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# The Significance of Temperature Based Approach Over the Energy Based Approaches in the Buildings Thermal Assessment

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***Abstract* – The design of low energy buildings requires accurate thermal simulation software to assess the heating and cooling loads. Such designs should sustain thermal comfort for occupants and promote less energy usage over the life time of any building. One of the house energy rating used in Australia is AccuRate, star rating tool to assess and compare the thermal performance of various buildings where the heating and cooling loads are calculated based on fixed operational temperatures between 20 °C to 25 °C to sustain thermal comfort for the occupants. However, these fixed settings for the time and temperatures considerably increase the heating and cooling loads. On the other hand the adaptive thermal model applies a broader range of weather conditions, interacts with the occupants and promotes low energy solutions to maintain thermal comfort. This can be achieved by natural ventilation (opening window/doors), suitable clothes, shading and low energy heating/cooling solutions for the occupied spaces (rooms). These activities will save significant amount of operating energy what can to be taken into account to predict energy consumption for a building. Most of the buildings thermal assessment tools depend on energy-based approaches to predict the thermal performance of any building e.g. AccuRate in Australia. This approach encourages the use of energy to maintain thermal comfort. This paper describes the advantages of a temperature-based approach to assess the building's thermal performance (using an adaptive thermal comfort model) over energy based approach (AccuRate Software used in Australia). The temperature-based approach was validated and compared with the energy-based approach using four full scale housing test modules located in Newcastle, Australia (Cavity Brick (CB), Insulated Cavity Brick (InsCB), Insulated Brick Veneer (InsBV) and Insulated Reverse Brick Veneer (InsRBV)) subjected to a range of seasonal conditions in a moderate climate. The time required for heating and/or cooling using the adaptive thermal comfort approach and AccuRate predictions were estimated. Significant savings (of about 50 %) in energy consumption in minimising the time required for heating and cooling were achieved by using the adaptive thermal comfort model.**

***Keywords* – Building thermal simulation; adaptive thermal comfort; sustainable building design**

## 1. INTRODUCTION

Many factors influence the thermal performance of a complete building, some of these factors are self-governing, while others are inter-related, and not all factors affect the thermal performance of the building in the same way as some have a greater influence than others [1].

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Buildings and their heating, cooling and ventilation systems have become significantly more varied and complex in recent years, which affects the accuracy of the existing thermal assessment packages. The enormous numbers of materials, glazing systems, wide range of passive techniques, different construction types and heating and cooling systems have become broader and more complex. In addition, the move towards highly insulated, more airtight, low energy buildings has modified the energy balances so the internal and solar energy gains have a much greater effect [2].

Heat transfer in buildings is a dynamic phenomenon with continuous changes with time. There are different methods for solving dynamic heat transfer equations, such as the heat balance method, the admittance method, various finite difference methods, and even electrical circuit solving programs, but these modules have huge numbers of inputs, elements and variables, such as:

1. The physical elements of the building (e.g., orientation, width, height, length);
2. The thermal properties of all the elements (e.g., thermal conductivity, heat capacity, *R*-value);
3. The climatic conditions (temperatures, solar radiation, wind speeds and direction, humidity).

To solve all these variables, a set of equations describing the heat flow through all the elements and the heat stored inside the elements is required. However, these large numbers of coupled differential equations are usually solved numerically.

These many variables are changing all the time, which makes it challenging to precisely calculate the thermal performance of a complete building. To achieve an accurate thermal performance of a building, account must be taken of the building as a complete system [3].

The key to efficient design is the implementation of a factor which correctly encapsulates the influences of the thermal mass and insulation properties under a dynamic temperature environment. A more representative parameter than the thermal resistance (*R*-value) is essential to fully capture the dynamic thermal behavior of a building’s walling system. A new thermal performance factor has been developed at the University of Newcastle. It is called the dynamic temperature response (*T*-value), which encapsulates the impact of all of the physical parameters affecting the thermal performance of walls, which not only accounts for the wall thermal resistance (*R*-value), but also its thermal mass [3].

