2018 Building Performance Analysis Conference and
SimBuild co-organized by ASHRAE and IBPSA-USA
Chicago, IL
September 26-28, 2018

IMPLICATIONS OF EPBD COMPLIANT FACADE ON PRIMARY COOLING ENERGY DEMAND IN CENTRAL EUROPE: THEORY VS. PRACTICE

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ABSTRACT

The buildings sector is responsible for 40% of energy consumption and 36% of the CO_2 emissions in the European Union [1].The non-residential building sector makes 25% of the total EU building stock which is more challenging to evaluate due to mixed building types (offices, hospitals etc.) and respective usage pattern. Due to recent rapid development in the commercial sector, the electricity consumption has increased in an average by more than 70% primarily due to high plug loads, hence increasing the cooling energy demand. In line with the key EU directives targeting CO_2 emission reduction, current regulations have stringent insulation requirements for the building envelope. The current study focuses on evaluating the effect of the regulations on high internal load (plug loads, occupancy etc.) buildings in central Europe. The annual primary heating and cooling energy demands have been calculated by dynamic thermal simulation software for standard and future IPCC (2030) A1B climatic scenarios for three buildings in Budapest, Hungary that meet EU's directives, the Energy Performance of Buildings Directive (EPBD). The results show that by implementing the current local regulations (TNM recast) with more stringent requirements than the previous code (7/2006 TNM) leads to increased primary cooling energy up to 10% in all the simulated cases. This increase is even more profound with IPCC (2030) A1B weather scenario. With increasing thermal insulation due to the current regulatory framework, the consequences can be adverse on overall primary energy consumption and appear to conflict with future EU's low-energy, net zero energy and CO2 emission reduction goals.

INTRODUCTION

The space heating and cooling load of buildings is a vital component in determining the energy demand within the buildings. This building energy end use is the largest contributor to the total EU energy consumption in the commercial buildings. The environmental impact of buildings has approached a critical stage and is considered one of the leading contributors of green-house gases to the environment. Non-residential buildings account for 25% of the total stock in Europe, out of which 23% [2] is the commercial office stock which comprise a more complex and heterogeneous typology and hence quite challenging to address the underlying issues. Energy security and climate change are driving a future that must show a dramatic improvement in the energy performance in Europe's buildings. In line with this idea, the 27 Member States have set an energy savings target of 20% by 2020, mainly through energy efficiency measures. The European Union has also committed to 80-95 % GHG reduction by 2050 as part of its roadmap for moving to a competitive low-carbon economy in 2050 [3]. More than ever, building energy use is becoming a critical factor in climate change mitigation, and reducing this energy use is essential to meeting national and regional energy reduction goals.

It is well understood from the basic principles of building physics that the most efficient ways to minimize the heat transmission and energy consumption for thermally conditioned buildings is the use of an appropriate thermal insulation in the building envelope [4]. Furthermore, the space heating the load is derived from a building model including average indoor-outdoor temperatures, transmission and ventilation losses, etc. whereas space cooling load of the building very much depends on local and behavioral circumstances and can only be derived indirectly, i.e. from equipment parameters [5]. Many past research publications on envelope performance in a built environment indicate similar trends in residential buildings however the commercial buildings show contradictory behavior due to heterogeneous nature of the buildings and possibility of high internal loads (IT, Hospitals and large commercial establishment). The effect of thermal mass on the energy required to heat and cool buildings in hot climates is an effective strategy to reduce energy use [6]. The advantage of thermal mass due to envelope and structural element can't be easily implemented in the large commercial buildings due to space constraints. Furthermore, the analysis of the building energy balance to investigate the effect of thermal insulation in summer conditions for residential and commercial buildings shows that the predominant influence of the Envelope contributions on the energy performance of the residential building is more critical than commercial buildings. The contribution of the Non-Envelope terms (Internal heat gains such as equipment, people and lighting) has a more profound effect than that of the Envelope terms and hence plays an important role in the determination of the building energy performance [7]. For the same purpose, this is crucial to understand and optimally use them as designed and simulated plug loads during permit/early stage analysis. In the direction of determining optimal plug loads, a survey conducted by the US Green Building Council for LEED certification for more than the 1,000 buildings indicated that 40% of the modelers use values between 10.8 and 16.1 W/m^2 for thermal simulation whereas strong majority (approx. 60%) use less than 10.8 W/m^2 for the average plug load energy use intensity. Although there is a strong variation in as-designed, measured and recommended peak plug load values in commercial settings, 76% of the users~~,~~ indicate a tendency to incorporate experience from practice alongside published guidelines [8].

