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A Design Chart to Determine the Total Emitted Quantity of Heat from the Users, Within a Functional Space, as a Function of Their Mass, Height, Activity, and Number

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Abstract

Casual heat gains should be calculated accurately to determine the actual heat emissions, within a functional space. Casual heat gains are emitted from different equipment, fixtures, and users. The paper's main objective is to create a design chart. This design chart could be used to determine the total emitted quantity of heat from the users, within a functional space, as a function of their mass, height, activity, and number. The Design chart comprises three integrated graphs. The first graph illustrates an estimate of the body surface area using DuBois formula as a function of the body mass and height. The second graph represents the power density, per unit body surface area of the user, depending on the activity level. The third graph indicates the number of users, within that functional space. Using the three graphs of the design chart would result in finding the total quantity of heat emitted from the users, within a functional space, which in turn would be beneficial, especially in the preliminary stages of design, to address such amount of emitted heat which would affect the decisions that are taken to ensure the achievement of thermal comfort for the users.

Keywords: Building Physics, Casual Heat Gain, Design Charts, DuBois Formula, Thermal Comfort.

1 Introduction

Casual heat gains should be calculated accurately to determine the actual heat emissions, within a functional space, to ensure achieving the thermal comfort [1], that reveals satisfaction of the users with the thermal environment [2]. Building physics is responsible for organizing the conditions of the building environment such that, around 80% of the users are experiencing thermal comfort [3]. Casual heat gains are emitted from different equipment, fixtures, and users.

The paper is concerned with the total emitted quantity of heat from the users. This total emitted quantity of heat is a function of the body shape of the users as well as the activity level [4], which are contributing factors to thermal comfort [5]. To maintain thermal balance, the human body must lose excess heat [6] at the same rate of metabolic rate production, which is a main function of the activity level [7]. The unit developed for this purpose is the "met," which is equivalent to 58.2 W/m^2. A cooler environment would be needed for higher levels of "met" to facilitate heat dissipation [8]. Body shapes, i.e., different body masses (weights) and heights, also affect the total emitted quantity of heat and this could be signified by DuBois formula who proposed an estimate of the body surface area (DuBois Area) based on body mass and height of the user [9].

The paper's main objective is to create a design chart. This design chart could be used to determine the total emitted quantity of heat from the users, within a functional space, as a function of their mass, height, activity, and number.

Nomenclature		
M	Body mass	kg
h	height	m
A_D	Estimate of the body surface area (DuBois Area)	m^2
n	Number of users	…
Pd	Power density, per unit body surface area	W/m^2
q	Emitted quantity of heat	W
q_T	Total emitted quantity of heat	W

2 Methodology

Simplifications, assumptions, and calculations were made in a trial of creating the proposed design chart that determines the total emitted quantity of heat from the users, within a functional space, as follows.

2.1 Simplifications and Assumptions

The design chart is not concerned with all types of casual heat gains, within a functional space, but it is concerned with the total emitted quantity of heat from the users themselves based on their activity level and their body shapes. It is applicable for most functional spaces that can accommodate up to hundred users whether they were adults or youngsters, with a range of body shapes, i.e., different body masses (weights) and heights.

2.2 Calculations

The Design chart comprises three integrated graphs. Each graph represents one of the variables that affect the total emitted quantity of heat from the users, within a functional space.

The first graph determines an estimate of the body surface area A_D $[m^2]$ as a function of the body mass M $[kg]$ and height h $[m]$. This is calculated using DuBois formula as follows [10].

$$A_D = 0.202M^{0.425}h^{0.725}\ [m^2]$$

The second graph determines the emitted quantity of heat per user q_{user} $[W]$ as a function of the activity level. This is calculated by multiplying the estimate of the body surface area A_D $[m^2]$ using DuBois formula, determined from the first graph, by the power density, per unit body surface area of the user, depending on the activity level Pd $[W/m^2]$ as follows.

$$q_{user} = A_D \times Pd\ [W]$$

The third graph determines the total emitted quantity of heat from the users q_T $[W]$ as a function of the number of users n, within a functional space. This is calculated by multiplying the emitted quantity of heat per user q_{user} $[W]$, determined from the second graph, by the number of users n, within a functional space as follows.