The limitation of the thermal resistance (*R*-value) is a clear indication of the drawback of the energy based approach which is based on the thermal resistance of the walls to predict the thermal performance of complete buildings.

In general; there are three principal approaches to house energy rating based on the energy consumption of a building [4]:

- Prescriptive Approach: Offer least standards for the materials, equipment and the methods and it are mandatory to meet the requirements for an energy efficiency evaluation such as Deemed-To-Satisfy Provision;
- Calculation-based Approach: Used computer based software to calculate building thermal performance and then compare that to the mandatory requirements in each country/state in order to be acceptable for construction under the program such as AccuRate in NSW, Australia;
- Performance-based Approach: Applies real building energy consumption records to assess a building’s energy efficiency then compares these with the compulsory standards required in the proposed construction area. This approach is applicable to existing buildings only.

The prescriptive and calculation approaches are more dominant; while the performance based rating approach is uncommon because it is time consuming to collect the data [4].

Current building assessment systems lean towards creating a number of simplifying assumptions and results in inconsistencies between the free running mode and the conditioned mode. For example, an efficient design for a building in a conditioned running mode differs from exactly the same building in the free running operation mode, which is the primary reason for the incapability of existing energy based rating schemes to effectively assess a building's performance in a temperate climate [5].

A comparison of Home Energy Rating Systems (HERS) ratings and real utility billing data for about 500 houses in four states in the United States found that HERS can, on average, forecast annual energy cost accurately. However, on an individual house basis, the match between the predicted energy cost and the actual energy cost was often poor, especially for older houses [6].

There are a wide range of building assessment tools and the comparison between the tools and their results are very difficult because different tools were designed for evaluating the performance of different types of buildings, they are applied to different stages of the life cycle, and depend on different guidelines, databases and questionnaires [6].

AccuRate is an energy based assessment tool used in Australia. It gives a star rating (bands) to the residential houses between 0 and 10 where the higher bands, the better the thermal performance. AccuRate uses set for each climate for equitable comparison between buildings in different climates [7].

The main issue with AccuRate is that there are big discrepancies between the AccuRate results and the recorded temperatures inside the buildings. This required extra analysis for the continuing improvement and modification for the AccuRate to increase the accuracy of the program [8].

In AccuRate Software; the current heating and cooling loads estimation were based on average historical weather data called typical meteorological year (TMY) to represent the long-term typical weather data which is in 1974 for Newcastle area in Australia [9].

In AccuRate Software; heating and cooling loads are available at fixed operating temperatures between 20 °C to 25 °C to sustain occupants thermal comfort. However these fixed values for the operating time and temperatures increases the time heating and cooling required where higher or lower internal air temperatures will lead to the heating and cooling be activated, while the adaptive thermal model apply wider range of temperatures (19 °C to 28 °C) and allowed the occupants to interact with the outside environment which minimize the need for heating and cooling.

The large inconsistencies between the AccuRate results and the measured temperatures in various building zones necessitates an additional examination for the ongoing development and adjustment of the AccuRate software to avoid compromising the precision of the heating and cooling loads and, therefore, the accuracy of the star rating [10].

Naturally ventilated buildings which used less mechanical heating normally consume less than half the energy compared with air conditioned buildings because the inhabitants adapt to a considerably broader range of temperatures that fall out of the comfort zone defined by the Predicted Mean Vote model (PMV) [11]. The PMV model also predicts that inhabitants will feel hotter than they actually do, and therefore encourages the consumption of more air conditioning than needed [12].

Heating and cooling can be reduced when occupants accept wider ranges of internal air temperature which results in lower energy usage and running costs, and therefore enhancing the economic and environmental performance of the building [13].