Though much research has been done on thermal insulation requirement for residential buildings, unfortunately, despite the importance of Capital expenditures (CAPEX) and operating expenses (OPEX), there are few studies looking at its effects in a generalizable, quantifiable sense in the office buildings.

RESEARCH AIM

This research aims to study the current changes in the envelope requirements prescribed under TNM recast compared to previous code (7/2006 TNM) and its effects on the primary heating and cooling energy demands. The following questions were the driving force to conduct the current study:

- What should be the calculation path; Dynamic simulation vs Standard spreadsheet calculations to get local permit approval for the new office buildings?
- What should be the basis of using internal loads (plug, people and lighting) for preliminary stage heating and cooling demand estimation to get local permit approval for the new office buildings?
- What should be the optimum insulation thickness to be used e.g., an old (TNM 7/2006) or new local code (TNM recast)) opaque envelope for determining primary heating and cooling energy estimation for the new office buildings?
- How to address the heterogeneous nature of the internal loads in typical office buildings so that current local code could be generalized to have an inclusive approach towards most of the upcoming buildings?

Therefore, it should be principally possible and worthwhile to find a linkage between them to answer core research questions that leads to optimal design solutions for the façade. In order to understand this phenomenon, the thermal analysis method applied in this study where different internal loads and heat transfer through the building facade has been studied. The comparison was made based on annual primary cooling ($Q_{cooling}$) and heating energy ($Q_{heating}$) demand in the purview of an old (TNM 7/2006) and new local code (TNM recast) requirements. The following equation indicates annual Cooling demand for the building simulated with TNM recast (TNM 2018) is greater than the old TNM 7/2006 (TNM 2016). The second equation indicates that the summation of annual Cooling and Heating demand for the building simulated with TNM recast (TNM 2018) is greater than the old (TNM 7/2006) (TNM 2016).

$$\mathbf{Q_c TNM2018 > Q_c\ TNM2016}$$
$$\mathbf{Q_{c+h}\ TNM2018 > Q_c + h\ TNM2016}$$

In the pursuit of achieving each country's emission reduction targets, the newer version of requirement TNM recast (TNM 2018) should have lower cooling demand whereas it has opposite trend. Since Building is internal load driven, the cooling demand proportion is much higher than the heating demand and hence the trend is adverse.

METHODOLOGY

The current study includes three different office buildings located in Budapest, Hungary minimally complying with TNM 7/2006, which were simulated and compared with the current regulations; TNM recast. The building typology, façade orientation, building shading and associated boundary condition shown in the figure 2 was deployed while developing thermal modeling. The detailed simulation parameters are given in table 1 which includes design and local code simulation parameters. The well-defined building geometry as per actual building design and critical variables relating to external (Envelope Insulation) and internal (internal equipment loads) conditions have been considered for evaluation using EnergyPlus 8.5 software program. Although the annual energy performance for primary cooling and heating energy demand have been investigated along with optimum daylight in the space, only the impact of increased insulation requirements on the primary cooling and heating energy demand has been elaborated in the results section.

