Oct. 2014. Vol. 5. No. 05 ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

MIXED-MODE VENTILATION AND THERMAL MASS: IS THIS THE FUTURE FOR SCHOOL CLASSROOMS IN OCEANIC CLIMATES?

[1] ZOHREH SOLEIMANI, [2]ANDREW SHEA, [3]ZAKIEH SOLEIMANI

[1, 2] University of Bath, Department of Architecture and Civil Engineering, Bath BA2 7AY, UK.
[3]Islamic Azad University Science and Research Branch Yazd, Department of Computer Engineering, Yazd, Iran .
E-mail: [1]zohreh_soleimani@yahoo.com, [2]a.shea@bath.ac.uk, [3]zakieh_soleimani@yahoo.com

ABSTRACT

This article investigates the performance of an innovative hybrid ventilation system applied to a secondary school classroom subject to current and future U.K. (London) climate data. The resilience of the occupied space with regards to the limiting of summertime internal air temperatures is evaluated for both thermally lightweight and heavyweight building envelope constructions. The proprietary building dynamic simulation software IES-ve was used for all simulation work and the results indicate that, in the current climate scenario, the hybrid ventilation system meets acceptable summertime overheating criteria in both heavyweight construction and lightweight construction. However, by 2030 only the thermally heavyweight construction met the same limiting temperature targets. Further, thermal comfort and the energy impact of increased thermal mass is discussed.

Keywords: ***Building Thermal Property, Dynamic Simulation, Energy Performance, Future Schools, Hybrid Ventilation***

1. INTRODUCTION

Predicted increases in summertime temperatures due anthropogenic climate change present a major challenge to designers of buildings in the 21st century. School buildings often present the greatest challenge due to high casual gains and a need to keep operational energy costs low and, therefore, a desire to operate as a 'free-running' space for as much of the occupied period as possible. Increased awareness of occupant thermal comfort needs and the health, wellbeing, and productivity benefits of good Indoor Environmental Quality (IEQ) further promote the need for effective ventilation systems that minimize energy use whilst maintain appropriate comfort levels. The majority of exiting UK schools are designed to operate passively i.e. employing natural ventilation in both summer and winter (Godoy-Shimizu et al., 2011). However, it is reported (Jones et al., 2012) that around 50% of schools would not meet current guidance for CO2 levels and that only 30% would meet the ventilation rate requirements identified in guidance document Building Bulletin 101.

Many authors (Wargocki et al., 2007; Bakó-Biró et al., 2012) have reported the undesirable effects of under-ventilation and the resulting elevated indoor temperatures and CO2 concentrations which significantly impair pupils attention, memory and concentration. Pupils spend 30% of their life in the schools and around 70% of that time inside a classroom (Bakó-Biró et al., 2012), consequently there should be considerable focus from policy makers and designers to ensure that future school buildings out-perform the existing stock with regards to both energy performance and occupant thermal comfort. However, there exists a further challenge in the form of predicted increases in summertime temperatures due anthropogenic climate change. By 2030 schools are predicted to exceed the overheating standards of CIBSE guide A and BB87 (Jenkins et al.,2009). In addition to potential changes in the external climate, there is an increasing trend towards deep plan spaces for optimum use of the available floor area, which has a negative impact on natural ventilation performance (DfES,2006). The increased use of information communication technology (ICT) presents additional heat load and items such as electronic white boards often result in both increased internal gain but also restrictions to

 ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

airflow due to the accompanying use of blinds for easier vision of the board(DfES,2006). Whilst casual gains rise and natural ventilation effectiveness is decreased, fabric thermal performance has increased, i.e. lower U-values, often resulting in very lightweight building solutions that respond quickly to solar gain (Jenkins et al.,2009) which, if coincident with other casual gains and reduced ventilation rates clearly exacerbates the problem of overheating. In urban locations such as London (U.K.) Montazami et al.,(2012)identify a high likelihood of closing windows during quiet activities, which highlights the additional design consideration of meeting ventilation rate requirements whilst maintaining acceptable IEQ.

Overheating is most likely of greater concern in secondary schools than the primary schools due to greater fresh air requirements, due to increased occupant density, and higher ICT equipment and internal gains (Godoy-Shimizu et al., 2011). Consequently it is likely that natural ventilation will fail to meet the overheating performance standards for future schools(Jenkins et al.,2009). Accordingly, the application of air conditioning systems could become more commonplace in response to the need to address overheating and IAQ issues. The adoption of such measures would however strongly conflict with the goal of reducing building-related energy use and greenhouse gas emissions. Hybrid ventilation systems present a potentially lower energy choice, as they attempt to utilize natural driving forces for as long as suitable environmental conditions permit and then employ mechanical ventilation when necessary, which also enables the use of heat recovery in winter-time operation. Consequently, a hybrid system can potentially reduce energy consumption and CO2 emissions, not only relative to full air-conditioning but also in comparison with a completely free-running alternative. Additionally, a hybrid system has potential to improve annual energy efficiency whilst maintaining good indoor air quality and thermal comfort of occupants (Steiger et al., 2013).