Studies of the indoor environments in tropical climates, based on Fanger's predicted mean vote (PMV/PPD), have found that this model does not effectively describe comfortable conditions because it fails to give correct information about an occupant's comfortable temperature. In addition, PMV/PPD studies do not provide the occupant's clothing details. This leads to specific clothing level assumptions which require a fixed internal air temperature, thereby encouraging the designers to use mechanical cooling to reach the thermal comfort level [12].

Inhabitants with greater individual control over their environment have a tendency to accept wider ranges of indoor temperatures. On average, they accepted a 2.6 °C lower operative temperature and showed a lower motivation to modify their current environment (by using air-conditioning) compared with those without personal control. It is recommended that inhabitants have a chance to interact with their thermal environment through openable windows and doors, low energy fans and minimizing the usage of controllable heating/cooling systems [14].

While the PMV/PPD models use energy to obtain comfortable conditions, the adaptive thermal approach uses low energy solutions, such as clothing, open windows/doors, fans, personal heaters/coolers, drinking water and sun shades. To encourage sustainability where reasonable low-energy solutions are accessible, they should be favored.

The adaptive thermal comfort model (temperature based approach) uses wider ranges of thermal comfort temperatures which can be used to assess the thermal performance of complete building by measuring the number of hours where the internal air temperature remains within the thermal comfort range (80 % acceptability limits). Occupants in the adaptive thermal approach can interact with their environment to maintain their thermal comfort [9]. In the adaptive approach, the thermal comfort limits for 80 % acceptability limits are 3.5 °C either side of the ideal thermal comfort temperature and the 90 % acceptability limits are 2.5 °C either side of the ideal thermal comfort temperature [15] as shown in Fig. 1.

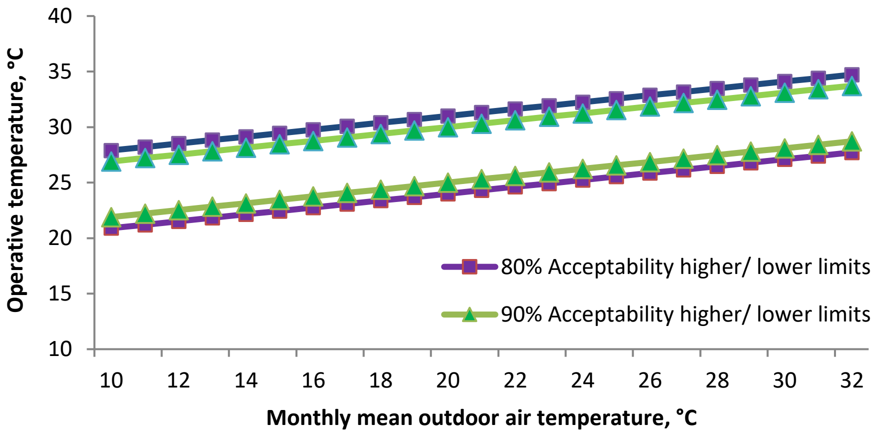


Fig. 1. The 90 % and 80 % acceptability limits for indoor operative temperatures.

## 2. METHODOLOGY

Recorded data from full-scale housing test modules were used to compare the adaptive thermal comfort model and energy based approach (AccuRate) to evaluate the differences between energy and temperature base approached to assess the thermal performance of the modules.

### *2.1. Full-Scale Test Modules*

In the Priority Research Centre for Energy at the University of Newcastle, Australia the thermal performance of Australian buildings have been under investigation since 2001. This has included the construction and detailed monitoring of the thermal performance of four housing test modules exposed to the moderate Newcastle climate. The four modules had a square floor plan of 6 m × 6 m and were spaced 7 m apart to avoid shading and minimize wind blockade as shown in Fig. 2.


Fig. 2. Full scale test modules.

