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THE UTILIZATION OF ROOM AND BUILDING COMFORT EQUATION FOR REPORTING THERMAL COMFORT: A CASE STUDY AT LABORATORY BUILDINGS

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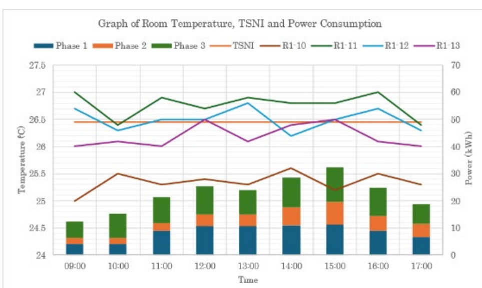
Graphical abstract



Abstract

As a tropical country, the government of Indonesia issued energy conservation standards for air conditioning systems in buildings through the Indonesian National Standard (SNI) 6390:2020. However, this SNI has not provided specific calculations to identify the comfort level of parameters in a building. This study aims to provide clear limits by providing conditions for fulfilling comfort conditions for indoor temperature parameters and buildings using a new proposed equation, namely the Room Comfort Equation (RCE) and Building Comfort Equation (BCE). These methods are based on the average ratio of room data parameters to SNI limited by a widening factor of 1% to 5% as comfort temperature tolerance threshold values. RCE is an Indoor temperature measurement compared to the SNI, resulting in a temperature parameter ratio $P_1 = T_1 / T_{SNI}$. At the same time, BCE is the sum of the RCE across the building. The room temperature was measured for 4 weeks manually using a digital Environmental meter in four rooms R_{1-10}, R_{1-11}, R_{1-12} and R_{1-13} at the Integrated Laboratory and Technology Innovation Center (LTSIT) Building, University of Lampung. The calculation results obtained a temperature parameter ratio (RCE) of 0.958, 1.012, 1.002, and 0.990, so a BCE of 3.96 was obtained. This result shows that the building temperature is ideal by a 5% widening factor, but there are two rooms (R_{1-10} and R_{1-11}) has a passing tolerance limit of 1% widening factor. This finding successfully identified that the cause was the behavioural factor of busy users during practical hours. These results also show that room temperature comfort is more straightforward to measure and report. Therefore, additional efforts are needed to obtain the ideal/optimal temperature, such as upgrading HVAC systems with distributed adaptive control, which can be an effective temperature control solution while compensating for disturbances due to occupant behaviour and the influence of differing ambient weather conditions.

Keywords: Building comfort equation (BCE), room comfort equation (RCE), SNI standard temperature, temperature ratio.

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1.0 INTRODUCTION

Thermal comfort in the building is an important factor that affects residents' appreciation of the space [1,2]. Previous research has found that the building sector is one of the most resource-intensive areas in global energy consumption [3–5]. Maintaining good thermal comfort for residents is the primary energy consumption in buildings [6]. Therefore, there is an urgent need to strike a balance between thermal comfort and energy efficiency [7–9].

Several studies have investigated thermal comfort in various types of buildings in Indonesia, highlighting both common challenges and unique findings. Karyono et al. (2015) [10] examined thermal comfort in naturally ventilated public buildings such as cathedrals, museums, and markets in Jakarta, discovering that despite the different activities and clothing insulation values of the occupants, comfort temperatures were similar across these buildings, though the comfort range varied significantly. Another study by Karyono (2000) [11] focused on office buildings in Jakarta, revealing that comfort conditions could be achieved without unnecessary cooling, emphasizing the potential for energy savings. Research on residential buildings by Permana et al. (2020) [12] stressed the importance of integrating energy-efficient design to achieve thermal comfort, criticizing the often superficial implementation of green building concepts. Further, a study by [13] in Bandung found that adaptive thermal comfort models could be effective in Indonesia, while [14] demonstrated the impact of sun shading and wall openings on thermal comfort in colonial office buildings in Semarang. These studies collectively underscore the need for tailored thermal management strategies across different building types to enhance indoor comfort and energy efficiency in Indonesia.