A study by Cambridge University and the Massachusetts Institute of Technology (MIT) has been made, leading up to the introduction of e-stack ventilation (Energy world, 2012). In deed, e-stack is a type of mixed-mode ventilation with the central idea of overcoming the overheating problem both in summer and winter times. Reaching the target, it applies natural ventilation in summertime and mechanical ventilation in wintertime. As the result, it has shown the capability in both reducing the carbon footprints and providing proper IAQ and thermal comfort in the schools (Breathing Buildings,n.d.).

However, for more extreme weather files such as London Design Summer Years (DSY), the system can perform properly where the internal gain of the classrooms is reduced (Breathing Buildings, n.d.). DSY is introduced by the CIBSE to assess the performance of buildings under extreme intolerable conditions. A DSY is a complete year for which the average temperature of the period April–September ('summer') is at the midpoint of the upper quartile of ratings acquired from about 20 individual years, which means the third hottest April–September period in a series of 20 years and the approximate of a 1 in 10 chance to have April-September average temperatures exceeding the DSY (CIBSE,2002).

Consequently for high risk of overheating that threats the secondary schools of London in the future, more studies are needed for finding the performance of the e-stack as a newborn ventilation system. This work evaluates the role of e-stack as a ventilation technique for the secondary schools of London both in 2014 and 2030s climates. In fact, the variable for this evaluation is the thermal properties of the fabrics.

2. METHODOLOGY

The proprietary dynamic building simulation software IES-ve was used to estimate thermal comfort and IAQ in a reference classroom. The IES <Virtual Environment> (IES <VE>) is an integrated suite of applications linked by a common user interface and a single integrated data model (Crawley, 2005). To simulate the hybrid ventilation in IES properly, four component 'Engines' and the 'Building Template Manager' were utilized as presented in Figure 1. Thermally heavyweight and lightweight envelope designs were simulated, under each of two climates, namely, London 2014 and London 2030.

2.1 Weather Data

The climate of London was studied using data in IES-ve weather file and Future weather file from the Exeter center for energy and the environment for London.

The thermal comfort criteria for defining acceptable indoor thermal comfort conditions are refereed from Building Bulletin 101 (BB101) and Part F of the Building Regulations. London has marine west coast climate by mild and no dry winters and summers. The annual average maximum and minimum temperatures are respectively 15.3ºC, and 7.8ºC . The hottest month is July, presenting a maximum and minimum mean temperature of 23.4ºC and 13.7ºC respectively. On the contrast, the coldest month is January with a maximum and minimum mean temperature of 8.1ºC and 3.1ºC respectively (Met Office, 2013). Moreover the annual average of wind velocity in this town is 4.63 m/s, whereas the prevailing wind direction is from South-West (31% probability) all year around. Moreover, the maximum probability of wind distribution from this direction is 34%, which is in July and August (Met Office, 2013).

2.2 Building Geometry

The modeled school was a simple single-story building, 3 m high, with 6 classrooms and a dividing corridor. BB98 indicates a standard classroom with 25 students' capacity should be 51-60m2 (DfES, 2004) and, therefore, a class of 8 m x 7 m (56 m2) was modelled. Figures 2 & 3 present the modelled building. A single classroom, outlined in Figure 2, formed the basis of the evaluation.