The only difference between the modules is walling system combinations [16]. They are:

- Cavity Brick (CB) module consists of two 110 mm brickwork skins with 50 mm cavity;
- Insulated Cavity Brick (InsCB) module consists of two 110 mm brickwork skins with 50 mm cavity and R1 polystyrene insulation;
- Insulated Brick Veneer (InsBV) module consists of an external 110 mm brickwork skin and timber frame with low glare reflective foil with R1.5 glass wool batts covered by 10 mm plasterboard internally;
- Insulated Reverse Brick Veneer (InsRBV) module which has an opposite configuration of the InsBV walling system.

More than 100 sensors were installed in each module to record the external weather conditions (i.e. air temperature, relative humidity, solar radiation on each wall surface, wind speed and direction), ground temperature and internal air temperature. The internal air temperature was determined only by the influence of the external weather conditions with no ventilation allowed [17].

The internal and external air temperatures recorded on the site for all modules during 2009. These data were used to find the number of hours falls outside the thermal comfort zone sets by AccuRate (20 °C to 25 °C) and for the adaptive thermal comfort wider ranges(19 °C to 28 °C).

In AccuRate for Newcastle area; the operational temperature is set constant for 20 °C in winter and 25 °C in summer where lower than 20 °C in winter required heating and higher than 25 °C in summer required cooling. For the energy based approach (AccuRate) the internal air temperature fall outside the comfort zone for most of the time during one year which required mechanical heating and cooling to sustain occupants thermal comfort.

One the other hand, the adaptive thermal comfort temperatures (from Eq. (1) and Eq. (2)) peak at 24.5 °C in summer and drop to 22.5 °C in winter. The 80 % acceptability limits expand the thermal comfort zones (19 °C to 28 °C). These wider ranges will ultimately save large amount of predicted heating and cooling loads. However this will make some of the inhabitants slightly uncomfortable with the new temperatures but they can easily overwhelmed by small additional actions to reinstate their thermal comfort such as; opening windows for ventilation, shading and wearing suitable clothes.

### *2.2. Adaptive Thermal Comfort Model*

The adaptive thermal temperature and the 80 % acceptability limits for Newcastle can be calculated through these equations [18]:

$$T_c = 17.8 + 0.31T_o, \quad (1)$$

where

$T_o$ The monthly mean of the outdoor air temperature (ºC);

$T_c$ Comfort temperature (ºC).

$$80\ \%\ acceptability\ limits = (T_c \pm 3.5)\ ^{\circ}C. \quad (2)$$

80 % acceptability temperature limits means that at least 80 % of the occupants are satisfied with these temperature ranges.

### *2.3. AccuRate*

AccuRate, rating software uses the heating and cooling requirements to calculate energy required to maintain thermal comfort for occupants for one typical year in Newcastle area as shown in Table 1.

TABLE 1. ANNUAL ENERGY REQUIREMENTS (MJ/M$^2$ PER ANNUM) FOR EACH STAR RATING (BANDS) [7]

| Stars/Bands | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Annual energy requirements | 349 | 232 | 159 | 114 | 86 | 67 | 50 | 34 | 19 | 6 |

## 3. RESULTS AND DISCUSSIONS

The annual heating and cooling energy requirements and star ratings for the InsBV module (as an example) are shown in Fig. 3.

| PROJECT DETAILS | |
|---|---|
| Postcode: 2308 | Climate Zone: 15 |

| CALCULATED ENERGY REQUIREMENTS* | | | | |
|---|---|---|---|---|
| Heating | Cooling(sensible) | Cooling(latent) | Total Energy | Units |
| 41 | 14 | 7 | 63 | MJ/m².annum |

* These energy requirements have been calculated using a standard set of occupant behaviours and so do not necessarily represent the usage pattern or lifestyle of the intended occupants. They should be used solely for the purposes of rating the building. They should not be used to infer actual energy consumption or running costs. The settings used for the simulation are shown in the building data report.

| AREA-ADJUSTED ENERGY REQUIREMENTS | | | | |
|---|---|---|---|---|
| Heating | Cooling(sensible) | Cooling(latent) | Total Energy | Units |
| 29 | 10 | 5 | 45 | MJ/m².annum |
| Floor area | conditioned: 36.0 m² | unconditioned: 0.0 m² | garage: 0.0 m² | |

| BAND RESULT |
|---|
| 7.3 |

Fig. 3. An example of AccuRate certificate which shows the annual heating and cooling energy requirements and star ratings for the InsBV module [7].