To encourage the balance between thermal comfort and energy efficiency, the government of Indonesia issued energy conservation standards for air conditioning systems in buildings through SNI 6390:2020 [15]. This standard is intended as a guideline for all parties involved in planning, implementing, supervising, and managing buildings to achieve efficient use of energy. Compared with global standards such as the American Society of Heating Refrigerating and Air Conditioning (ASHRAE 55) and ISO 7730, SNI is more appropriate for implementation in Indonesia, which has a tropical climate [16]. This claim was reinforced by research by Karyono (1995, 1996, 2000), which showed that subjects felt more comfortable at higher indoor temperatures compared to those recommended by other standards such as ASHRAE 55 and ISO 7730 [11,17,18]. However, this SNI has not provided specific calculations to identify the comfort level of parameters in a building [19].

This identification forces people to draw their conclusions from the data in the report. So far, the reporting of comfort data in buildings that have been carried out has traditionally felt long-winded because the report is carried out by presenting existing data by comparing the recommended SNI standards. So here, there is no strong affirmative element or clear [19]. Several methods of space comfort assessment studied in Indonesia, such as Indoor Air Quality (IAQ) [20], environmental quality index (IKLS) and temperature heat index (THI) [22,24] and several other qualitative methods [25,28] have also been conducted. These methods successfully identified the comfort temperature of the space according to the characteristics of tropical areas in Indonesia. However, the research involved various additional parameters such as humidity, air, building materials, vegetation, and other environmental influences [20,22,24,25,28]. Those parameters will increase complexity and inefficiency, especially when reporting building comfort based on SNI. Therefore, we propose that the RCE and BCE methods aim to provide clear limits by providing conditions for the fulfilment of comfort conditions for indoor temperature parameters and buildings, especially those owned by the Indonesian government. The RCE and BCE methods are some of the breakthroughs that are seen and felt to be more practical and efficient. In this paper, the preliminary study of the use of RCE and BCE will focus on temperature comfort only.

2.0 METHODOLOGY

2.1 Study Area

This research was conducted in the Integrated Laboratory and Technology Innovation Center (LTSIT) building of the University of Lampung. This building was chosen as a case study because it has a lot of laboratory equipment, is a campus research centre with many activities, and has laboratory equipment that must be maintained in a comfortable system. This research was carried out during peak working hours from 9:00 to 17:00 for a total of 4 times, with the duration of each measurement being 1 week in the period from February to August 2024. Data collection was not carried out continuously due to the limitations of manual equipment. The determination of the day of data collection was based only on different ambient air temperature conditions to represent seasonal variations such as rain, cloudiness, or hot weather. The measurement was focused on four sample rooms, namely R_{1-10}, R_{1-11}, R_{1-12} and R_{1-13} with an area on R_{1-10} is 16 m^2, and the other three rooms are 9 m^2.

The first stage before the temperature measurement is carried out is to control the electrical installation system of the building to ensure that the electrical installation system of the building is proper. The parameters are the amount of voltage and current as well as the electrical power used by the transformer in the building using a clamp meter. These measurements are not intended for energy audits but as comparative information regarding the causes of parameter changes or disturbances to room temperature comfort. The measurement of electrical parameters is carried out again to obtain data on the stability of the building's electrical condition. The results of the measurement of average electrical data at the LTSIT Building can be seen in Table 1.

Based on the results of current measurements on the three-phase power source used in the LTSIT building, fluctuations in current values tend to increase. The peak load appears to be reached at 15:00 in all phases and then begins to decrease. With the average voltage measurement results at 220 Volts, the electrical power obtained also fluctuates, as shown in Figure 1.