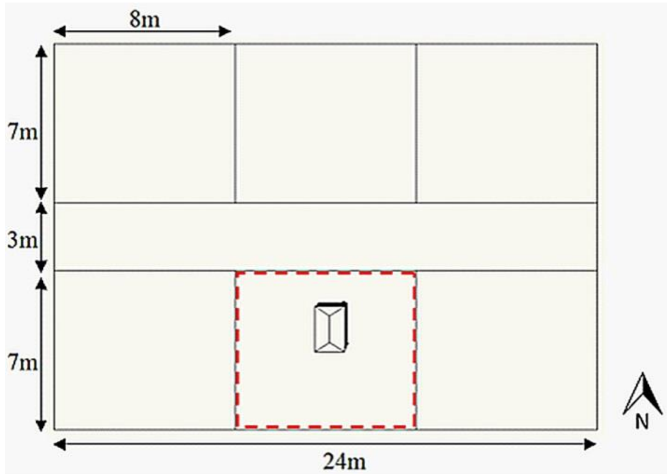

Figure 2: Plan of the Modelled Secondary School

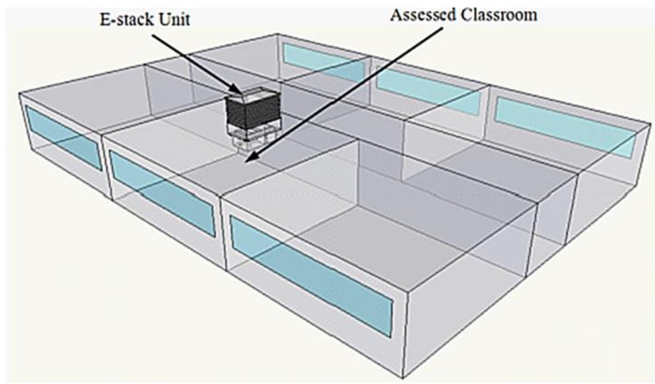

Figure 3: 3-D Image of the Modelled Secondary School

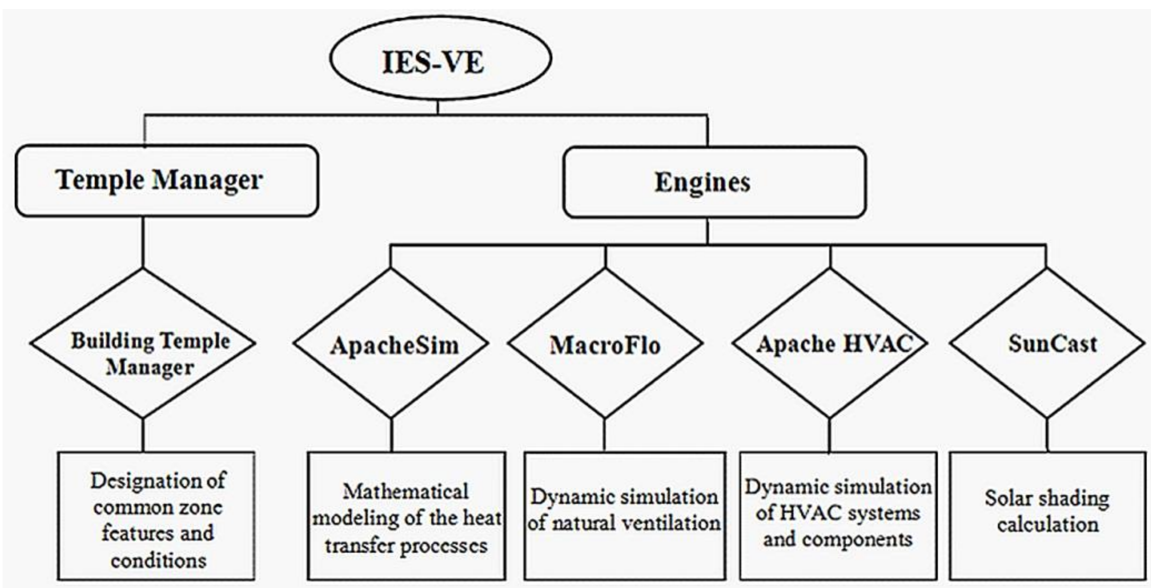

Figure 1: IES-VE Components

Oct. 2014. Vol. 5. No. 05 ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

2.3 Construction Details

Thermally heavyweight and lightweight construction options were modelled and the structure was designed to meet the steady-state, U-value, thermal performance standards typical of a UK building regulations-compliant new-build non-domestic building. The corresponding U-value are presented in Table 1.

2.4 Ventilation and Cooling System

The considered hybrid ventilation system consists of a single roof-mounted e-stack unit in the assessed classroom, which performs in conjunction with the top hung window on the outside wall of the classroom. Both the e-stack unit and the top hung window are free from obvious shielding, obstacles or architectural features, since no vegetation or surrounding structure is placed within 10m of the building. Figures 4 and 5 present the layout of the e-stack unit and the top hung window respectively.

2.4.1 E-stack Performance

In the summer the system operates as a buoyancy-driven natural ventilation system. It performs in conjunction with the operable top hung window on the external facade of the classroom, providing an upward displacement with air being drawn through

