PREDICTING THE IMPACT OF UPGRADING CHINESE BUILDNG DESIGN STANDARDS ON THE ENERGY PERFORMANCE

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ABSTRACT

In order to reduce building energy consumption, Chinese government has revised the Chinese building design standard. In the new guide the use of individual room temperature control is highly recommended for new and refurbishment buildings. However, critical evidence on how this improvement can have an impact on the building energy consumption is not clear. This paper is aiming to explore how the upgrading residential standards affect the building energy performance. In order to evaluate its impact on the building energy consumption, two buildings were chosen: one complying with the old Chinese building design standard, while the other complies with the new standard. Additionally, the real time measured data from a typical residential building in China are used to validate a dynamic building performance simulation.

KEY WORDS

China, Residential Buildings, Energy efficiency, Simulation Analytics Method

INTRODUCTION

In the past 20 years, building energy consumption in China has an increasing rate of more than 10% every year (Cai, et al., 2009; JE & DG., 2000; J, et al., 1999; Lang, 2004). China's building section accounts for 23% of the country's total energy consumption (Building Energy Conservation Research Center of Tsinghua University, 2011). In China, every year more buildings that are residential have been built. In addition, the energy consumption of building improved frequently, meanwhile, the level of energy efficiency in buildings, particularly in residential stock, remains low (Yao, et al., 2005). The space heating in the residence plays a significant role of energy consumption in the residential sector in China (Yoshino, et al., 2004). Therefore, it is important to understand current energy consumption for residential buildings in China. Generally, China can be separated into five climatic zones namely severe cold, cold, hot summer and cold winter, hot summer and warm winter and moderate as shown in Figure 1 (GB 50178-93, 1993). Xi'an city is located at latitude 34°16´N, longitude108°56´E, is typical city in cold zone in the northwest of China, and belongs to the Shaanxi province. Xi'an has a typical cold and dry climate in winter in cold zone.

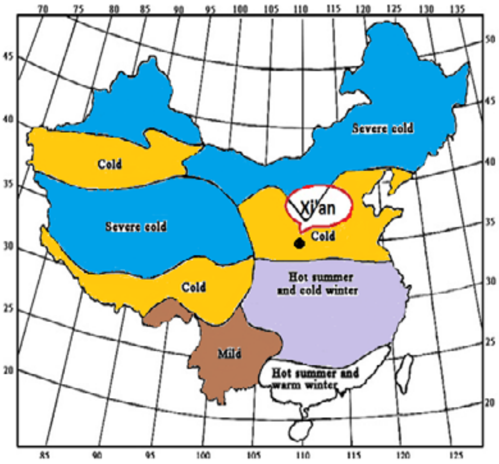

Figure 1 Five climatic zones of China based on GB50178-93

In order to reduce building energy consumption in China, the new building codes have issued by Chinese government. The national standards JGJ134-2001 for energy efficiency of residential buildings were launched with the target of a 50% reduction in energy consumption (Yu, et al., 2009). Based on different zones in China, Chinese government firstly announced an energy conservation standard JGJ26-95 for new built Chinese residential buildings in cold and severe cold zone. The household-based heat meter and Thermostatic Radiator Valves (TRVs) have been encouraged to use in new standard (JGJ26-95, 1996). In 2010, the standard was revised and the new version of Design Standard JGJ26-2010 for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones has a mandatory requirement on the heating system, that it should be installed with household-based heat meters and TRVs for each radiator (JGJ26-2010, 2010). Currently, there are two common types of heating systems in Chinese residential buildings, with respect to the controllability of the central heating system; one is an old central heating system without any possibility of controlling room temperature. Moreover, another is a new central heating system that provides temperature control of individual rooms. Central heating system is common heat supply system in cities in China. The principle of centralized heating is urban heating network, district heating networks or central heating boiler room as a heat source for heating mode. In the central heating system, hot water is generated by a boiler or cogeneration plant, meanwhile the water flow through to radiators in the living spaces through a network. The requirement of typical indoor temperatures ranged from 16 to 18°C for residential buildings equipped by central hot water system (Siwei & Yu, 1993).