$$q_T = q_{user} \times n\ [W]$$

2.3 Verification of the Used Formulas

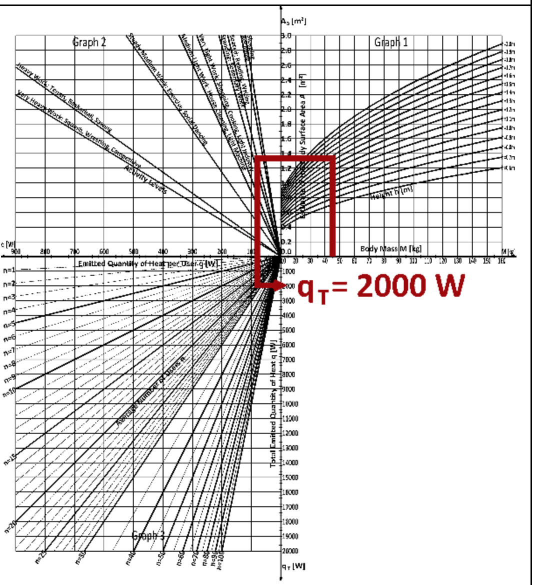
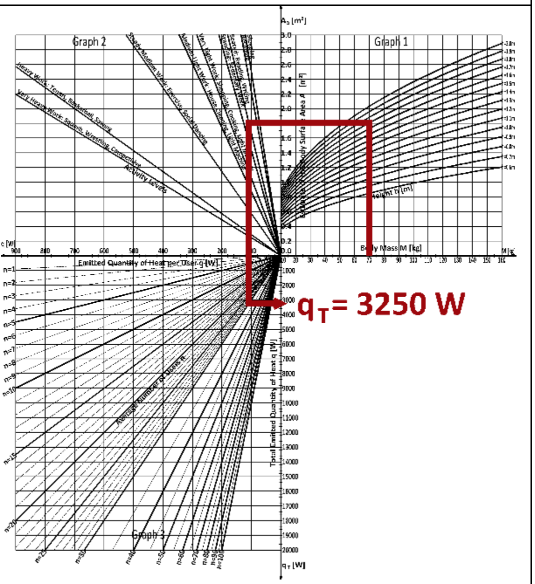
The formulas used in the graphs that constitute the design chart were verified mathematically by matching the $q_{T_{Design\ Chart}}$ that was determined from the design chart, up to the values q_T that was obtained from calculations using the following combined formula.

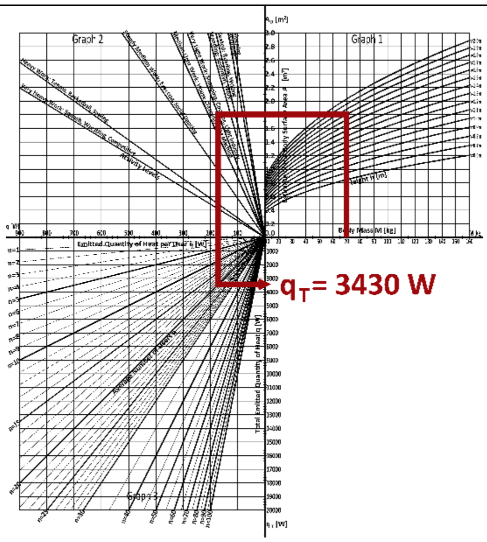
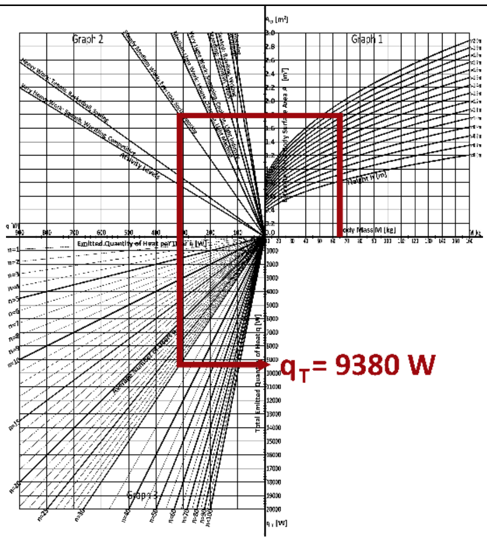
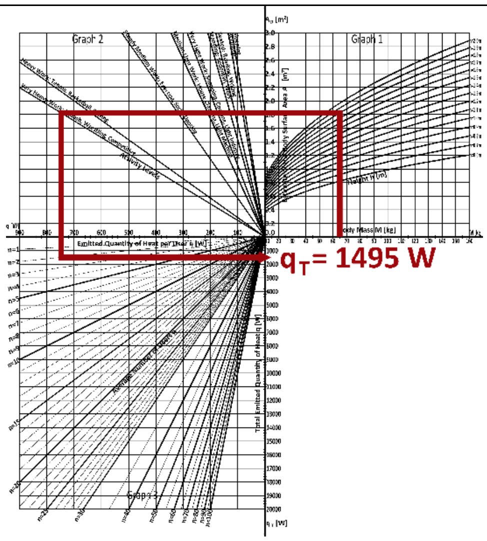
$$q_T = A_D \times Pd \times n\ [W]$$