Note: the sensible cooling load refers to the dry-bulb temperature of the building and the latent cooling load refers to the wet-bulb temperature.

All modules experienced the worst thermal performance in winter months where the main energy was required for heating. For example, the InsBV module required 29 MJ/m$^2$ per annum for heating in winter time. The annual heating energy requirement for all the modules is shown in Fig. 4.

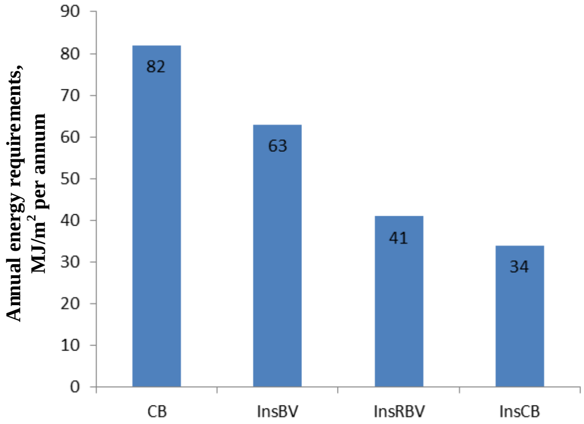


Fig. 4. Annual energy requirements for all the modules.

The 2009 observations were used to perform this analysis for all the modules. The external and internal temperature fluctuations for one year and the thermal comfort range for the InsBV module is shown in Fig. 5.

In AccuRate the heating and cooling thermostat settings are fixed at 20 °C in winter and 25 °C in summer. Using one year of observations recorded from the modules showed that the internal air temperatures falls outside AccuRate thermal comfort zones for most of the time.

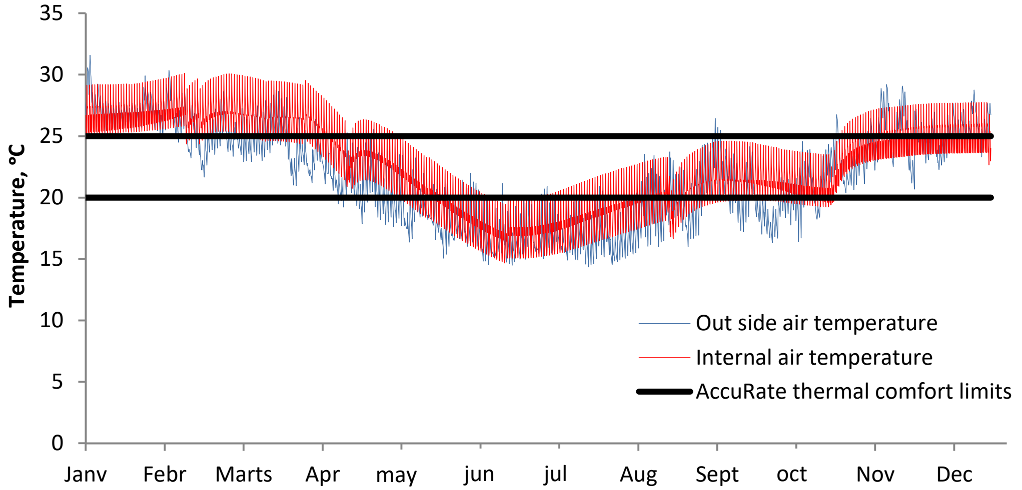


Fig. 5. Internal air temperatures and thermal comfort ranges for the InsBV module for one year.