As can be seen from some previous researches have attempted to investigate the potential variables have impact on the energy consumption in Chinese residential buildings. A review study conducted by Chen et al. of field study in Shanghai of China showed that how the various potential variables result in different of annual energy consumptions characteristics between old and new residential buildings. They analysed further reasons lead to different energy consumption between old and new dwellings. The results indicated that the average annual energy consumption quantities in old buildings are higher than that in new ones. However, there are not significate differences of the building envelop between old and new dwellings. It also can be explained by different climatic zone and different building design standards (Chen, et al., 2009). Cao et al. have shown that new individual heating system and old central heating system result in different human thermal sensations can be explained by individual control mode. Therefore, the two types of heating systems have impact on occupant’s thermal sensation due to different heating set-point and they found that the dwellings operated by new individual boiler heating system have more acceptable for thermal environments. However, there not has any further analysis about the insulation level and energy consumption (Cao, et al., 2014). Yoshino et al. investigated the indoor thermal environment of residential buildings in nine cities during summer and winter, in order to evaluated the thermal comfort and predict the residential energy consumption for space heating and cooling, it also notes that the thermal insulation and airtightness are important factors impact on the energy consumption for residential building in Beijing (Yoshino, et al., 2006). Liu opines that the effectiveness of insulation level for residential and commercial buildings, in addition, the better insulated in new buildings lead to the more energy saving and could save money (Liu & Liu, 2011). A survey and field observations conducted by Xu et al in China and investigated that the central heating system with TRVs adjusted by occupants in new residential buildings together with new heating payment, it also indicated that momentous difference in the frequency of occupant adjusted the TRVs set-point result in energy saving compared with old traditional heating payment (Xu, et al., 2009). However, in this study, there are not comparisons between old and new residential buildings on further deep research, such as analyses of influence factors (indoor thermal environment, insulation level, thermal sensations, occupants’ window behaviours and so on). Meanwhile, further studies in other countries have suggested the variables impact on heating energy consumption. The study of Schuler (Schuler, et al., 2000) described how insulation standards might be considered as an important determination in demand of space heating for household. The work described in the paper of Haas et al, confirmed that the impact of residential house insulation on the energy demand for space heating (Haas, et al., 1998). As a previous study(Leth-Petersen & Togeby, 2001) using technical characteristics method in space heating energy consumption of Danish apartment blocks has been analysed, and it indicated that the dwelling insulation also do not relevant for the energy efficiency of space heating. The simulation model was calibrated using the measured data; however, the one of most important challenges is unpredicted human behaviour. For instance, the database schedules of occupancies and activities were inserted into energy simulation models to emulate the internal loads, however, the actual usage of building changes on a daily basis (Maile, et al., 2007).

Based on above research, it is found that there are few comprehensive researches considering all aspects such as the analyses of influence factors, energy consumption prediction and so on. Furthermore, there are only very limited study comparing the predicted and real measurement of the building envelop, thermal comfort and the heating energy consumption characteristics of both new and old Chinese residential buildings. Previous studies have suggested that the various factors have effect on the energy consumption in residential buildings. In order to identify the effectiveness of updated building design standards on energy efficiency in Chinese residential buildings it is necessary to look into how the each potential variables impact on the energy consumption of old and new residential buildings, (i.e constructions, insulation level, window operation, heating set-point).Thus, this paper is aiming to analyse the indoor thermal environment, insulation levels, and occupants’ behaviours of residential buildings, using simulated analytics method to validate various potential variables how result in energy consumption for old and new residential buildings. Furthermore, this study provides critical evidence on the impact of new building standard on the energy performance and hopefully it would guide Chinese government to refurbish more old Chinese existing buildings with old heating systems.

METHODOLOGY

Building description

This study was carried out in seven flats in the old residential building and seven flats in the new residential building, during the period of February 15th to March 15th 2014, when heating is on. The observed two buildings are located in the same district in the City of Xi'an in Shaanxi Province of China. The new building employing heating control system, together with 'pay for what you use' tariff; the old building employing central heating without control system based on floor areas. The two types of buildings are both multi-stories and floor areas are same in both new and old building. The new residential building was newly built within five years and the old building was built late 1990s. Both The typical monitored building is shown in Figure 2(a) and Figure 2(b).