Table 1: Simulation Input Parameter

Building parameter		Unit	Building-1	Building-2	Building-3
Location		-	Budapest	Budapest	Budapest
Orientation		-	NE	NE	NW
Net Internal Conditioned Floor Area		m^2	21 500	10 350	5 130
Roof Construction	TNM recast	W/m^2. degC	0.17	0.17	0.17
	TNM 7/2006		0.25	0.25	0.25
External Wall construction	TNM recast	W/m^2. degC	0.24	0.24	0.24
	TNM 7/2006		0.45	0.45	0.45
Window Wall ratio		%	58	59	40
Glazing	TNM recast	W/m^2. degC	1.4	1.4	1.4
	TNM 7/2006		2	2	2
Ground Floor Construction	TNM recast	W/m^2. degC	0.17	0.17	0.17
	TNM 7/2006		0.25	0.25	0.25
Internal Equipment Load	Standard	W/m^2	7	7	7
	As design		28	28	28
			35	35	35
Lighting Power Density		W/m^2	6	6	6
Occupant Density		m^2/person	5	5	5
Ventilation Rate		m^3/hr per occupancy	45.4	45.4	45.4
Heating Source		-	District Energy		
Cooling Source		-	Electricity		

In the ongoing effort of the European Commission to assess the energy impact of all the new construction buildings design, Hungary has completed all the preliminary action for facilitating the implementation of Energy Performance of Buildings Directive (EPBD) in the country. Ministerial Decree TNM 7/2006 was published in May 2006 which governs the implementation of EPBD Code [9] in the country. Since then some revisions have been made based on minimum efficiency requirements as a part of EPBD future reduction targets. Part of that is the recent changes in the previously existing code (7/2006 TNM) envelope section, which has been revised as a TNM recast and will be discussed in the following article. According to this, all the envelope (opaque and transparent) thermal requirements should meet as per country's minimum legislation set as per EPBD recast. In general, the aims and the holistic approach of the EPBD are setting code requirements for the quality of the building envelope, while the HVAC equipment is based on standard prescribed values of occupancy, lighting and equipment power densities as prescribed in the code which lies far from real life scenario in most of the commercial buildings scenario. The EPBD permits to make buildings comparable with respect to their energy performance and to calculate target values for the consumption. Therefore, most calculation methods set standardized boundary conditions which, in turn create a greater disparity in calculations done at the designed stage compared to permit stage.

Climate plays a pivotal role in determining the efficient building and services design of a building. Budapest has cool -humid climate (ASHRAE climatic zone 5A) where summer outdoor dry-bulb temperature touches to 40 degC and winters dips to -15 degC with an annual sunshine hours ranging from 2,500-3,000 hours. The key parameters of climate that impact façade heat gain such as sun movement, solar exposed surfaces and outdoor temperature which has been generated for project specific locations. The two-climate scenario based on standard and IPCC 2030 A1B futuristic scenario has been generated with the help of Meteonorm software. Out of three IPCC scenarios for future periods namely B1 (low), A1B (mid) and A2 (high) scenario, the A1B (mid) weather scenario has been used to analyze annual cooling and heating energy demand requirements.

The following graphs show the typical weather scenarios for standard and IPCC 2030 A1B weather scenario for all the three locations. The graph indicates the Max-Avg-Min temperature variations across summer and winter season. For weather calculations, the Urban location scenario was used which uses the monthly average values (long term averages) to interpolate and then the hourly values are generated which have been used in thermal simulations.

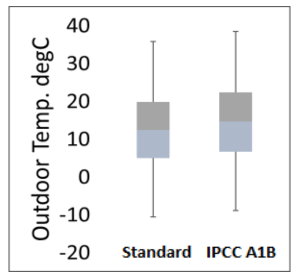

Figure 1: Box plot representing outdoor temperature distribution of the simulated Buildings

The climate scenario, namely standard and IPCC futuristic scenario are shown in Figure 1 for all the three office site locations. Since the locations of all the buildings are in Budapest, the deviation in mean, median and maximum is in the range of 0.7, 0.3 and 0.8 degC respectively.

CASE STUDY DISCUSSION

Three case studies were considered in the thermal evaluation of the buildings. All the three building are multistory commercial office building establishments which are under design and construction. The building's "as designed" building geometry has been developed for thermal simulation. All the design parameters are kept consistent with the design requirements and reflects same across all three simulated cases.