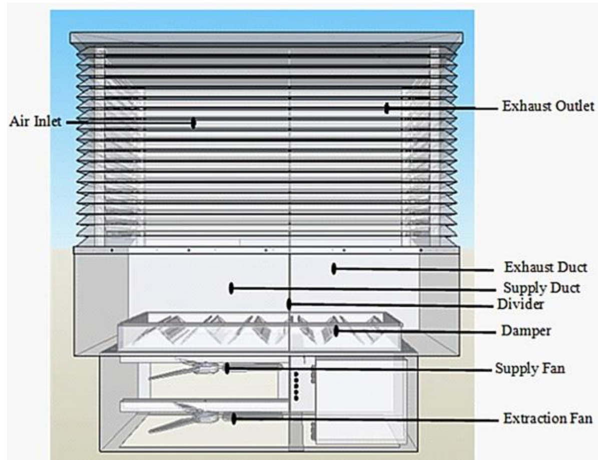

Figure 4: Layout of the E-stack Unit

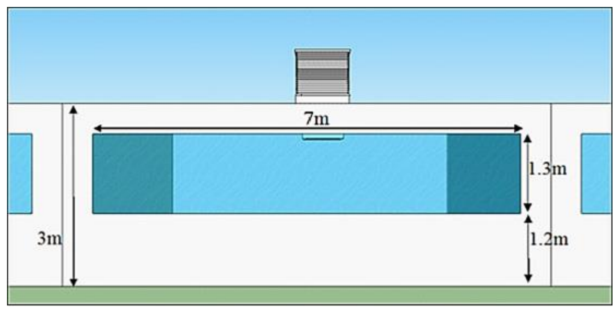

Figure 5: Layout of the Top Hung Window

Table1: Form of Constructions and Associated U-value

	Construction and the corresponding U-value (W/m2K)				
	Walls	Internal partition	Floor	Roof	Glazing
Heavyweight	Screed Insulation Heavyweight (HW) concrete block Gypsum plaster	Plaster HW concrete block Insulation HW concrete block Plaster	London Clay Insulation HW concrete block Cast concrete Carpet	Stone chippings Felt/Bitumen Layers EPS slab Timber board Concrete block	6mm (low emissivity glass) 16mm (argon filled cavity) 4mm (low emissivity glass)
	0.15	0.16	0.15	0.12	1.2
Lightweight	Cement board Cavity Insulation Cement board Steel Insulation Steel Plasterboards	Plasterboards Cavity Steel Insulation Steel Cavity Plasterboards	London Clay Brickwork Cast concrete Insulation Chipboard Carpet	Chippings Felt/Bitumen Layers Cast concrete Glass-fibre quilt Cavity Ceiling Tiles	6mm (low-e glass) 16mm (argon cavity) 4mm (low-e glass)
	0.15	0.16	0.15	0.12	1.2

ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

the room into the unit and discharged to the atmosphere via ducts (Breathingbuildings, n.d.) as presented in Figure 6. However, in winter natural ventilation shifts to a mechanical ventilation, as fresh air is brought in via the supply fan in the supply duct and before entering the occupied space mixed with hot interior air sucked up via the extraction fan, which is in the supply duct as well. Then the pre-heated air with internal warmth enters the occupied area. The stale air is exhausted passively from the room through the exhaust duct (Breathingbuildings, n.d.) as presented in Figure 7.

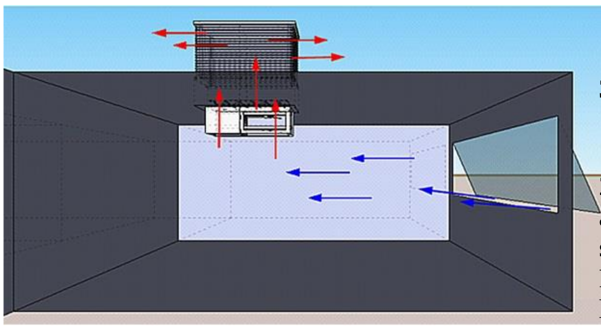

Figure 6: Classroom Ventilation - Summertime Operation

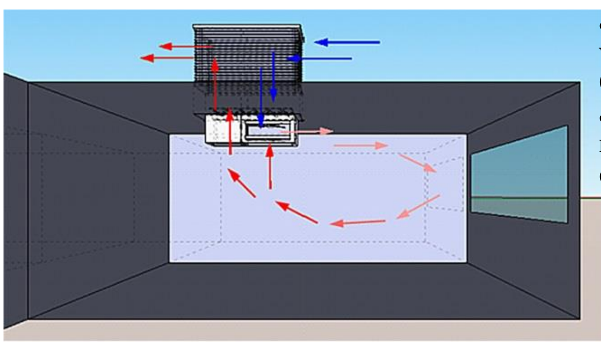

Figure 7: Classroom Ventilation - Wintertime Operation

2.5 Initial Setup

Figure 8 shows the initial setup in IES-VE simulation and Figure9 shows the designed HVAC prototype for mechanical ventilation of the e-stack unit in the wintertime. The corresponding performances in Figure9 are as follows:1- Air Inlet, 2-Dependent Controller, 3-Supply Fan, 4-Damper, 5- 8Independent Controllers, 9- Classroom,10-Extraction Fan, 11-Air Outlet. It should be added that in HVAC engine, the assessed classroom is considered to be heated with a radiator operates during the school time when outside temperature is below 16ºC and inside temperature is less than 18ºC with heating set point of 18ºC.

3. RESULTS AND DISCUSSION

In the UK, Building Bulletin 101 (BB101) (DfES, 2006) provides the regulatory framework for the adequate provision of ventilation and air quality in schools and is additional to part F of the Building Regulations (ODPM, 2006). Table2 shows the limitation of these criteria for school classrooms IAQ. The considered criteria for the internal temperature and relative humidity (RH) are set according to the use of internal space heating, whereas the heating season is defined from 1st October to 30st April. Further, in order to show that a school will not suffer from overheating during non-heating seasons, two of the three related criteria showed in table2 must be met.