Figure 2 (a) photo of monitored old building

Figure 2 (b) photo of monitored new building

The old residential building supplied by central heating is equipped by water flow through with constant speed via pipe network. The changes of water temperature are operated by heat source or substation, in accordance with the changes in outdoor temperatures and have no direct control for occupants and they can only open the window or door to adjust their thermal environment. The new residential building operated by central heating system with TRVs in each radiator, the room temperature can be adjusted within a range. The hot water system is not supplied in two buildings. The two typical radiators of hydraulic heating system in new and old buildings can be seen in Figure 3(a) and (b).

Figure 3(a) central heating system with TRVs in typical new residential building

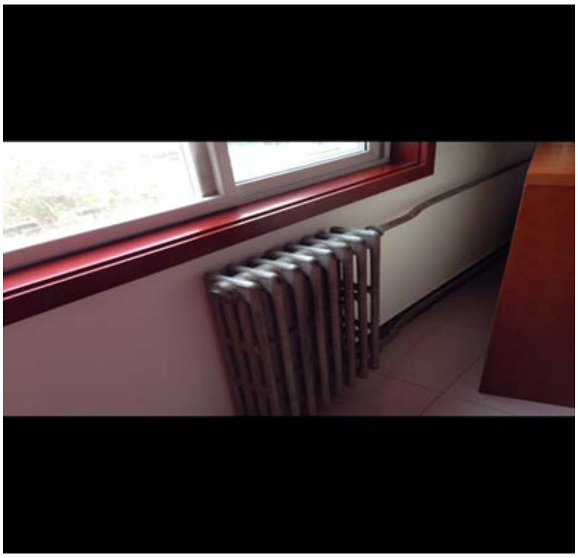

Figure 3(b) central heating system without TRVs in typical old residential building

Experimental data collection methods

In this study, seven flats from each building were monitored longitudinally between 15th February and 15th March, 2014. The indoor temperature of each flat was measured and recorded by a Hobo data Logger at an interval of 10 minutes, in both living room and main bedroom. The measurement location was chosen with a consideration of minimizing the influence of direct sunshine and local heat recourses. The window state was monitored every one minute by a pair of window contactors and the change of window states (either from open to close, or from close to open) was instantly recorded by a Hobo U9-001 data logger, as shown in Figure 4. The hydraulic flow rate for the heating system in the old building was monitored by a Portaflow 330 flow meter. Additionally, the water temperature of supply and return heating pipes in each apartment logged for one hour interval. Based on the measured flow rate and water temperatures, the heat consumed by each apartment was calculated. In each apartment in the new building, an energy meter is installed to measure the heating consumption as shown in Figure 5. In order to assess occupants' heating behaviour in the new building, a further questionnaire was distributed to each household, asking them to self-record their heating behavior (i.e. adjustment of the TRV settings) over a whole week period.

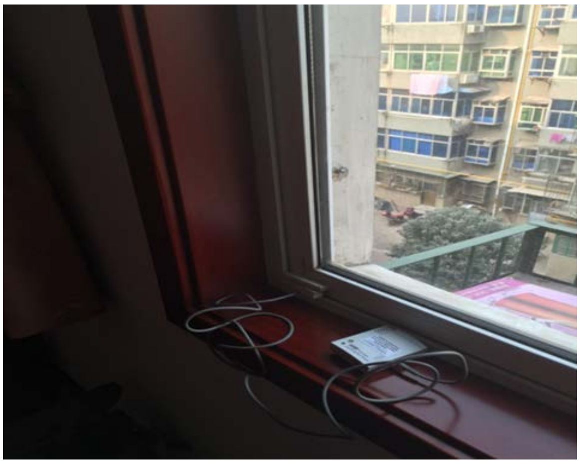

Figure 4 window opening monitored by sensors in new and old buildings

Figure 5 the heat meter installed on input water pipe of heating system in new building

Simulation model and validation methods

The real measured all parameters of building performances in two buildings are applied in a dynamic building performance simulation application in DesignBuilder interface for the EnergyPlus Simulation tool. The sample of model block is shown in Figure 6.

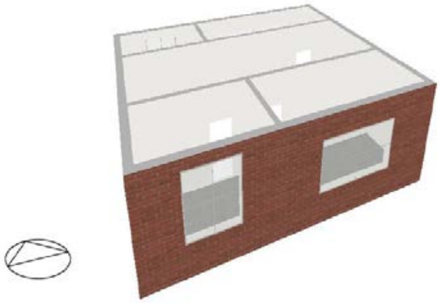

Figure 6 sample of Model Block

The layout of imported floor plan is given in Figure 7. It contains 5 different zones: One Living room, two bedrooms, one kitchen and one toilet. As stated above, the building construction and envelops based on design standards for new and old building, heating set-point, window operation are acquired from real measured data, and they are applied in model block.