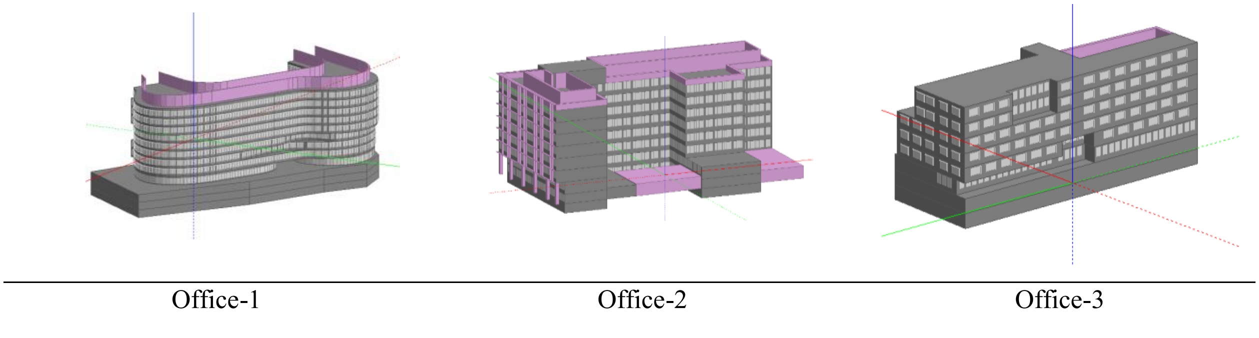

Figure 2: Simulated Office case studies

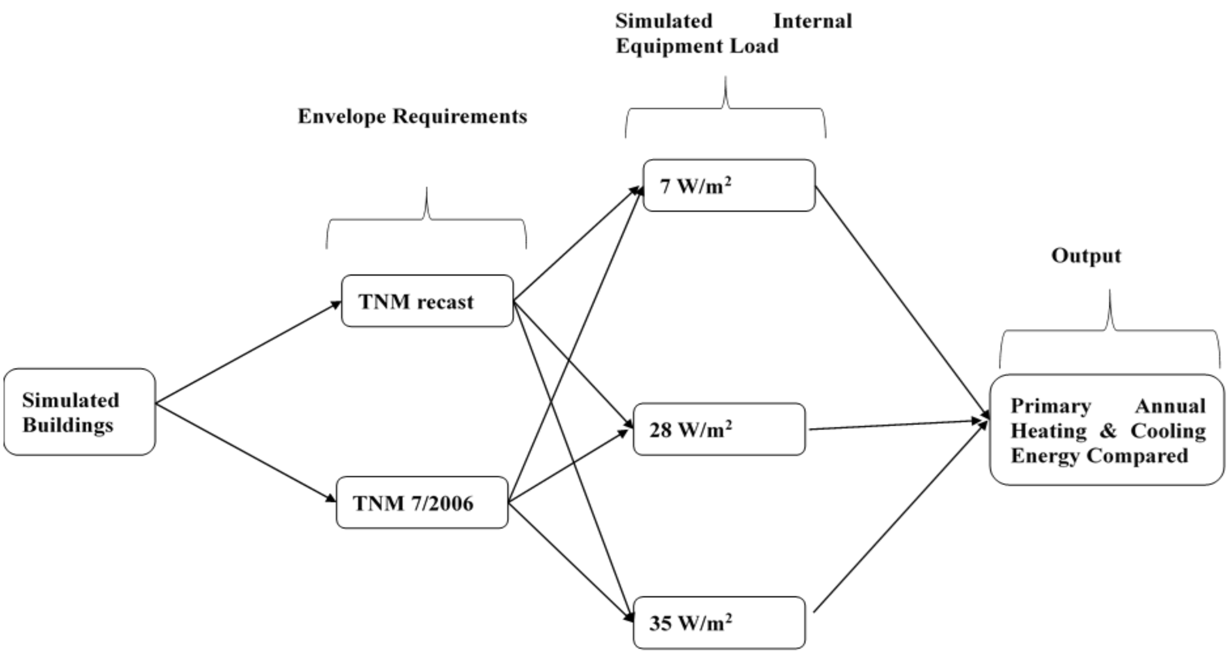

Figure 3: Simulation work flow with critical variables analyzed

Simulation parameters

To bring forth the comparative study of different commercial design, the overheating risk due to the increased internal load and current insulation requirements was studied thoroughly. To study the implications, few combinations are made with code envelope requirements vs different internal equipment loads for all the three buildings under considerations as per following figure 3. The choice of three different equipment power densities is dependent on the workstation power requirements per occupant. The 7 W/m^2 power densities (35 Watt/workstation) is the standard power density as prescribed under the local code for office buildings used for the building's permit submissions whereas 28 W/m^2 and 35 W/m^2 are based on owner's project requirement considering 140 and 175 Watts/workstation respectively.

The Figure 3 shows basis of developing simulation cases and underlying assumptions. Firstly, the three cases were developed as design and envelope parameters were set as per TNM 7/2006 and TNM recast guideline. Further, each case was simulated with three different internal loads, 7 W/m^2 as recommended by the code for permit level submissions and 28W/ and 35 w/m^2 which is a basis for most of the current under design leasable office buildings in Budapest. Moreover, each case were also simulated with IPCC futurstic weather scenario to see the impact of increased outdoor temperature on the heating and cooling primary energy demand. In the end, the results were analysed and reported in the sresults section.

Another critical parameter is building operational diversity as shown in figure 4, which drives building energy consumption to a large extent. Although some countries developed their own operational schedules to be used for primary energy demand calculations for EPBD regulatory compliance, there is no EU-wide accepted standard for these schedules. On