Case study on a wooden single-family house with its impacts on heating load and thermal comfort under future climate scenario in Sweden

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Introduction

Buildings provide occupants a shelter envelop and comfort interior climate condition. Thus, climate has great influence on both building design and building overall performance. Nowadays, passive design has been getting popular for taking advantage of the regional climate to maintain a comfort indoor climate, while reducing or eliminating the need for active system. Nevertheless, it is undoubted that there is an ever-widening disparity between historical weather patterns and current-not to mention future-climate conditions resulting from anthropogenic changes [1] [2] [3] [4]. Shen et al [5] previous draw a straightforward portrait of the existing building in Sweden, which concluded that the existing building stock would face the issues of inadequate cooling (7.6% in 2012) in a long term due to the annual share of the major renovation for residential building was 0.8%.

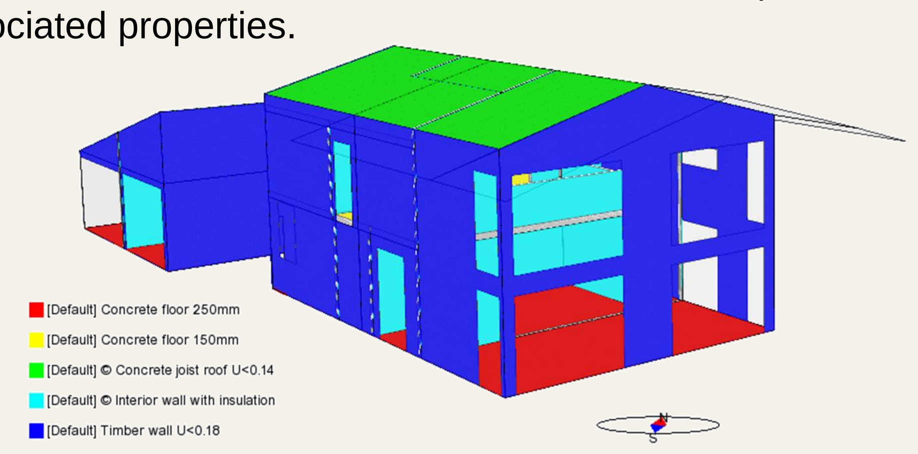
This study thus aims to start with a case study to gain insight into indoor thermal conditions and energy demand by means of simulation engine of IDA-ICE, according to Building and Planning's building code in Sweden (BBR) under future climate scenarios. By running the dynamic building performance simulation, it attempts to attain a qualitative understanding the shift of the thermal risk and heating loads, due to future climate change in Borlänge, Sweden.

Materials and Methods --The studied building

Figure 1: Building information integrated 3D model in IDA ICE

The proposed 2-floor wooden villa is a single-family demonstration house that financed by Dalarnas Försäkringsbolag, an insurance company in 2018. The total gross floor area is 180.4m² (house 150.4m² and garage 30m²). It is located in Borlänge (Dalarna region), Sweden.

The design ideas of this energy-efficient wooden villa are: 1) the energy use in the operation phase; 2) low environmental impact in a life cycle perspective; and 3) healthy indoor climate during occupancy period [6]. Figure 1 presents the building model for Dalarnas Villa prepared by the City Information Modelling group in Högskolan Dalarna, while Figure 2 demonstrates both construction materials position and associated properties.



Name	U-value, W/(m2 K)	Thicknes s, m	Layer material	Layer thickness, m	Layer material	Layer thickness, m	Layer material	Layer thickness, m	Layer material	Layer thickness, m	Layer material	Layer thickness, m
Timber wall U<0.18	0.1636	0.075	© Chip...	0.01	© Vacc...	0.04	© Chip...	0.012	© Gyp...	0.013		
© Interior wall with insulation	0.6187	0.146	© Gyp...	0.026	© Air in...	0.032	© Light...	0.03	© Air in...	0.032	© Gyp...	0.026
Concrete floor 150mm	2.385	0.175	© Floo...	0.005	L/W co...	0.02	© Con...	0.15				
© Concrete joist roof U<0.14	0.1133	0.21	© Vacc...	0.06	© Con...	0.15						
© Concrete floor 250mm U<0.15	0.1323	0.313	© Chip...	0.013	© Vacc...	0.05	© Con...	0.25				
Rendered concrete wall 200	3.332	0.21	© Ren...	0.01	© Con...	0.2						
Concrete floor 250mm	2.9	0.255	© Floo...	0.005	© Con...	0.25						