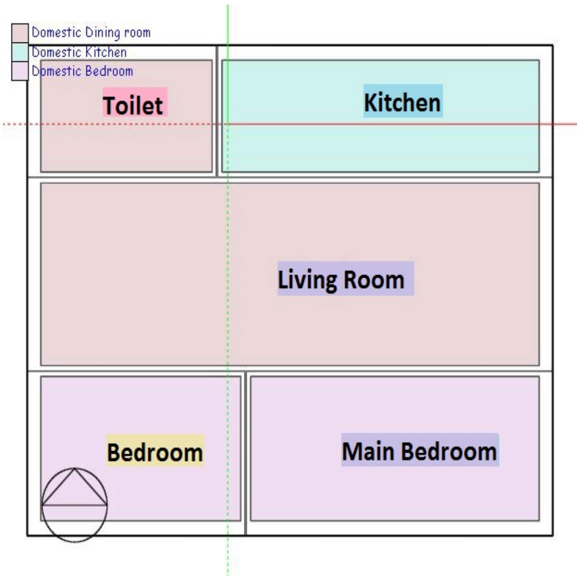

Figure 7 layout of floor plan

Table1 compares the insulation level for both old and new model blocks, based on the thermal transmittance (U-value) from building design standards. It shows that the new model block offers much better insulation than the old one. Table2 lists important definitions of building construction for both old and new model blocks based on real construction. Therefore the real detailed information about new and old building construction and insulation levels used as input in both old and new model blocks shown in Table2.

Table 1
Thermal transmittances (U-value) of old and new model blocks

	Old Model Block(W/m2°C)	New Model Block(W/m2°C)
External Wall	1.69	0.7
Window	5.8	3.6
Floor	2.48	2.28
Roof	2.48	2.28

Table 2
The building construction and general information of old and new model blocks

	Old Model Block	New Model Block
External Wall	240mm Solid Bricks, Plastering mortar	240mm Cavity Bricks, EPS insulation, Plastering mortar
Window	Single-glazing	Double-glazing
Roof	Concrete, Roof Bricks, Chalk	Concrete, Roof Bricks, Asphalt

For HVAC zone data model, the collected experimental data is inserted. "Hot water radiator heating, nat vent" were inserted in appropriate HVAC template. Based on design standard (JG/T-195, 2007), the room temperature set point of Thermostatic radiator valves(TRVs) indicate that the maximum opening temperature value is 18°C≤T_{max}≤25°C while the minimum opening value is 5°C≤T_{min}≤12°C. Therefore, for the heating operated with control system in each flat of new building, the heating set-point in model blocks use the mean experimental indoor temperature. In addition, hot water system was not supplied in model. In another set of simulation, natural ventilation was turned on, and time of window operation inputs were replaced with schedule of real monitored window states. The default inputs of occupant densities and occupancy schedules from the DesignBuilder database replace with the investigated occupant densities and occupancy schedules. And the computers, office equipment were turned off. Furthermore, the most appropriate DesignBuilder template was chosen in each zone (i.e. for the main bedroom zone, the DesignBuilder "Domestic bed room: an area primarily used for sleep" was used).

To predict and identify how each parameters effect on energy consumption, four test case models were studied: 1)Old model block use with input of U-value and construction in new model block; 2)Old model block use with input of heating set-point in new model block; 3)Old model block use with input of window operation in new model block. 4) Old model block use with input of all parameters (insulation level, construction, heating set-point and window operation) in new model block.

DISSCUSION AND RESULT ANALYSIS

Experimental Results

The mean outdoor air temperature is 8.9°C; the maximum and minimum temperatures are 27.7°C and -1.9°C respectively during the 15^{th} Feb to 15^{th} Mar heating period. The mean indoor temperature of living room in all old flats is 22.3°C and the indoor air temperature in new ones is 20.8°C which is respectively 1.5°C lower than the value measured in old flats. Meanwhile the mean indoor air temperature is 21.1°C in main bedroom of old flats and 19.8°C in new flats which is respectively 1.3°C lower than that in old ones.