Table2: Standards for IAQ in UK School Classrooms

Summertime Temperature (1st May-30st Sep)	✓ There should be no more than 120 hours when the air temperature in the classroom rises above 28ºC ✓ The average internal to outside temperature difference should not exceed 5ºC (i.e. The internal air temperature should be no more than 5ºC above the outside air temperature on average) ✓ The internal air temperature when the space is occupied should not exceed 32ºC.
Wintertime Temperature (1stOctober to 30st April)	✓ Between 19-21ºC
CO_2 concentration	✓ A maximum concentration of 5000 parts per million (ppm) ✓ A mean concentration below 1500 ppm ✓ The ability to lower the concentration to 1000 ppm
Mean RH	✓ Must not exceed 70% for more than 2 hours in any 12 hour period ✓ Must not exceed 90% for more than 1 hour in any 12 hour period, during the heating season

Oct. 2014. Vol. 5. No. 05 ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

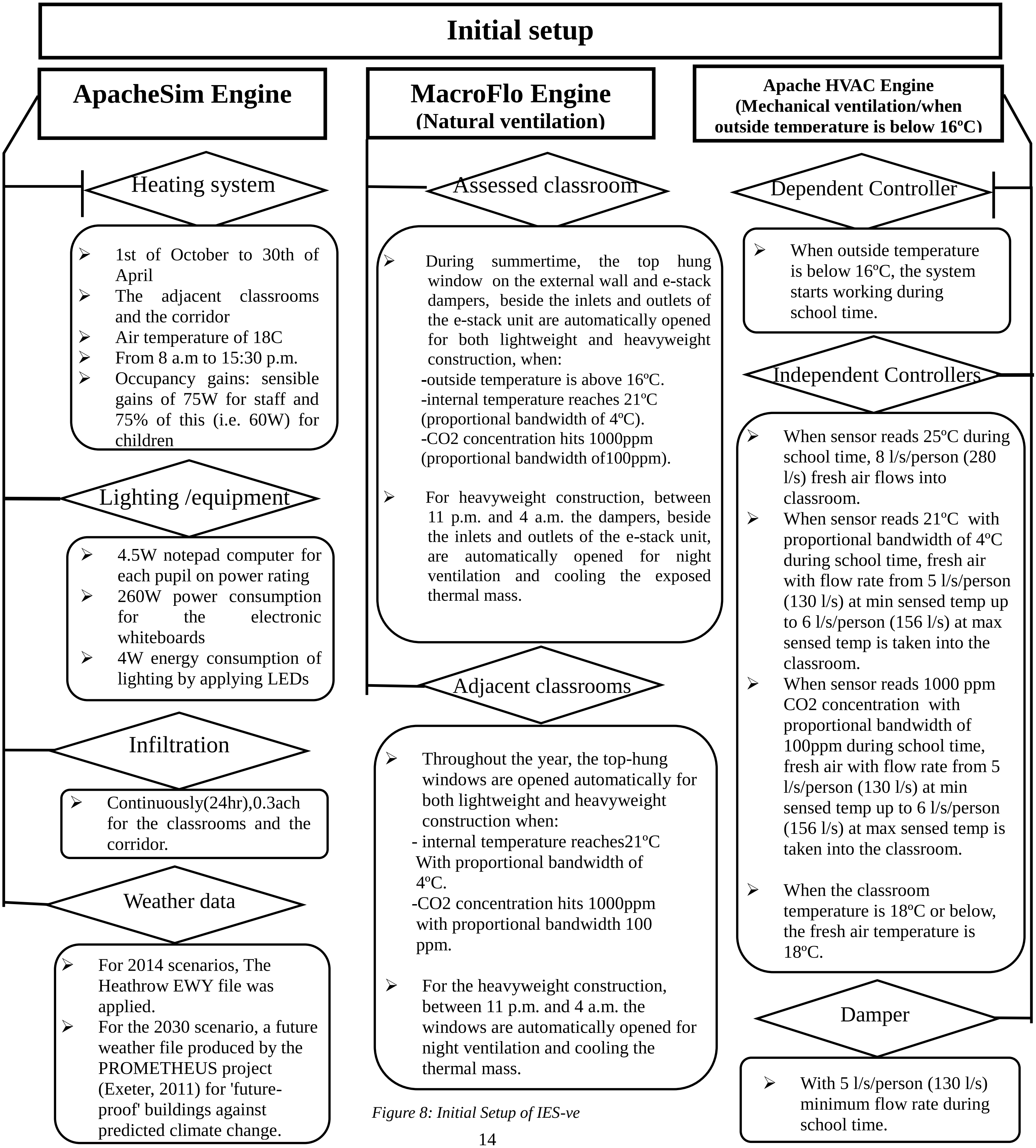

Figure 8: Initial Setup of IES-ve

ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

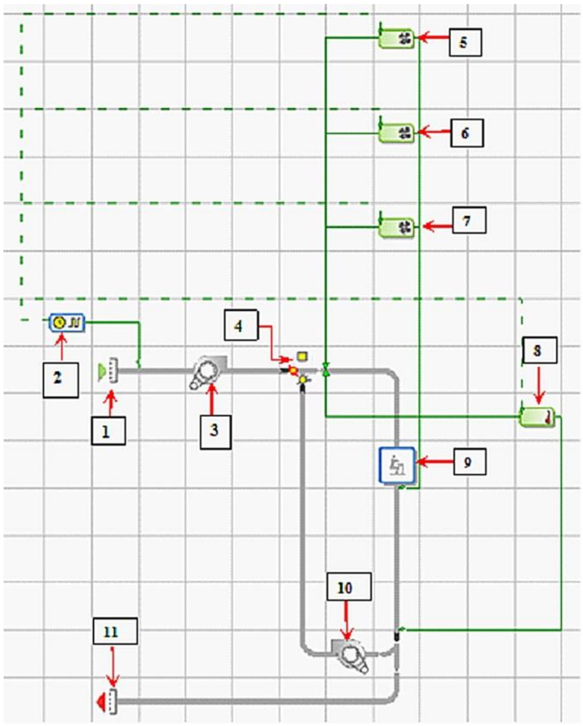

Figure 9: Designed HVAC Prototype for Mechanical Ventilation of the E-stack Unit in the Wintertime

3.1 Thermal comfort

The results of the simulations for overheating requirement are shown in Table 3. According to the summertime overheating requirements of BB101, the mean internal air temperature of the assessed classroom will rise by 2030s compared to 2014 for both lightweight construction and heavyweight construction. As seen in Table3, for lightweight construction, only in 2014, the classroom can meet the maximum limit of 32ºC set by BB101 for summertime overheating and none of the two scenarios exceeds 28ºC for more than 120 hours during the summer time, besides both scenarios were found to have a mean internal temperature that was greater than the mean external temperature by dT ≥ 5ºC. So as meeting two of these three overheating criteria showing that the classroom will not suffer from overheating, the summertime overheating requirements of BB101 is met only in 2014 climatic condition.

However, for heavyweight construction the assessed classroom met the maximum limit of 32ºC set by BB101 for both 2014 and 2030 climatic condition and none of the scenarios exceeded 28ºC for more than 120 hours during the summer time, besides the requirement for the mean temperature difference between external and internal was not met. As the result, both of the two scenarios met the summertime overheating requirements of BB101.