the other hand, an increasing number of LEED and WELL certified buildings support the idea to refer the ASHARE standards. Hence, there were three different sources of operational diversity such as standard ASHRAE 90.1-2007 manual, diversity based on central plant sizing and LBNL Occupancy simulator could be referred for the analysis. The figure 4 shows ASHRAE 90.1-2007 peak diversity is highest around 95% highest in all the three cases. Based on the discussions with the designer, the peak operational diversity of 85% has been used in current analysis against 95% and 90% recommended by ASHRAE 90.1-2007 and LBNL occupancy simulator respectively.

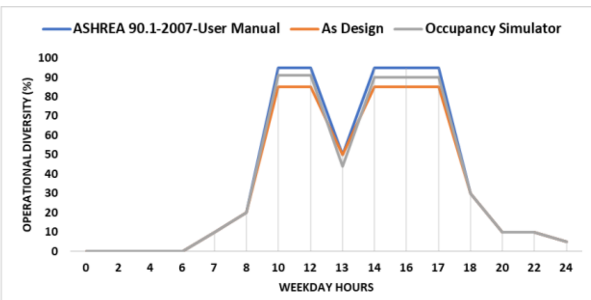

Figure 4: Occupancy and Plug load diversity profiles from different sources

Given the focus on the effect of internal loads on cooling and heating energy demands with increased insulation requirements, the external shading was not modeled in this analysis. However, internal flexible shading was considered in the design to achieve optimum daylight and avoid glare in the office areas.

RESULTS AND DISCUSSION

This section represents the results for all the simulated cases, three commercial office establishments based on standard and climate change scenario showing the effect of revised thermal properties on the primary cooling and heating energy demands on an annual basis. Section 3.1 indicates the primary cooling and cumulative cooling and heating primary energy regime based on old and recast code envelope thermal requirements.

Impact of Increased Insulation

All the envelope insulation parameters based on TNM 2016 and TNM recast were varied for all the case studies to analyze the impact of increased insulation on Building's normalized Cooling and Heating primary demand requirements. All the parameters in Table 1 are considered in the analysis unless otherwise specified. This analysis has also shown how different trends of high internal occupancy and eventually the high internal load in different sized office buildings impacts the primary cooling and heating energy demands.