For the window operation, the investigation revealed that the occupants are worked from morning 9AM to 5PM regularly during the weekdays. Based on the window devices monitoring, the results showed that overall, the majority of occupants in both types of buildings used to open the window for ventilation during the morning time around 7AM to 9AM when they get up. The measured results reflect that the windows in the old building were opened for 54% of the monitoring time, while windows were opened only for 29% of the monitoring time in the new building. This means that occupants in the new building prefer to leave windows closed to reduce heat loss. Occupants' thermal comfort in both building was examined as well, and the results reflect that generally occupants in new building give higher acceptable evaluation compared to occupants in old building.

Comparison of real measured and simulation results in energy consumption

Figure 8 shows the comparison analysis of real measured energy consumption in new building and old building, also shows the predicted energy consumption in old and new model simulation blocks. The measured results show that in the new building consumed 1328.4kWh heating energy during the survey period and this in the old building consumed 2427.3kWh heating energy, leading to an energy saving of 45%. For model simulation results indicated that in the new model block consumed 1138.2 kWh heating energy during the survey period and this in the old model block consumed 2358.1

kWh heating energy, leading to an energy saving of 52%. The measured heating energy consumption in old flats is 2427.3kWh and the simulated data is 2358.1kWh which is respectively 69.2kWh lower than the measured one. It reveals the differences between measured and simulated data in old building were within 3% range, which means a good agreement between the measurement and the simulation results in old building. However, there are an enormous difference between the measurement and the simulation results in new building, and difference value is 190.2kWh (within 14% different range). This is can be related to the occupants' heating behaviour in new building, occupants can adjust the TRVs of heating in order to satisfy their needs for indoor environment in new building. Furthermore, the limitation of simulation is not able to predict the real occupants' heating behaviour in new model block. Additionally, in model blocks simulation, the input of TRV set-pint(heating set-point) replaced with measured mean air temperature. Thus, there are significant discrepancies between simulation results and the actual measured results of real new building. However, in old building occupants do not have any control devices of heating and they only can open the window or door to adjust the indoor air temperature if the rooms were overheated. Additionally the real monitored window operation has been input in old block model. Therefore, there have good agreement between the simulation results and measurement results for old building.

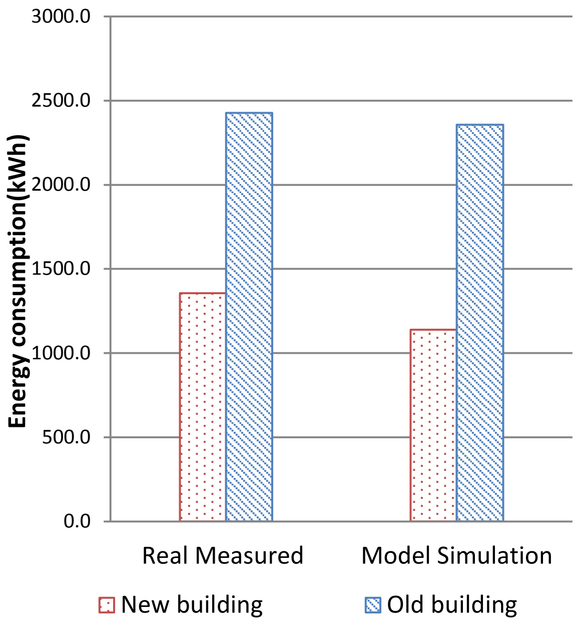

Figure 8 difference comparisons of energy consumption in measured and simulation for old and new buildings

Simulation results analysis of test case models based on new standard in energy consumption

As previous mentioned both measured and simulated results of energy consumption in new building are much lower than that in old one. It can be related to the each parameters effect on energy consumption for both new and old building. Thus four test case models were set to evaluate how each parameters effect on energy consumption and to validate the parameters for potential energy saving of new building into old building. The results of each test case models are given in figure 9.