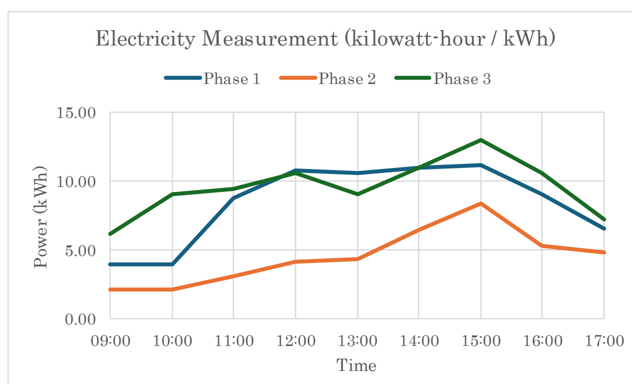

Figure 1 Electrical power consumption curve during temperature measurements

Table 1 Data on electricity measurement results at the LTSIT Building

Measurement Time	Average Current (Ampere)			Average Power (kWh)		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
09:00	18	10	28	3.96	2.20	6.16
10:00	18	10	41	3.96	2.20	9.02
11:00	40	14	43	8.80	3.08	9.46
12:00	49	19	48	10.78	4.18	10.56
13:00	48	20	41	10.56	4.40	9.02
14:00	50	29.5	50	11.00	6.49	11.00
15:00	50.5	38	59	11.11	8.36	12.98
16:00	41	24	48	9.02	5.28	10.56
17:00	30	22	33	6.60	4.84	7.26

Figure 2 Room conditions of R_{1-10} (a), R_{1-11}(b), R_{1-12} (c) and R_{1-13} (d) during temperature data measurement

The following parameter measured was the temperature in four rooms whose comfort level was unknown to the SNI standard temperature, as shown in Figure 2. The equipment used in this temperature measurement is a digital Environmental meter. When carrying out the process of measuring room temperature, the air conditioner's position relative to the room's volume is checked so that the speed of indoor temperature propagation that runs convection and meets SNI standards can be known. The equipment we use to know the position of this air conditioner is a digital laser meter. The research data in the form of temperature is then collected to be processed in data processing to get the average of the entire data collection period according to the acquisition hours (Table 2).

2.2 The Process Of Propagation Of Heat In The Air

The air temperature in the room is a form of heat stored in the gaseous fluid trapped in the building [18,20]. The heat propagation process in the gas is known as convection. The heat in the fluid propagates convectionally from the air conditioning system equipment throughout the room until there is a heat balance in all the air in the room [21,23]. Air cooling in a room due to air conditioning work activities requires time according to the air conditioner's working capacity and the air volume of the cooled room [25,27,28]. In the event of convection, the equation applies Equation 1 below [29,30].

$$H = KA.(dT/dL) \tag{1}$$

With H is the number of heats propagated (watt.m °C), K is a convection constant, A is the area of the propagation area (m^2). At the same time, dT and dL are the change in temperature (°C) and the length of the heat propagation trajectory (m), respectively.

The process of temperature increase in each mass of material cooled by the air conditioner applies Equation 2 as follows [29,30].

$$q = m.c_v.(dT) = m.c_v.(T_2 - T_1) \quad (2)$$

Table 2 Data on temperature measurement results in each room

Measurement Time	Average Room temperature (°C)			
	R_{1-10}	R_{1-11}	R_{1-12}	R_{1-13}
09:00	25.00	27.00	26.70	26.00
10:00	25.50	26.40	26.30	26.10
11:00	25.30	26.90	26.50	26.00
12:00	25.40	26.70	26.50	26.50
13:00	25.30	26.90	26.80	26.10
14:00	25.60	26.80	26.20	26.40
15:00	25.20	26.80	26.50	26.50
16:00	25.50	27.00	26.70	26.10
17:00	25.30	26.40	26.30	26.00
Average (°C)	25.34	26.77	26.50	26.19

Table 3 Room Comfort Temperature Standards [15]

No	Comfort type	Range Temperatur
1	Cold	20.50 °C – 22.80 °C
2	Standard comfort	22.80 °C – 25.80 °C
3	Comfortable room temperature	25.80 °C – 27.10 °C

With q is the heat contained in the material (calorie), m is the mass of air (gram), c_v and dT are the heat of the type of matter (gram/°C) and temperature changes (°C), respectively.

2.3 Room Comfort Equation (RCE) and Building Comfort Equation (BCE)

Indoor temperature comfort for tropical countries, including Indonesia, is based on SNI 6390:2020 [15]. The procedure for conditioning the air conditioning system is shown in Table 3. The T_{SNI} value is calculated based on the middle value of the temperature range for the comfortable room temperature type. Room and building comfort based on RCE and BCE are obtained through several stages. Measurement data from the room (dr) compared with standard data ds, namely the reference data from the SNI standard, so that an equation in the form of an indoor parameter ratio (RCE) is obtained in Equations 3 and 4.

