employees (administration)

3.2 Measured Room Temperatures

In general, the variation in the individual measuring points troughout the nursing home are very low. The maximum and minimum temperatures in Tab. 5 can be seen as temperature variations between rooms rather than variations over time.

Tab. 5 – Average, maximum and minimum temperatures, measured in both private living spaces and common areas of the participating nursing homes.

Location	Average [^{0}C]	Min [^{0}C]	Max [^{0}C]
Privat	23,5	21,1	25,6
Common	23,0	21,4	26,3

3.3 Metabolism

Based on the measured heart rate, the metabolic rate is calculated for each time step, and sorted according to subject groups. This gives, as illustrated in Fig. 5, a picture quite similar to the heart rate, where the residents have the lowest average metabolic rate and the caregivers have the highest. It is necessary to note that all three groups have minimum values below zero, which is not possible. This could be caused by the widening of the scope of the calculation method, or be an indication of a need for validation of the method used for estimating values of, for instance, heart rates at rest.

To minimize the effect of undetected uncertainties, all further analyses is therefore strictly based on the average of the calculated metabolic rate for each test subject.

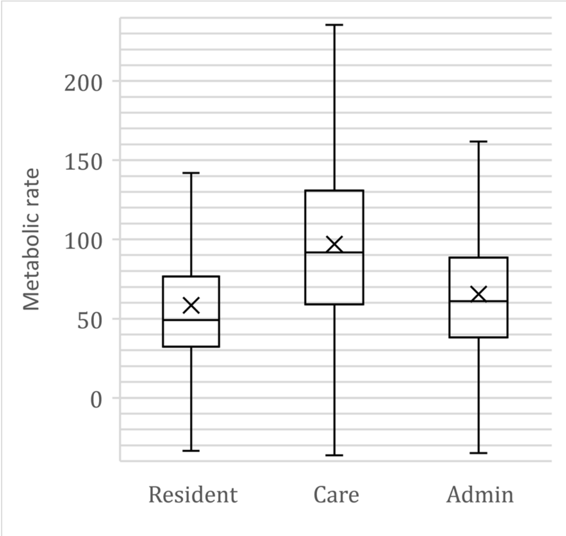

Fig. 5 – Calculated metabolic rate sorted according to groups of test subjects; Residents, Employees (care), employees (administration).

When plotting the calculated metabolic rate for each test subject according to age, some interesting tendencies are worth noticing, despite a low correlation to the linear regression (see Fig .6).

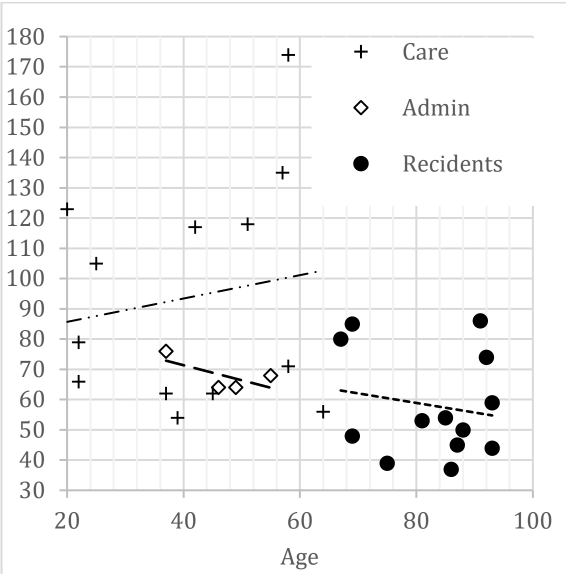

Fig. 6 – Average metabolic rate for each test subject in relation to the age of the test subject.

It could look like a part of the test subject identified as caregivers have more administrative work tasks than registered in the observations. The calculated metabolic rate also indicates a tendency to decrease with age. For 50% of the resident test subjects, the average metabolic rate is below 50 W/m^2, which is significantly lower than the metabolic rate for the activity level "seated relaxed" of 58,15 W/m^2 used in equation (6).

3.4 The Operative Temperature

For each test subject the ideal operative temperature is found based on calculated metabolic rate and the estimated clothing level. This gives a variation of the ideal temperature for each subject group as given in Tab. 6.

Tab. 6 – Average, maximum and minimum values of the calculated operative temperature based on the metabolic rate calculated from the measured heart rate.

Subject group	Average [⁰C]	min [⁰C]	max [⁰C]
Resident	24,1	20,1	27,6
care	22,7	13,9	27,9
Admin	24,5	20,5	26,1

This is a wide range, but when the calculated temperature is put in relation to the calculated metabolic rate, a nearly linearly relation is found for each subject group (see Fig. 7).