These set temperatures in AccuRate allowed the estimation of the percentage of time where heating and cooling was not required inside the thermal comfort zone of 33 %, 39 %, 42 % and 44 % for the CB, InsBV, InsRBV and InsCB modules respectively. This is in line with AccuRate energy rating evaluation and shown in Fig. 6.

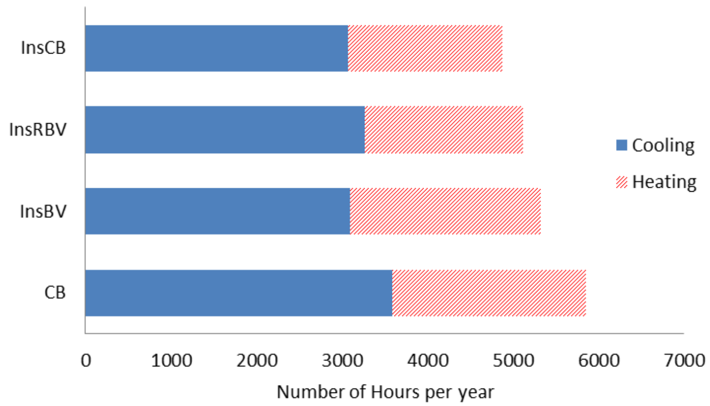


Fig. 6. Number of hours per year where heating and cooling was required based on AccuRate operating temperatures.

The adaptive thermal comfort approach uses wider and more flexible ranges (see Fig. 7) which will save a great amount of predicted energy but this will require occupants to perform additional small actions to maintain their thermal comfort.

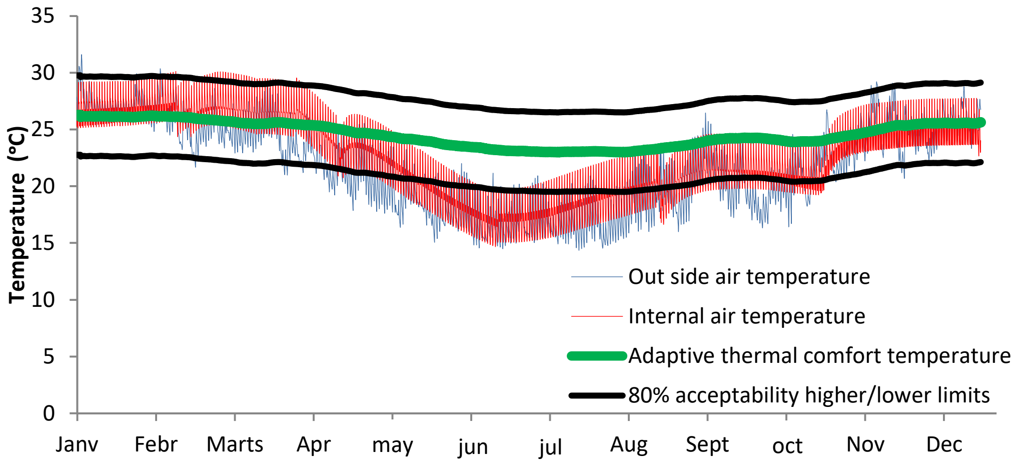


Fig. 7. Internal air temperatures and thermal comfort ranges for the InsBV module for one year using adaptive thermal range.

The number of hours per year where the internal air temperatures of the buildings were outside of the 80 % acceptability limits for heating or cooling was estimated using the adaptive thermal comfort limits and shown in Fig. 8.