Figure 2 Construction materials in the 3D model of Dalarnas Villa

Methodology -- Morphed future climate data

An hourly dependent climate dataset is indispensable part for the next dynamic simulation. With the intention of future hourly climate data, we utilize a morphing method to produce hourly climate datasets from 60 years back through the currently available climate file. The selected the typical climate data IWEC is with the format of ".epw", which is original from National Centre for Environmental Information as baseline climate dataset. After then, the 'CCWorldWeatherGen' tool, developed by Energy and Climate Change Division, University of Southampton, UK, was processed for the 'present-day' climate files as the baseline data preparation for the future climate morphing in the next stage [7]. The morphed weather data was recognized being compatible with the climate adaptive design assessment and the building performance simulation in the future study [5]. Here Figure 3 compares the difference among historical weather file, the morphed climate files in 2020, 2050 and 2080 respectively in terms of adaptive design strategies.

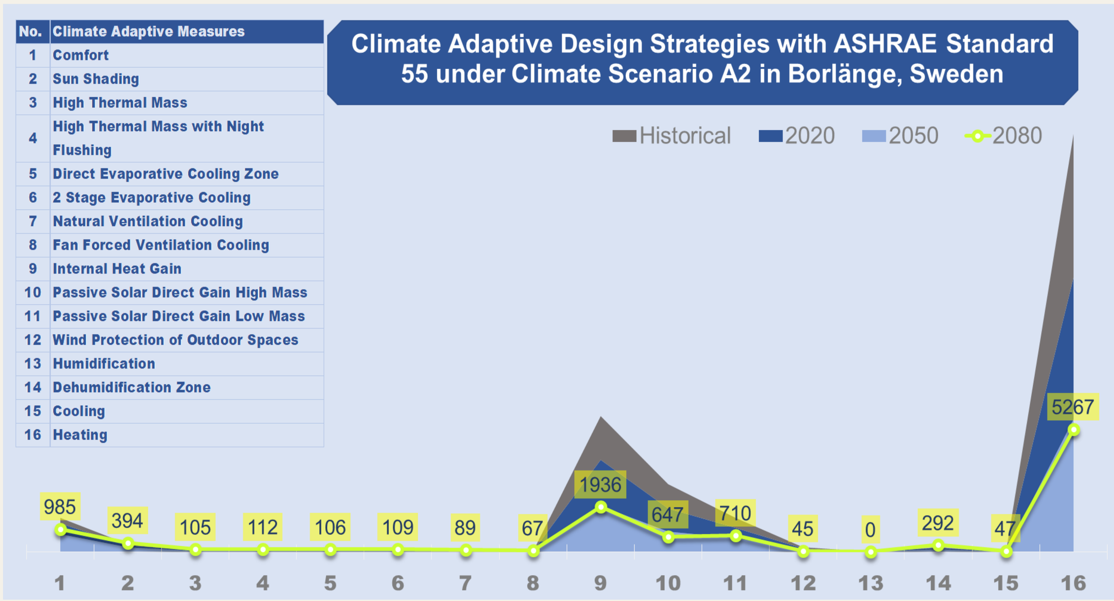


Figure 3 Brief comparisons among different climate scenario A2 in Borlänge, Sweden

Methodology -- Building simulation: IDA ICE

To investigate the impacts from future climate scenarios, the targeted building has been simulated using weather data files compiled from historic measured data at the Dalarna Airport Station during period 2003-2017 in the standard level of IDA ICE 4.8. The software relies on the building geometry, which in turn is possible to break into multiple zones that are studied individually. The energy balance is calculated depending on building geometry, solar radiation (both direct and diffuse), internal heat loads, HVAC (heating, ventilation and air-conditioning) conditions and building construction data.