$$q_T = \left(0.202 M^{0.425} h^{0.725}\right) \times Pd \times n\ [W]$$

The calculated values align with those determined by the design chart, as shown below in Table 1.

Table 1: The mathematical verification to verify the formulas of the design chart graphs.

Functional Space/Specs	$\boldsymbol{q_T = A_D \times Pd \times n\ [W]}$ $\boldsymbol{q_T = \left(0.202 M^{0.425} h^{0.725}\right) \times Pd \times n\ [W]}$	$\boldsymbol{q_{T_{Design\ Chart}}}$
1. Classroom • M = 45 kg • h = 1.45 m • n = 25 Students	$q_T = \left(0.202(45)^{0.425}(1.45)^{0.725}\right) \times (60) \times (25)\ [W]$ $q_T = 2000\ W$	
2. Restaurant/Food Hall • M = 70 kg • h = 1.70 m • n = 30 Guests	$q_T = \left(0.202(70)^{0.425}(1.70)^{0.725}\right) \times (60) \times (30)\ [W]$ $q_T = 3250\ W$	

Functional Space/Specs	$q_T = A_D \times Pd \times n\ [W]$ $q_T = \left(0.202M^{0.425}h^{0.725}\right) \times Pd \times n\ [W]$	$q_{T_{Design\ Chart}}$
3. <u>Restaurant Kitchen</u> • M = 70 kg • h = 1.70 m • n = 20 Chefs	$q_T = \left(0.202(70)^{0.425}(1.70)^{0.725}\right) \times (95) \times (20)\ [W]$ $q_T = 3430\ W$	
4. <u>Aerobics Gymnasium</u> • M = 65 kg • h = 1.75 m • n = 30 Athletes	$q_T = \left(0.202(65)^{0.425}(1.75)^{0.725}\right) \times (175) \times (30)\ [W]$ $q_T = 9380\ W$	
5. <u>Squash Court</u> • M = 65 kg • h = 1.80 m • n = 2 Players	$q_T = \left(0.202(65)^{0.425}(1.80)^{0.725}\right) \times (410) \times (2)\ [W]$ $q_T = 1495\ W$	

3 Results

Figure 1 shows the design chart that has been created by the author. It consists of three integrated graphs representing the different variables that affect the total emitted quantity of heat from the users, within a functional space.

3.1 Description of the Design Chart

The design chart, shown in Figure 1, consists of three integrated graphs that are used counterclockwise to determine the total emitted quantity of heat from the users, within a functional space, as a function of their mass, height, activity, and number.

The first graph, at the top right, determines an estimate of the body surface area A_D as a function of mass M and height h. It consists of two axes and fifteen curves. The horizontal axis represents the body mass of the user M $[kg]$ which ranges from 10 kg to 160 kg. The fifteen curves represent the height of the user h $[m]$ which ranges from 0.6 m to 2.0 m. The vertical axis represents the determined body surface area A_D $[m^2]$, as a function of as a function of mass M and height h, which ranges from 0.0 m^2 to 3.0 m^2.