$$\mathrm{P} = \frac{dr}{ds} \quad (3)$$

$$\mathrm{P}_1 = \frac{dr1}{ds1};\ \mathrm{P}_2 = \frac{dr2}{ds2};\ \mathrm{P}_n = \frac{drn}{dsn} \quad (4)$$

With P adalah Room Comfort Equation (RCE), dr and ds are indoor and reference parameter data (SNI standard), respectively. If we add up the temperature ratio in each room that produces RCE, it will produce the Building Comfort Equation (BCE) or P_t, as can be seen in Equation 5.

$$P_t = P_1 + P_2 + \cdots + P_n \quad (5)$$

Based on the ratio of room data parameters to SNI standard data, the ideal comfort price $P_t = 1 \pm (1 \times 0{,}01)$ if $n = 1$. For widening tolerance, the level of elasticity can be added by 1% to 10%. Room comfort levels (RCE) with amplified temperature comfort of 1% and 5% can be seen in Equations 6 and 7.

$$n - (n \times 0.01) \leq P_t \leq n + (n \times 0.01) \text{ (1\% widening)} \quad (6)$$

$$n - (n \times 0.05) \leq P_t \leq n + (n \times 0.05) \text{ (5\% widening)} \quad (7)$$

If the ratio of temperature parameters of each room can be written $P_1 = T_1/T_{SNI}$, $P_2 = T_2/T_{SNI}$, $P_3 = T_3/T_{SNI}$ dan $P_4 = T_4/T_{SNI}$, which is also known as RCE. These RCE elements will be summed up to obtain $P_t = P_1 + P_2 + P_3 + P_4$ which is referred to as BCE. The use of RCE and BCE in identifying the temperature in a building will make it easier to unite many homogeneous and heterogeneous parameters. In this study, the results of measuring four homogeneous parameters (temperature) in 4 rooms will be united so that the comfort limit equation $n = 4$. This number is significant to determine the limit of the building's temperature comfort interval using equation 5 so that the limit condition is obtained at $3.96 \leq P_t \leq 4.04$. In this study, the temperature of 4 rooms has been identified and compared with the room temperature recommended by T_{SNI} is 26.45 °C.

3.0 RESULTS AND DISCUSSION

3.1 Variation in Temperature Changes

Based on the measurement data in Table 2, the temperature change conditions in each room during the measurement period were obtained. Variation in temperature change from measurement to temperature T_{SNI} shown by the curve in Figure 3. In the room R_{1-10} the room temperature is consistently below T_{SNI}. Meanwhile, in the other three rooms, the temperature changes around the temperature T_{SNI}. Temperature in the room R_{1-11} looks tend to be on top T_{SNI}, otherwise temperature R_{1-13} tends to be below T_{SNI}. While the temperature R_{1-12} looks the most stable in between T_{SNI}.

In order to maintain the LTSIT room temperature comfortable in accordance with the T_{SNI} temperature, Figure 3 shows that electrical power usage increases until it reaches a high at 3:00 p.m. The peak load increase occurred in all three electrical phases, with the maximum load exceeding 30 kWh. This scenario is undoubtedly a problem for optimizing power to make it more effective by minimizing air conditioning loads [31,32], particularly in rooms with temperatures below T_{SNI}. In this scenario, setting the temperature threshold for the air conditioner to R_{1-10}, which is always lower than T_{SNI}, can be an alternative to lowering electrical power usage.

3.2 RCE and BCE Analysis

Calculations are carried out using RCE to determine whether the room's temperature settings vary and are included in the comfortable category according to SNI. This calculation makes it easier to classify room comfort based on value comparison of T_{SNI}. The results of the RCE calculation in each room are shown in Table 4. Since the parameter measured in the room is only one parameter, the comfort of the room is represented only by the parameters of P_1. In other words, $P_t = P_1$, where P_t is BCE and P_1 is RCE. Results of data processing of temperature parameter ratio in the room with SNI temperature standard (T_{SNI}) for one temperature parameter obtained the comfort value in rooms R_{1-10}, R_{1-11}, R_{1-12} and R_{1-13} each (P_t) is 0.958, 1.012, 1.002, 0.990, respectively.