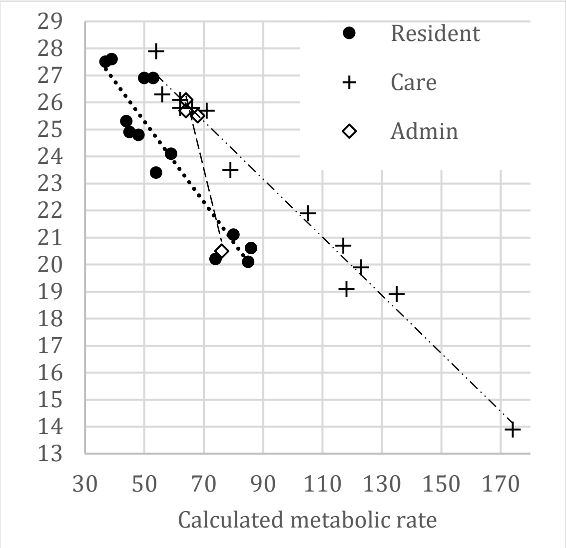

Fig. 7 – Optimal operative room temperature based on the calculated metabolic rate for each test subject.

For comparison to standardized investigation methods, the operative temperature, for the three groups of test subjects, is found based on tabular values for metabolic rate of the observed activities to the values given in Tab. 7

Tab. 7 – Average, maximum and minimum values of the calculated operative temperature based on table values of the metabolic rate for the observed activities.

Subject group	Average [⁰C]	min [⁰C]	max [⁰C]
Resident	24,1	22,7	26,4
care	19,3	18,1	20,8
Admin	24,3	21,4	25,4

By using the tabular values for the observation based activity estimations, the deviation in the optimal temperature becomes smaller and the individual differences in activity cannot be taken into account. Notice the close correlation of the average ideal temperatures for the resident and administrative test subject in Tab. 6 and Tab. 7.

4. Discussion

This study contains several assumptions and simplifications which can influence the results or indicate requirements of further investigations.

None of the test subjects fulfill the required minimum heart rate of 120 BPM, that makes the mental component in relationship to the metabolic rate negligible according to [11]. This could question whether the used widening of the scope of the heart rate to metabolic rate conversion is acceptable. Meanwhile the focus of this study was not to increase precision of the determined metabolic rate, but to evaluate whether or not a simple heart rate measurement, can be used as an indicator for thermal comfort when working with test subjects that are not cognitively capable of answering a classical questionnaire.

Only a single resident test subject chose to stop wearing the activity tracker before time. This indicate that the intended minimum impact is obtained, even though the residents were wearing the activity tracer around the clock.

The accuracy of the proposed method has to undergo further investigation. This include finding an explanation of the negative values of the calculated metabolic rate. It could be caused by; a systematic error in the equipment, inaccuracies in the determination of heart- and metabolic rate at rest or because the correlation between heart rate and metabolic rate is significantly different for activities with a heart rate below 120 BPM.

P.O. Fanger's comfort equation have been used in the original form, even though it is clearly stated that it is not valid for field studies or measured metabolic rate. In lack of a better solution, this widely used deviation [2] is also accepted as valid for this study, based on the purpose of the study.

Before the method can be used, the correlation between the calculated metabolic rates and P.O. Fanger's Comfort equation has to be investigated further. Particularly because this study does not include systematic subjective evaluation of the thermal indoor environment from the test subjects. This is a significant drawback in relation to evaluating the method's ability to predict a PMV score, or defining a set point for the operative temperature.

The number of test subjects and the length of the measuring period is too small to provide the statistical foundation for a modification of any parameters in the process. It only provides the possibilitie to test and illustrate pros and cons in the conceptual idea and determine relevant focus points for future studies.

5. Conclusion

This pilot study has shown that it could be possible to use simple heart rate measurement to determine metabolic rate with a precision, at least comparable with general observation. Furthermore, the method has the potential to provide a more detailed description of the activity level of the individual test subject, and thereby an individually based regulation of the thermal indoor environment in the future.

The study has also demonstrated that the impact on the individual test subject, by wearing the wrist worn activity tracer, makes it possible for persons suffering from dementia to be enrolled as test subjects.

6. Acknowledgement

Cathrine Schermer Riis and Amalie Dokkedal Jensen for systematic and qualified work in the measuring period.

Innobyg for financial support.

Aarhus Friplejehjem and Meta Marie Hjemmet, for cooperation in finding test subjects and allowing the measurements to take place in their facilities.

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Data Statement

The datasets, generated during and/or analysed during the current study, are not publicly available because of GPDR but will be available in anonymized form by contact to the main author.