The second graph, at the top left, determines the emitted quantity of heat q per user as a function of the activity level. It consists of two axes and nine diagonal lines. The vertical axis, which is aligned with the vertical axis of the first graph, represents the determined body surface area A_D $[m^2]$ which ranges from ranges from 0.0 m^2 to 3.0 m^2. The nine diagonal lines represent a variety of typical activity levels that include sleeping, reclining, seated, standing, very light work, medium light work, steady medium work, heavy work and very heavy work (see Table 2). The horizontal axis represents the determined emitted quantity of heat per user q $[W]$, as a function of the activity level, which ranges from 0 W to 900 W.

Table 2: Metabolic rates at different activities [10].

Activity	Pd $[W/m^2]$
"Sleeping"	40 W/m²
"Reclining"	45 W/m²
"Seated": Reading, Writing	60 W/m²
"Standing": Sedentary Work	70 W/m²
"Very Light Work": Shopping, Cooking, Light Industry	95 W/m²
"Medium Light Work": House Cleaning, Light Machine	115 W/m²
"Steady Medium Work": Exercise, Social Dancing	175 W/m²
"Heavy Work": Tennis, Basketball, Sawing	350 W/m²
"Very Heavy Work": Squash, Wrestling, Competitive	410 W/m²

The third graph, at the bottom left, determines the total emitted quantity of heat from the users q_T $[W]$ as a function of the number of users n. It consists of two axes and diagonal lines. The horizontal axis, which is aligned with the horizontal axis of the second graph, represents the determined emitted quantity of heat per user q $[W]$, as a function of the activity level which ranges from 0 W to 900 W. The diagonal lines represent the number of users n which ranges from 0 to 100. The vertical axis represents the determined total emitted quantity of heat from the users q_T $[W]$, as a function of the number of users n, which ranges from 0 W to 20000 W.