Figure 10 illustrates the mean internal air temperature of the assessed classroom during the occupied time in the coldest heating season in London, January. Accordingly, by 2030s the mean internal air temperature will rise in winter months compared to 2014 both in heavyweight and lightweight constructions. Further, heavyweight construction can not meet the standard of 19 to 21ºC both in 2014 and 2030 with the considered heating system (radiator/ 18ºC heating set point). However for lightweight construction, the standard is only failed in 2014 and can be met in 2030.

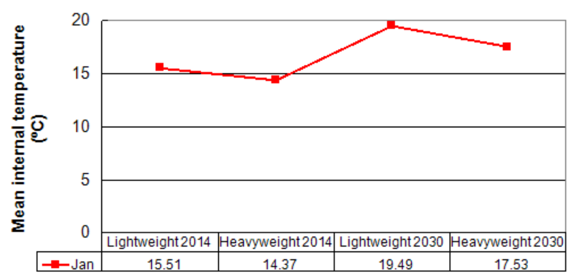

Figure 10: Mean Internal Air Temperature from 9A.m. to 15:30 P.m.(Monday-Friday)

3.2 CO2 Concentration and Relative Humidity

The IAQ was also a concern in the simulations. The average concentrations of CO2 and RH for 26 occupants in the classroom (25 students+1 teacher) can be found in Table 4. Accordingly, the e-stack unit is capable of meeting the maximum limit of 5000ppm and the required mean CO2 level of 1500 ppm of BB101 in all the four scenarios. The average CO2 concentration was, because of the sensor control, very similar in all scenarios in wintertime, but it significantly changes in summertime. In addition, RH is not a serious concern as for all the four scenarios it was within the range of 30 – 70% RH. Likewise, CO2 level, RH level is higher in the winter months compared to the summer months and by 2030 it will be lower than 2014. In addition, natural ventilation performs better than mechanical ventilation in terms of both CO2 and RH levels.

ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

Table 4 shows that natural ventilation performs better than mechanical ventilation. This trend is mainly because of the fresh intake air in the summer that enters the room via the top hung window and leaves via the e-stack unit, whereas in winter the intake fresh air before entering the occupied space is mixed with part of the inner exhausted air for pre-heating. As this circulation keeps on during the occupied hours, the internally exhausted air is not removed from the space completely. Further by 2030s the mean CO2 level in the classroom decreases significantly compared to 2014 during the summer months. This is due to the warmer climatic condition of 2030 relative to 2014 that makes the window be opened more frequently and provides lower CO2 level.

3.3 Ventilation Mode

Another outcome of the simulations was to estimate percentage of time during which the hybrid ventilation system would operate in the natural or mechanical mode. The results of the simulation are shown in Figure 11. The ventilation system operated for the longer time in the natural mode in case of the four scenarios compared to mechanical ventilation, while the mechanical ventilation has a downward trend from 2014 to 2030 and natural ventilation has an upward trend during the same period. The main reason of this decrease is that 2030 is a warmer climatic condition compared to 2014, which includes lower number of days in the winter strategy.