Overall, the simulation results indicate that the old model block applied with new input parameters of new model block lead to significant reduction in heating energy consumption. Energy saving of 23% can be seen after changes of insulation level and envelops in test case model 1. It demonstrated that different insulation could have obvious influence on the heating energy consumption. In addition, Figure 9 demonstrates that old model block use with new heating set-point in test case model 2 can effectively reduce the heating energy consumption by 19%. The field real measured data reflect that the windows in the new building, they were opened only for 29% of the monitoring time. It reveals that occupants in the new building prefer to leave windows closed to reduce heat loss. Therefore, the test case model 3 of simulation results confirm less of window opening can decrease heating energy consumption by 18%. Totally, old model block use with new insulation level, new heating set point and new window operation can lead to heating energy saving by 40% shown in test case model 4. Therefore simulation results exposed that the implementation of the proposed energy efficiency improvements in the old model block would provide heating energy savings.

The simulated results (figure 8) show that in the new flat consumed 1138.2kWh heating energy during the survey period and this in the old flat consumed 2358.1kWh heating energy, leading to an energy saving of 52%. In test case model 4, the old model block use with input of all parameters in new model block can lead to an energy saving of 40%. This means old building complying new standard can lead to an obvious energy saving. Therefore, it reveals that each parameter (insulation level, construction, heating set-point and window operation) have significant influence on energy consumption. Furthermore, this means the new building complying with new heating control system and new heat bill system can lead to obvious energy efficiency for heating in winter compared with old building.

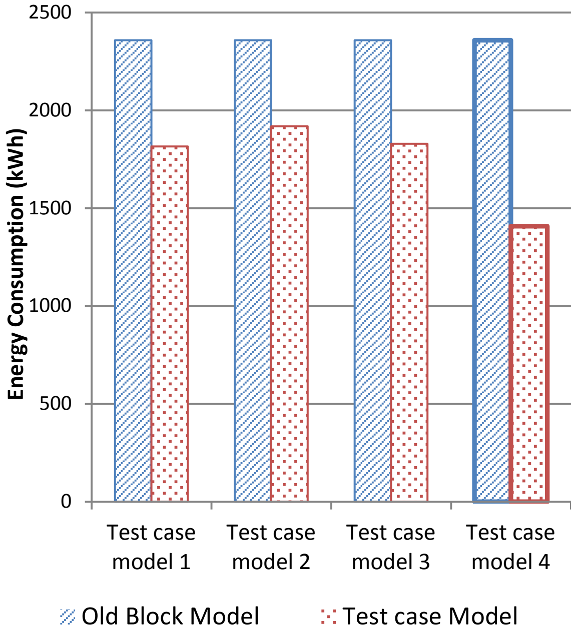

Figure 9 simulation results of energy consumption in old modelling block by each parameter inputted

CONCLUSION

This paper is investigating and predicting how the upgrading residential building design standard impact on the energy performance, together with the impact of each parameters(constructions, insulation level, heating set-point and window operation) on the building energy performance. This study investigated energy consumption in new and old residential building by both experimental measurements and numerical simulations. The model blocks are validated based on real measured data, and each parameters were used in test case model to analyse the impacts of various parameters on the heating energy consumption. There are four main findings are concluded as follow:

1) From the experimental results, it was found that both the living room and the bedroom temperatures in the old building are higher than those in the new building This may reflect that in the new building, occupants prefer a lower indoor temperature to reduce building energy consumption, as indoor temperature has been popularly used to reflect occupants' indoor temperature settings in winter in existing studies.

2) For the window operation, the measured results reflect that the windows in the old building were opened for 54% of the monitoring time, while they were opened only for 29% of the monitoring time in the new building. This means that occupants in the new building prefer to leave windows closed to reduce heat loss.

3) During the survey period, the measured results showed an energy saving of 45% in the new building when compared to the old building.

4) The quantitative energy saving potential of insulation level, construction materials and envelop on heating energy consumption were simulated using DesignBuilder. The simulation results indicated an energy saving of 52% in the new model block when compared with old model block. Additionally, it reveals the difference between measured and simulated data in both new and old building were within 7% range, which means a satisfactory agreement between the measurement and the simulation results.

5) In old model block, it investigated that the heating energy consumption deceased with application of envelops from new building, and the impact of the each influencing parameters on the heating energy consumption can be analysed quite precisely. Therefore, the simulation results of each test case models indicated that the old building employ new upgrading standard can lead to energy saving by 40%. Overall the results show the importance of refurbishing existing buildings with old heating systems and upgrading these to the new TRV and occupant control and interaction with their environment.

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