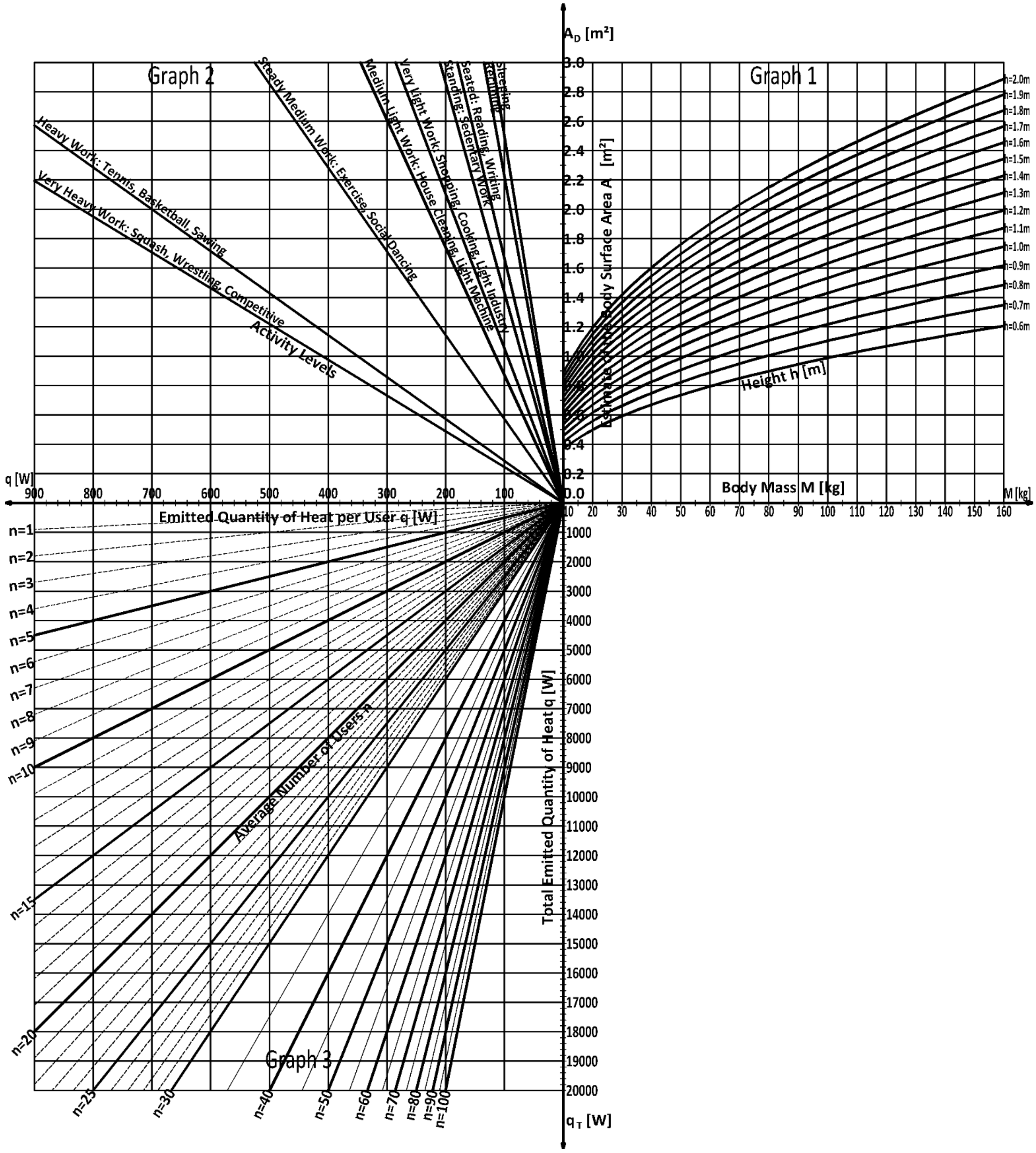


Figure 1: The design chart to determine the total emitted quantity of heat from the users, within a functional space, as a function of their mass, height, activity, and number. Source: the author.

3.2 Use of the Design Chart

To determine the total emitted quantity of heat from the users, within a functional space, all the three integrated graphs are used counterclockwise as follows.

Specify the body mass of the user $M\ [kg]$ on the horizontal axis of the first graph. Extend a vertical line, till it intersects one of the fifteen curves that represent the height of the user $h\ [m]$. Extend a horizontal line, till the body surface area $A_D\ [m^2]$ is determined on the vertical axis. Extend a horizontal line, till it intersects one of the nine diagonal lines of the second graph, which represent a variety of typical activity levels. Extend a vertical line, till it intersects one of the diagonal lines of third graph, which represent the number of users n. Extend a horizontal line, till the total emitted quantity of heat from the users $q_T\ [W]$, within a functional space, is determined on the vertical axis of the third graph.

Example: Use the design chart to determine the total emitted quantity of heat from 60 students, within a lecture hall in a university. The average body mass of the students is $70\ kg$ and the average height is $1.7\ m$.

Solution: Specify the body mass of the user $M = 70\ kg$ on the horizontal axis of the first graph. Extend a vertical line, till it intersects the curve representing the height of the user $h = 1.7\ m$. Extend a horizontal line, till the body surface area $A_D = 1.8\ m^2$ is determined on the vertical axis. Extend a horizontal line, till it intersects the diagonal line representing the activity level which is “Seated: Reading, Writing.” Extend a vertical line, till it intersects the diagonal line representing the number of users $n = 60$. Extend a horizontal line, till the total emitted quantity of heat from the users, within a lecture hall in a university, is determined on the vertical axis of the third graph $q_T = 6500\ W$ (see Figure 2).

3.3 Notes on the Design Chart

The design chart shows that the increase in the different variables; mass, height, activity, and number, would result in an increase in the total emitted quantity of heat from the users, but the effect of each one of them varies. This variation is obvious especially in the first graph which is a non-linear graph indicating different effects of the increase in its variables; mass and height. It is notable that the amount of total emitted heat from the users is significant and should not be ignored but rather considered when addressing the total heat transfer, within a functional space.

4 Discussion and Conclusions

The proposed design chart, which was created by the author, could be used by architects as a simple tool in the preliminary design stages. It can determine the total emitted quantity of heat from the users, within a functional space, as a function of their mass, height, activity, and number. It is beneficial, especially in the preliminary stages of design, to address that amount of emitted heat which would affect the decisions that are taken to ensure the achievement of thermal comfort for the users.