In addition, the use of the mechanical ventilation is higher in heavyweight construction compared to lightweight construction both in 2014 and 2030. In contrast natural ventilation is applied more in lightweight construction compared to heavyweight construction during the same period. The main reason can be for the difference between the thermal mass of the two construction, as lightweight construction is heated faster during summer months relative to heavyweight construction, which increases the natural ventilation strategy (summer months) for lightweight construction compared to heavyweight construction . In contrast, during wintertime internal temperature is higher in heavyweight construction compared to lightweight construction as it losses its heat slower than lightweight construction and consequently the considered ventilation mode (mechanical ventilation) is higher in the heavyweight construction compared to the lightweight one.

Because of this increase in natural ventilation requirement as a cooling system in the summertime from 2014 to 2030, there might be a potential of mechanical cooling by 2030 for providing better

Table 3: Results of Summertime Overheating

	Number of hours greater than 28ºC outside the heating season during the occupied hours (≤120 hrs)	Number of hours greater than 32ºC outside the heating season during the occupied hours (0 hrs)	Number of hours the average internal to external temperature difference is greater 5ºC (0 hrs)	Meeting summertime overheating requirement
1- Heavyweight construction-2014	0	0	5.98	✓
2- Lightweight construction-2014	19	0	7:18	✓
3- Heavyweight construction-2030	50.5	0	5.6	✓
4- Lightweight construction-2030	117	11	7:17	✗

ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

thermal comfort, which could increase the energy consumption and consequently CO2 emission of the classroom. Moreover, this issue is exacerbated for lightweight construction.

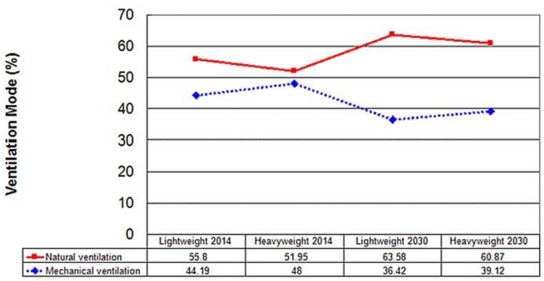

Figure 11: Annual Percentage of Ventilation Mode

3.4 Energy Consumption and CO2 Emission

One complication that has been left out in this discussion is the annual primary energy and CO2 emission of the electrical fan and fossil fuel heating system. The primary energy and CO2 emission factors to be used can be always discussed. In this paper,1.28 to gas and 3.28 to electricity, besides emission factors of 0.222 and 0.381kg CO2 per kWh applied for gas and electricity respectively (BRE, 2012). Figure 12 shows the annual primary energy consumption of the system. Conversely to figure11, the increase of the mean internal air temperature by 2030 decreases the energy requirement for space heating from 2014 to 2030 during the wintertime. This decrease is due to the warmer climatic condition of 2030 relative to 2014 that includes lower number of days in the winter strategy. Further, unlike the cooling requirement, the heating requirement will be about 228kWh and 171.5kWh more with the heavyweight construction compared to the lightweight construction in 2014 and 2030 respectively.

This is due to the thermal property of the construction that makes the lightweight construction be heated faster than heavyweight construction during the occupied hours in the heating seasons and consequently makes the heating system operates less in lightweight construction relative to the heavyweight construction, it supports figure 10 as well. Further, the consumed primary energy for heating the classroom is about 100 times and 60 times more in heavyweight construction and lightweight construction respectively compared to the primary energy consumed for the electrical fan that shows the hybrid ventilation system have relatively small portion of the overall energy use compared to heating system demands.

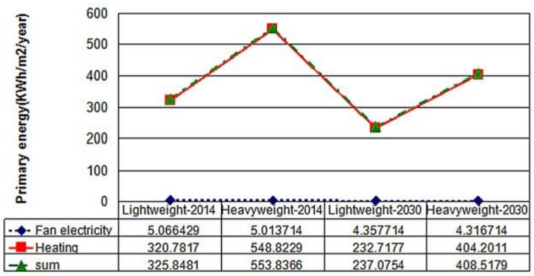

Figure 12: Total Annual Performance of the Classroom in Terms of Primary Energy

Table 4: Results of IAQ

Tabl

	CO2		RH		Meeting IAQ requirement
	Summer	Winter	Summer	Winter	
1- Heavyweight Construction-2014	980	1066.69	61.54	65.76	✓
2- Lightweight construction-2014	950.29	1065.93	57.61	60	✓
3- Heavyweight construction-2030	638.59	1068.34	45.45	57.80	✓
4- Lightweight construction-2030	641.70	1067.59	45.48	51.38	✓

Oct. 2014. Vol. 5. No. 05 ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

In consequence of the primary energy consumption, the lightweight construction results in 41% and 33% lower annual CO2 emission relative to the heavyweight construction in 2014 and 2030 respectively, as seen in figure13. Also, likewise primary energy, the portion of heating system in annual CO2 emission is greatly more than ventilation system. As the result, Being able to reduce heating system energy demands can therefore result in significant savings in overall demands and carbon emissions and in this term, lightweight construction would be a better option relative to heavyweight construction.