Based on the ideal limit of room comfort with the level of elasticity 1% ($0.99 \leq Pt \leq 1.01$), then there are two rooms, namely R_{1-10} and R_{1-11}. It is classified as an uncomfortable room because it exceeds the ideal comfort limit. However, no room passes the 5% widening tolerance ($0.95 \leq Pt \leq 1.05$). Room R_{1-10} is the most spacious room and has a lot of equipment to condition the air, such as fans and air conditioners. This condition is in line with the temperature variation curve in Figure 3, showing values that are consistently below the T_{SNI} limit or can be said to be colder. Room R_{1-11} is a centre of activity that uses a lot of laboratory equipment and lives continuously. Thus, it is possible to assume that this room consumes much electrical energy and produces heat. This condition is in line with the temperature variation curve in Figure 3, showing values that are consistently above the T_{SNI} limit or can be said to be hotter.

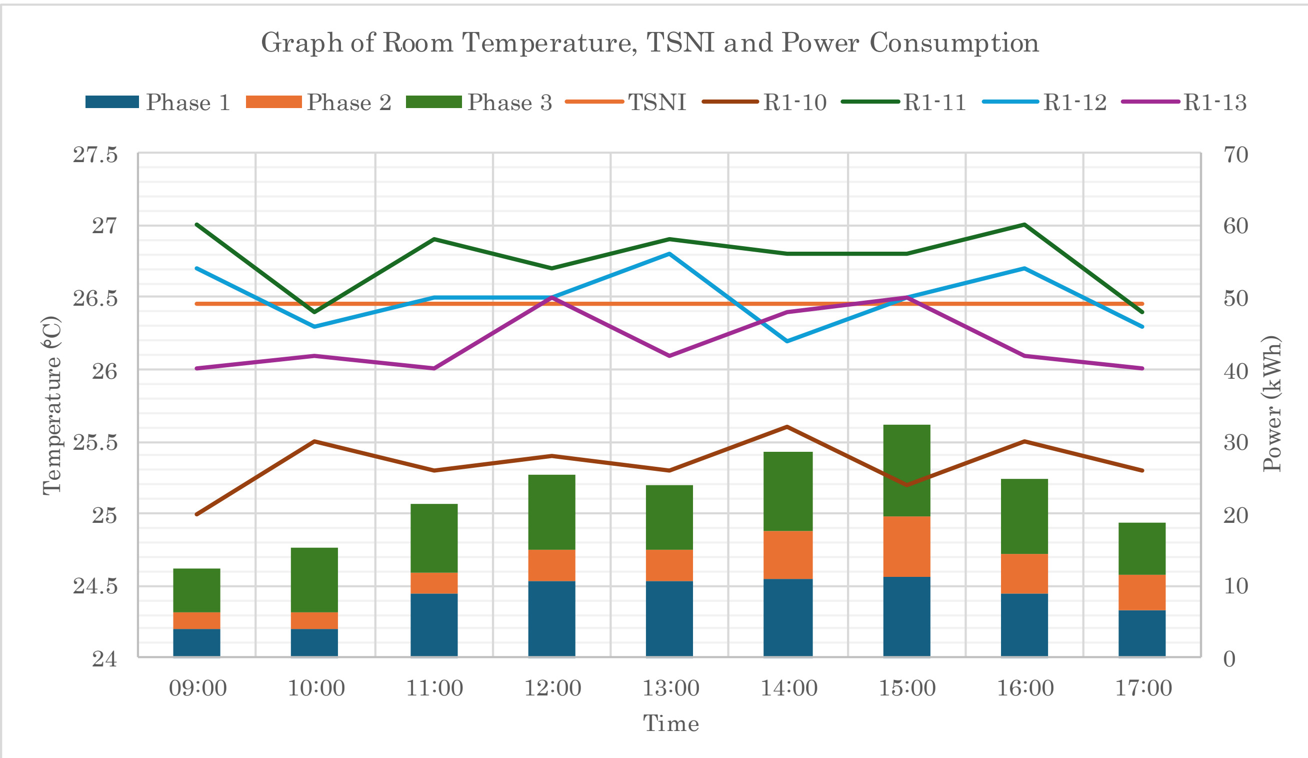

Figure 3 Graph showing the variation in temperature changes as measured against temperature T_{SNI} and power consumption.