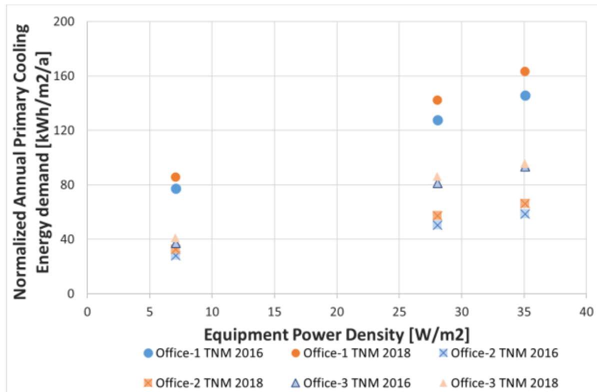

Figure 5: Profile showing different investigated buildings with different internal plug loads and its impact on normalized Annual Primary Cooling Energy demand

1. Figure 5 indicates that profile of normalized primary energy consumption in standard weather regime for all the simulated cases considering TNM 2016 and TNM 2018 as assessed on the Internal Power density of 7, 28 and 35 W/m^2 respectively. It can be noted that Primary cooling energy is higher in all the simulated buildings with standard and as designed internal power density based on TNM 2006 and TNM recast envelope parameters. The primary cooling energy demand difference from TNM 2016 to TNM recast is +2%, +12% and +12% higher with 7 W/m^2 in the simulated cases 1,2 and 3 respectively. Furthermore, the difference increases as the internal load increases from 28 W/m2 to 35 W/m^2 in all the cases.

2. In figure 6, the cumulative effect of total heating and cooling primary energy represents a similar increasing trend. Moreover, the difference in increased primary energy demand between the

TNM 2016 to TNM recast is reduced compared to only cooling primary energy because heating tends to decrease as the envelope has better insulating property as prescribed in TNM recast which balances out the increased cooling demand to some extent. The normalized primary heating and cooling energy demand difference from TNM 2016 to TNM recast is -1%, +2.4% and +8.6% higher with 7 W/m^2 in the simulated cases 1,2 and 3 respectively. Furthermore, the difference shows incremental profile at 28 w/m2 in all the simulated cases ranging from +2.3 to +7.6% wheras at 7 W/m^2 the, case-1 shows +2.6% increment and case-2 and 3 shows -6% and -3% decrease in the demands.

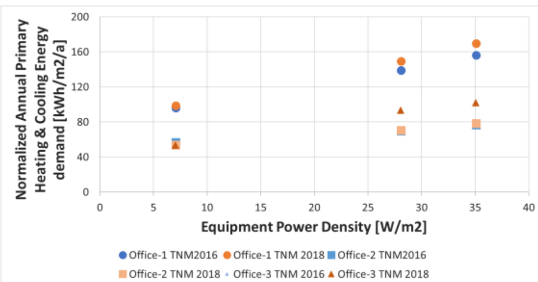

Figure 6: Profile showing different investigated buildings with different internal plug loads and its impact on normalized Annual Primary Cooling and Heating Energy demand

3. Furthermore, the impact of a futuristic weather scenario has also been studied with the similar set of TNM 2016 and TNM recast on different internal equipment loads were also studied which shows the similar increasing trend as the internal load and envelope insulation increases. With the IPCC weather scenario, the frequency of occurrence of hotter days when cooling is required is increased and heating. hours decreases due to warmer winters. The normalized primary heating and cooling energy demand difference from TNM 2016 to TNM recast is -3%, +3.1% and +2.6% higher with 7 W/m^2 in the simulated cases; 1, 2 and 3 respectively. Furthermore, the difference shows incremental profile at 28 W/m^2 in all the simulated cases ranging from +2.1 to +7.1% wheras at 7 W/m^2 the, case-1 shows +7.7% increment and case-2 and 3 shows -3% and -1% decrease in the annual demands.