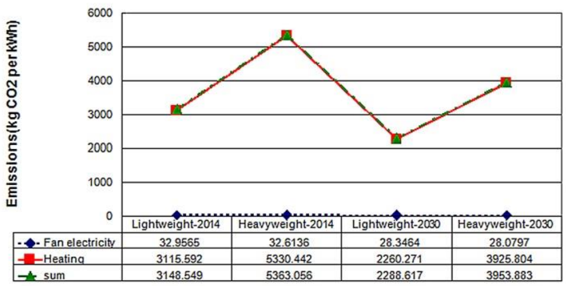

Figure 13: Annual CO2 Emissions

4. CONCLUSION

After analysing the results generated by IES<VE>, not surprisingly, the climatic condition and thermal properties of the building have a serious impact on the hybrid ventilation system performance. In summary, satisfying BB101 requirements for summertime overheating is possible via heavyweight construction by 2030, whereas lightweight construction would fail. Further, among the studied building thermal properties, higher and lower energy demands are associated with the heavyweight construction and lightweight construction respectively. As the result., the best performance in terms of CO2 emissions is delivered by lightweight construction; whereas, the highest pollution is produced by the heavyweight construction. Further, natural ventilation performs better than mechanical ventilation. Finally, the probable threat for the future secondary school classroom in the summertime would be overheating, while it is air quality in wintertime, because the higher internal air temperature in summertime results in the higher rate of windows opening and lowering the CO2 and RH level. Relatively, summertime overheating is more concerning in lightweight construction, whereas IAQ in wintertime is more critical in heavyweight construction.

5. REFERENCES

1. ASHRAE. (2005). American Society of Heating, Refrigerating and Air-Conditioning Engineers(ASHRAE). Fundamentals handbook, Chapter30.Non-residential cooling and heating load calculation.

2. Azadeh Montazami, Fergus Nicol. (2013). Overheating in schools:comparing existing and new guidelines. Building research & information 41(3), 317-329.

3. Bakó-Biró, Z., Clements-Croome, D.J., Kochhar, N., Awbi, H.B. and Williams, M.J. (2012). Ventilation rates in schools and pupils' performance. Building and Environment 48(0), 215-223.

4. Benjamin M. Jones, Ray Kirbyb. (2012). Indoor air quality in UK school classrooms ventilated by natural ventilation windcatchers.Available: http://discovery.ucl.ac.uk/1346486/2/Benjamin%20Jones%20-%20Paper%20and%20Plots.pdf. Last accessed 5 August 2013.

5. Breathingbuilding. (n.d.). R-Series Stack Based Ventilation. Available: http://www.breathingbuildings.com/products/r-series. Last accessed 12 August 2013.

6. CIBSE.(2002). Weather, Solar and Illuminance Data. Guide J, Chartered Institution of Building Services Engineers, London.

7. Daniel Godoy-Shimizu,Peter Armitage, Koen Steemers, Torwong Chenvidyakarn . (2011). Using Display Energy Certificates to quantify schools' energy consumption. Building Research & Information.

8. DfES. (2004). Building Bulletin 98 | Briefing Framework for Secondary School Projects.London: Department for Education and Skills.

9. DfES. (2006). Building Bulletin 101 | Ventilation of School Buildings. London: Department for Education and Skills.

10. D.P. Jenkins, A.D. Peacock, P.F.G. Banfill.

(2009). Will future low-carbon schools in the UK have an overheating problem?. Building and Environment, 490-501.

11. Exeter. (2011). Center for energy and environment. Available: http://emps.exeter.ac.uk/research/energy-environment/cee/projects/prometheus/ Last accessed 12 August 2013.

12. Fmctv. (n.d.). Interactive Whiteboard. Available: http://www.fmctv.co.nz/interactive-whiteboard/interactive-whiteboard.html. Last accessed 10 August 2013.

13. Met Office. (2013). Met Office. Retrieved 4 15, 2013, from http://www.metoffice.gov.uk/climate/uk/summaries/anomacts.

14. Simone Steiger, J. K. R. (2013). Hybrid ventilation-the best ventilation concept for future school buildings?, s.l.: Fraunhofer IBP.

15. BRE. (2012). The Government's Standard Assessment Procedure for Energy Rating of Dwellings. Available:http://www.bre.co.uk/filelibrary/SAP/2012/SAP-2012_9-92.pdf. Last accessed 15 Jul 2014.

16. Sust-it. (n.d.). Laptop computers ranked by annual running cost. Available: http://www.sust-it.net/energy-saving.php?id=21. Last accessed 12 August 2013