Table 4 The results of the RCE calculation in each room and the BCE value in the building

Measurement Time	Room temperature ratio			
	R_{1-10}	R_{1-11}	R_{1-12}	R_{1-13}
09:00	0.95	1.02	1.01	0.98
10:00	0.96	1.00	0.99	0.99
11:00	0.96	1.02	1.00	0.98
12:00	0.96	1.01	1.00	1.00
13:00	0.96	1.02	1.01	0.99
14:00	0.97	1.01	0.99	1.00
15:00	0.95	1.01	1.00	1.00
16:00	0.96	1.02	1.01	0.99
17:00	0.96	1.00	0.99	0.98
RCE	**0.958**	**1.012**	**1.002**	**0.990**
BCE	**3.962**			

Rooms R_{1-10} and R_{1-11} also tend to have higher occupancy than the other two rooms. This condition is thought to be due to student practicum activities most often done in the afternoon. This occupancy variation can affect the room's temperature, humidity, and CO_2 levels [33]. However, this study did not collect data related to occupancy specifically. Information related to occupancy variability may not significantly affect energy consumption. However, it can be important information in determining peak electricity demand [37].

Room comfort in LTSIT has a substantial influence on building energy usage. The factors impacting thermal comfort and energy consumption in LTSIT include indoor air and radiant temperature, consistent with the prior studies [34,36,37]. However, based on the calculation of the building comfort ratio or BCE, a value of 3.96 was obtained from the total RCE of the four rooms are still in the BCE standard, namely $3.96 \leq P_t \leq 4.04$. Therefore, even though two rooms exceed the T_{SNI} ratio value in the RCE value, the building authority does not need to change the room temperature level because the BCE ratio is still met. It is because of excess temperature in the room R_{1-10} can rearrange its distribution to the room R_{1-11} through the air temperature conditioning management. The application of an HVAC system with distributed adaptive control, as proposed in the research of Lymperopoulos & Loannou (2019; 2020), can be a solution to regulate temperature effectively while compensating for changes in parameters and disturbances due to occupant behaviour and the influence of differing ambient weather conditions [38,39]. In addition, checking ventilation, using thermal insulation and inspecting windows on the outside of the building periodically is highly recommended to overcome hot air leakage from outside, especially because the research location is in a tropical country like Indonesia [42,44,45]. With this distribution, there will be no increase in electricity consumption, so the use of electricity can be more efficient, and the comfort of rooms and building temperatures can also be achieved.

Studies related to room comfort in Indonesia show that room temperature comfort standards cannot be applied globally and only specifically to local residents' locations and behaviour [40,41,43]. Therefore, the use of T_{SNI} reference temperatures must be adjusted to the T_{SNI} of each region in Indonesia. However, the use of RCE and BCE equations can still be used in various conditions because the T_{SNI} reference value can be adjusted to each region's characteristics and temperature comfort references. In addition, the determination of the achievement of room and building temperature comfort using RCE dan BCE in reporting according to SNI can be done with more straightforward, firmer, and more practical calculations.

4.0 CONCLUSION

The study revealed that the temperature conditions in rooms R_{1-10}, R_{1-11}, R_{1-12} and R_{1-13} varied significantly in relation to the SNI temperature standard T_{SNI}. Rooms R_{1-10} and R_{1-11} were found to be less comfortable due to their temperatures consistently falling below and above T_{SNI}, respectively, while room R_{1-12} and R_{1-13} maintained stable and comfortable temperatures within the ideal range. The RCE values indicated that only room R_{1-12} and R_{1-13} met the ideal comfort range, with the other rooms falling outside the optimal range. Despite these variations, the overall building comfort efficiency (BCE) remained within acceptable standards, suggesting that no immediate adjustments are necessary. Effective temperature management and room redistribution could optimize comfort and energy efficiency without increasing electricity consumption. Improvement of HVAC systems with distributed adaptive control can be an effective solution for temperature regulation while compensating for disturbances caused by occupant behaviour and the influence of differing ambient weather conditions. In addition, regular ventilation checks, the use of thermal insulation, and inspections of the exterior windows of the building are highly recommended because the research location is in a tropical climate. The ease of use of RCE and BCE equations will be beneficial in identifying target rooms that need to be inspected. For more precise and practical reporting of room and building temperature comfort in compliance with SNI standards, it is recommended that RCE and BCE be implemented as more effortless, more straightforward calculation methods.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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