Results and discussion – Heating load calculation

Heating load is calculated under simulation tab of IDA ICE for sizing each room unit. It is assumed with the set point temperature of 21 ºC, 0% internal gains and 0 % of solar radiation on the coldest day on 15 Jan in each morphed future climate file, which aims to consider the worst case heating load. Figure 4 depicts the variations in both heating load under different climate scenarios.

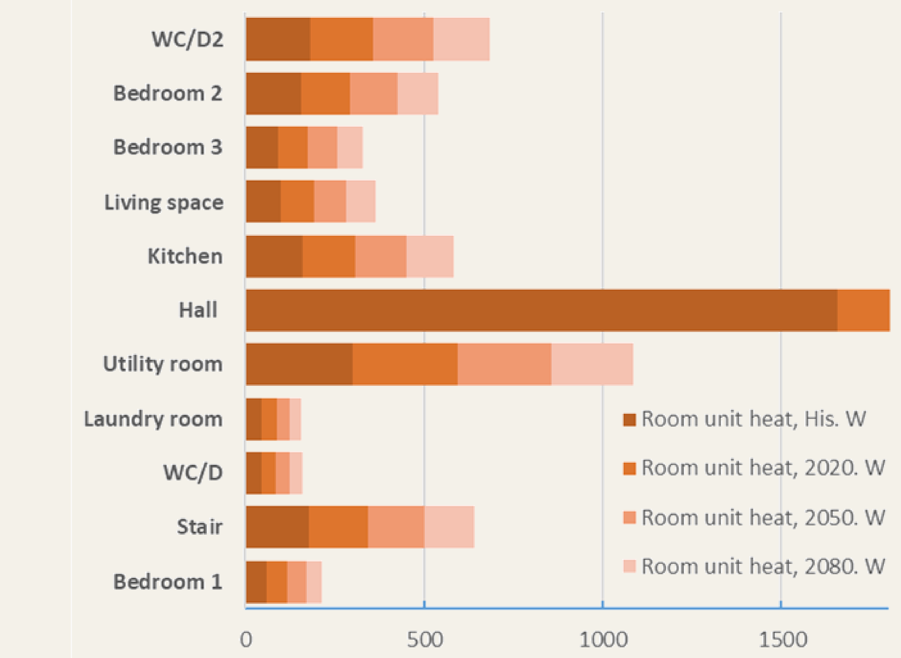


Figure 4: Variations in heating load for each zone under different climate scenarios

It is obvious that the living room, due to its characteristics of east-southern facing, higher ceiling height and large glazing ratio. Therefore, the space has the greatest heating load. In general, the overall heating load would experience a continuous decline in the coming 60 years, which would respectively be 3.3% for the 2020 case, 9.4 % for the 2050 case and 19.8 % for the 2080 case when compared to historical weather case. When looks into the final heat load growth that is compared from historical one to 2080 one, the substantial decline occurs in hall and kitchen with the reduce ratios of 26% and 23% respectively, where these two spaces are internal connected and featured with intensive internal gains. It exactly corresponds to the previous finding [5] that spaces with greater internal gains would benefit from such a kind of passive heat resource during the heating season soon. Fortunately, the remaining spaces would only have an average heating load reduction around 16%.

Results and discussion – Thermal Comfort

The effect of climate change on thermal comfort is another important research objective. The results are from the overheating assessment in relevance to EN15251, without cooling by calculating the heat balance of the building consecutively for each time step. When evaluating dynamic results, the number of hours out of the thermal comfort range is the typical method, based on EN 15251 [9].