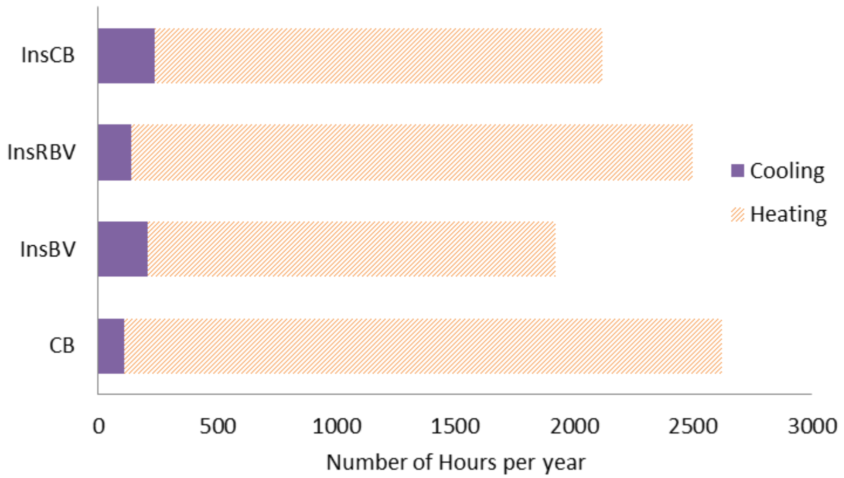


Fig. 8. Number of hours where cooling or heating required for each module using adaptive thermal limits.

The adaptive approach reduced the overall energy consumption requirement by reducing the need for heating or cooling time compared with AccuRate by more than half for all the modules. This is shown in Fig. 9.

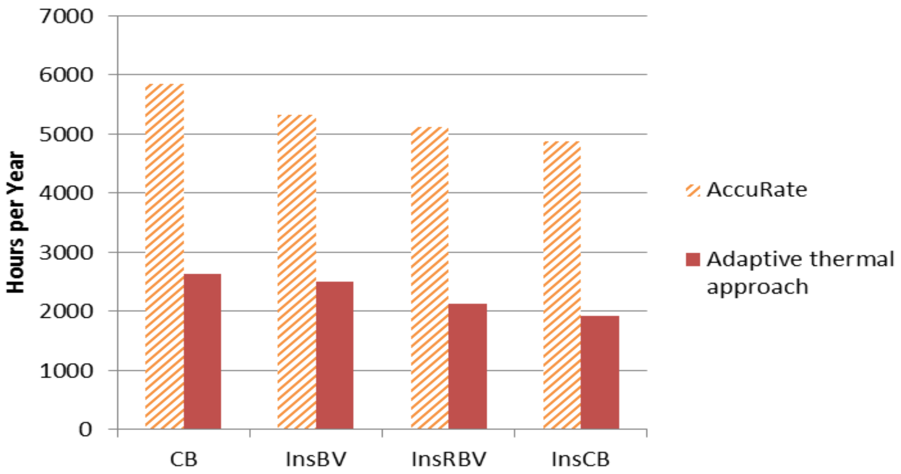


Fig. 9. Number of hours required either heating or cooling for AccuRate and the adaptive approach.

## 4. CONCLUSION

The accuracy of any thermal simulation has direct consequences on the estimation of the energy required for any building and for the design/installation of mechanical heating or cooling systems to maintain thermal comfort for the occupants over the life time of any buildings. Hence, the results of any simulation should imitate the real performance of the building and thus promote lower energy usage.

Energy based methods used to predict the energy consumption of any envelope will required a set of equations describing the heat flow through all the elements and the heat stored inside the elements. These can be highly variable and there are great differences between theoretical and real results, which prove the imprecision of energy based approaches to correctly predict the thermal performance of buildings.

Existing assessment programs encourage energy consumption when they require the use of additional energy to obtain thermal comfort, which is not a sustainable approach. For instance AccuRate required more than double the heating and cooling time compared with the adaptive thermal comfort approach. The energy based approach resulted in longer periods when heating and cooling were required compared with the temperature based approach by 55 %, 53 %, 59 %, 61 % for the CB, InsBV, InsRBV and InsCB respectively.

The assessment of the thermal performance using temperature simplifies the analysis and saves more building operation energy. On the other hand using the energy approach encourages energy consumption by using energy to sustain inhabitants' thermal comfort.

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