In future research, other design charts could be created addressing other factors affecting thermal comfort, within a functional space.

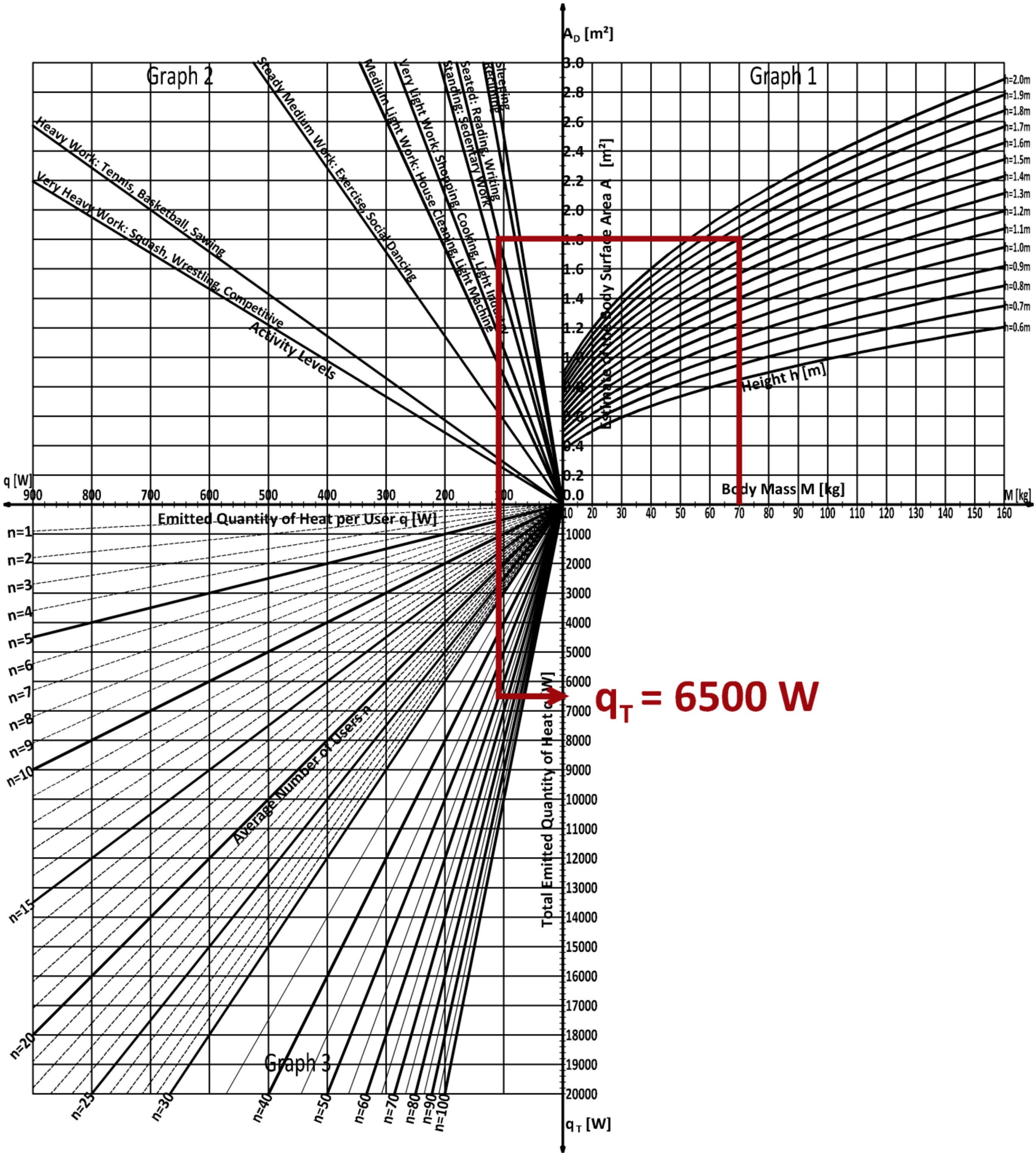


Figure 2: Example on how to use the design chart to determine the total emitted quantity of heat from 60 students, within a lecture hall in a university. Source: the author.

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