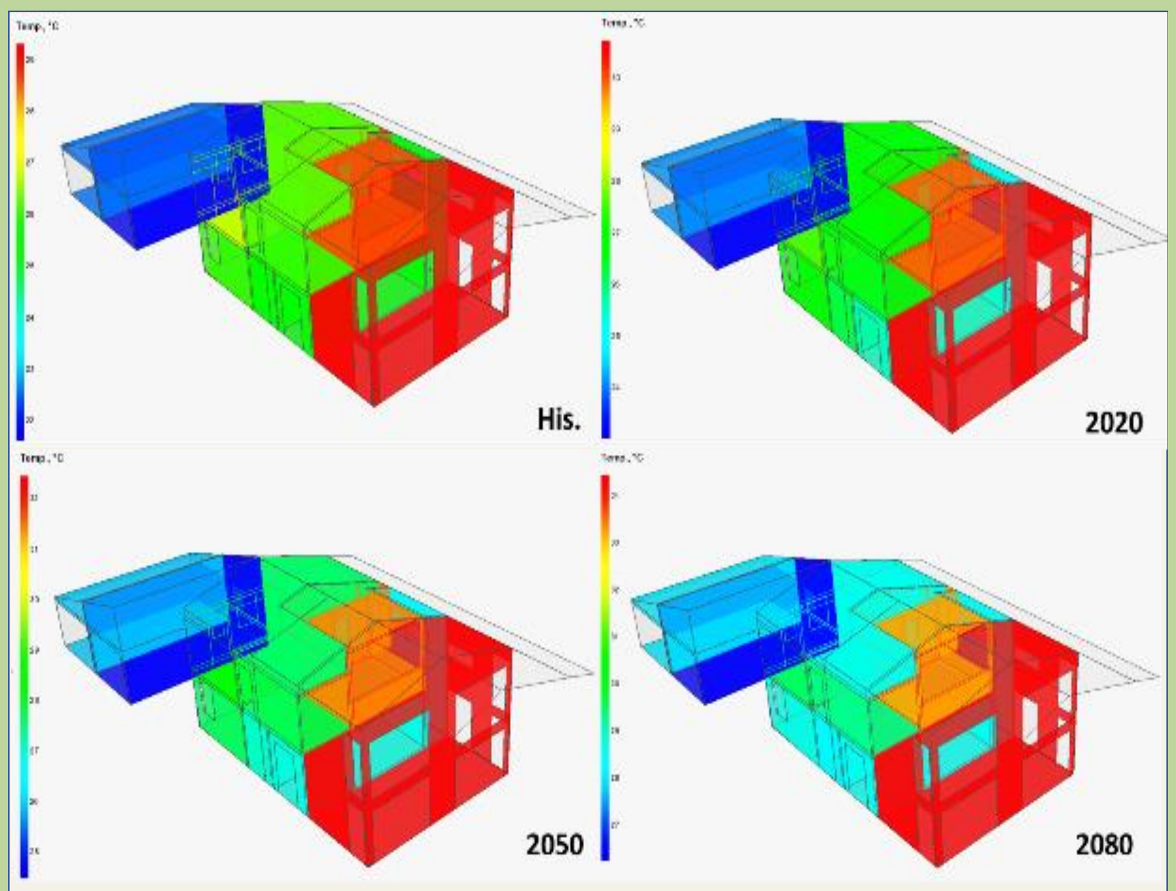


Figure 5:Mean air temperature in the zone at the time of maximal heat removed under different climate files

Figure 5 shows the conformance on thermal comfort for all spaces zone at the time of maximal heat removed under different climate files. For such a highly standard new building, the overall thermal performance seems to get worse: 1) the average mean air temperature would rise up to 29.82 ºC till in 2080 (which is 26.41 ºC from historical one); 2) the hottest space always lies in upper living room from 29.31 ºC from historical one till 34.44 ºC in 2080. It is true that with the move towards more energy-efficient buildings and global warning effect, it is worthy to pay more attention to the associated increased risk of overheating. In this study, the overheating assessment employs indicators of Operative temperature, Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD). Owning to the limited simulation time, only three highly occupied spaces are investigated here. The operative temperature (Op. temp.) is an intuitive representation of the temperature experienced by the body in a room. It is shown that the studied three occupied spaces have similar 4.58 ºC temperature difference in operative temperatures. The results indicate that the targeted space would have deteriorated thermal environment.

Conclusion

This study shows comprehensive understanding of passive design potentials according to climate analysis. Therefore, it helps in getting preparation for the greater integration of climate science with architectural engineering to mitigate the adverse effects of the built environment and adapt to the changing context. Through attaining a qualitative understanding of the thermal risk and system demands of the studied building, it reveals that (1) it would have continuous heat demand decline; (2) it has growing overheating risks, it is vital to implement all the available passive cooling strategies in the energy-efficient residential building, such as shading, natural or demand-response ventilation.

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