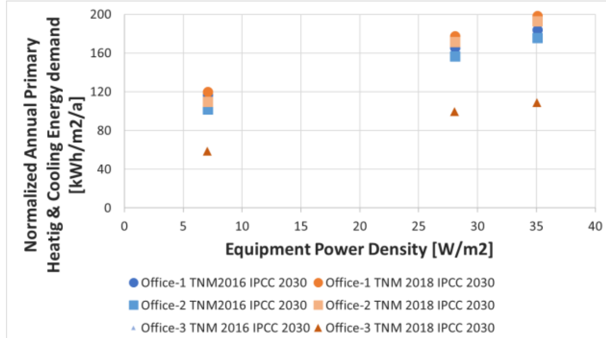

Figure 7: Profile showing different investigated buildings with different internal plug loads and its impact on normalized Annual Primary Cooling and Heating Energy demand in IPCC weather scenario

In general, the disparity between the standard and as-designed plug loads in the Energy and demand estimation caused large deviation in the predicted primary cooling and heating demands.

CONCLUSIONS

This study analyses the influence of high thermal insulation on Primary heating and cooling energy demands of three different offices buildings in Hungarian climates, typical standard and IPCC 2030 A1B scenarios. Primary energy demand implications based on different envelope requirements; applying the new local code (TNM recast) and previous code (TNM 7/2006) requirements were evaluated for winter and summer by using simulation program, EnergyPlus. The aim of this paper is to provide a substantial ground to understand firstly, how the recast local code impacts the primary heating and cooling energy demands. Secondly, what should be the futuristic approach to decide what level of envelope insulation is optimum for low Capital and Operational point of view. The results of the analysis show the following outcome:

- Current regulatory body recommends high Insulation to be implemented in the new design based on standardized Internal Load (7 W/m^2) scenario whereas reality (in the range of 20-35 W/m^2) lies far from standardized assumptions.
- Currently, in the absence of building's realistic operational profile, the as-designed operational profile was used with 85% diversity factor as suggested by the designer. It is worth noticing that ASHRAE 90.1-2010 peak office profile and average sub-hourly profile generated through LBNL Occupant simulator recommends using 95% and 90% respectively which will have more serious

implications on the internal load heat additions. In the future, it would be worth analyzing actual building operational diversity as a part of Monitoring and Verification scope to understand the estimated vs. realistic implications of high internal loads.

- Due to the mild outdoor dry-bulb temperature for approx. 4,000-4,500 hours during the year, the contribution of envelope on peak cooling load is in the range of 10-15% whereas internal loads such as receptacle and occupancy contributes 60-65% of the total load and eventually offset heating demand in the buildings.
- The contribution of high internal loads makes building internal cooling load-driven and tends to neutralize the heating energy demand to large extent. For instance, office-1 shows a 6% decrease in primary cooling and heating demand at 7 W/m^2 whereas primary cooling and heating demand shows an 8% increase at 35 W/m^2.
- Primary cooling energy demand increases up to 10% with increased insulation requirements from previous TNM 7/2006 code to revised new TNM recast for all the simulated cases. Increased insulation thus produces the opposite impact to what is intended.
- The combined total primary cooling plus heating energy demands increases up to 9% with increased insulation for most of the simulated cases except few shows marginal increase in the range of 1-3%.
- Increased primary cooling energy demand is profound when analyzed with futuristic weather scenario; IPCC 2030 A1B in all the cases
- Market players raise concern over high CAPEX due to increased insulation requirements which eventually increases primary cooling energy demand during operations due to heat retention within the building.
- Therefore, the primary energy demand calculation through simple calculation follows a conservative approach for the demand estimation whereas the dynamics of all the design parameters through thermal modeling could help in benchmarking on buildings energy demand.

As a further development it is recommended that the preliminary analysis done at the time of permit should be evaluated through use of robust hourly dynamic simulation options. Furthermore, all the buildings undergoing permit stage evaluation should be evaluated on a case-by-case basis to factor in unique design inputs, performance and boundary condition's pertaining to specific projects to avoid adverse repercussion of increased insulation which could affect the future reduction targets.

ACKNOWLEDGMENT

The authors gratefully acknowledge all the team members of Advanced Building and Urban Design and Building Performance Team for providing all the necessary help in thermal modeling and quality inputs. Furthermore, we would like to acknowledge the software and Infrastructure support to facilitate the research provided by the Advanced Building and Urban Design.

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