USING BUILDING SIMULATION TO EVALUATE LOW CARBON REFURBISHMENT OPTIONS FOR AIRPORT BUILDINGS

James Parker[1], Paul Cropper[1], Li Shao[1]
[1]Institute of Energy and Sustainable Development, De Montfort University, Queens Building,
The Gateway, Leicester, LE1 9BH, United Kingdom

ABSTRACT

The case study described in this paper illustrates the role building simulation can play in evaluating refurbishment options that reduce the carbon footprint of existing airport terminals. A model of the terminal building at a busy United Kingdom (UK) regional airport is used to test the effect of different interventions on the environmental and economic performance of the facility. A calibration process is described and each version of the model is simulated to include future passenger increases and weather scenarios. This research will ultimately contribute towards the creation of a retrofit pathway for airport terminals that reduces their carbon footprints.

INTRODUCTION

Airports are amongst the most energy intensive centres in modern society (Edwards, 2005). Emissions from terminals are inexorably linked with aviation but airport buildings actually contribute to the non-domestic building sector. This sector accounts for 18% of the UK's total carbon footprint (Carbon Trust, 2009).

The UK government's Climate Change Act commits to a binding target of an 80% reduction in carbon emissions by 2050 (HM Government, 2008). It is estimated that 87% of existing buildings will still be functioning by then (Kelly, 2009). Demand for air travel is predicted to continue growing in the 21st century (House of Commons Transport Committee, 2009) but the majority of infrastructure that will serve UK airports has already been built. It is therefore through refurbishment of existing facilities that significant carbon footprint reductions can be realised in this sector.

This research uses the definition of a carbon footprint as set by the UK government in accordance with the World Resources Institute (World Resources Institute and World Business Council for Sustainable Development, 2004). It should however be noted that emissions other than carbon dioxide (CO_2) made up less than 1% of the emissions from the case study airport's carbon footprint in 2008. Therefore analysis concentrates on CO_2 emissions only.

Terminal buildings are complex and their common characteristics are identified in the first section of this paper. Issues relating to ambiance, acoustics and security further complicate their design and refurbishment (Macintosh et al, 2010). This case study is based upon the terminal building at East Midlands Airport (EMA) in the UK. Over 4 million passengers are processed through the terminal each year. It is owned and operated by the Manchester Airport Group (MAG).

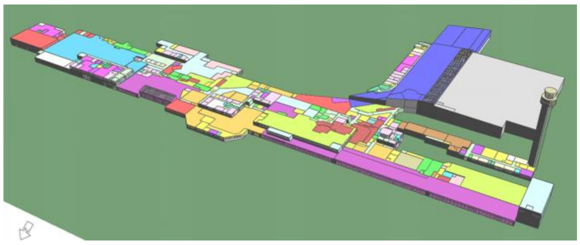

Figure 1: Simulation model of EMA Terminal

Economic and environmental impacts of retrofit interventions have been evaluated using building simulation model outputs. The second section of this paper describes how the baseline model has been calibrated by comparison with the real terminal. The third section compares the annual CO_2 emissions savings achieved by different refurbishment options applied to the baseline model. All versions of the building have been simulated including forecast increases in passenger numbers and future weather conditions. The final section estimates the effect refurbishment options will have on the Net Present Value (NPV) of the facility. The economic viability of each refurbishment strategy is then compared using the estimated NPV.

AIRPORT TERMINAL BUILDINGS

Most non-domestic buildings are heterogeneous in design and function. They require bespoke solutions to reduce emissions (Jenkins et al, 2011). This is true for airport buildings (Balaras et al, 2003) but there are similarities in the design of terminals throughout the world.

Terminals have four key functions: to transfer passengers between modes of transport; to process passengers through official checks; to provide secondary passenger services; and to group passengers together ready for departure (Edwards, 2005). Density and distribution of occupants in different areas is highly variable as passengers flow through the building.

Established layout concepts and a wide variety of structures and fabric are evident in existing airport terminals. The 'naked airport' concept coined by La Corbusier sees aircraft as the main aesthetic and has influenced the use of large glazed facades, a common feature in modern airports (Gordon, 2008). Areas with high ceilings and large open plan spaces are also frequently used in terminal design (Balaras et al, 2003).

Functional space can be divided in to passenger areas and restricted zones. The UK National Calculation Method (NCM) allows for the following passenger areas (landside or airside): Baggage reclaim, Check-in, Eating/drinking facilities, General sales areas, Public circulation space, Public toilets, Speculative sales and Waiting rooms (departures and arrivals). Restricted zones include: Circulation, Food preparation, Meeting rooms, Office space, Plant & machinery, Reception areas, Storage and Toilets (Department for Communities & Local Government, 2011). The EMA terminal model has been divided into these functional areas.

Airport terminal carbon footprints

No published data exists for UK terminal carbon footprints and there is limited international information. Data for United States of America (USA) airports published in 2003 reported an average electricity consumption figure of just over 500 kWh/m^2/year (Clean Airport Partnership, 2003). A study of Hellenic airports found that heat loss was dominated by infiltration and then, in order of most heat lost: windows, roofs (due to the large plan area) and walls (Balaras et al, 2003). Average energy consumption in these buildings was 234 kWh/m^2/year (Balaras et al, 2003).

The Chartered Institute of Building Services Engineers (CIBSE) publish energy benchmarks for UK buildings (Butcher, 2008). Annual benchmarks for terminals are: Electricity consumption of 75kWh/m^2 (41.3kgCO_2/m^2) and Fossil-Thermal consumption of 200kWh/m^2 (38kgCO_2/m^2). Fossil-thermal consumption for the EMA terminal in 2010 was 206.6 kWh/m^2, equivalent to 40.5 kgCO_2/m^2.

Development of terminal facilities

UK air passenger numbers have grown from 2,133,000 in 1950 to a peak of 239,968,000 in 2007 (Department for Transport, 2009a). Throughout 60 years of unremitting growth in passenger numbers and technological advances airports have been in a constant state of change (Gordon, 2008). It is common for terminals to remain operational during refurbishment requiring off-peak (night) working schedules and re-routing of passengers (Macintosh et al, 2010), (Fawcett & Palmer, 2004).

Figure 2 illustrates how the EMA terminal building has grown since built in 1964. The diagram is based upon information provided by EMA's Engineering department. Understanding of thermal performance and energy use in buildings has advanced significantly during its life span. Fabric insulation standards enforced by the UK Building Regulations have increased accordingly during this time (HM Government, 2010), (King, 2007).

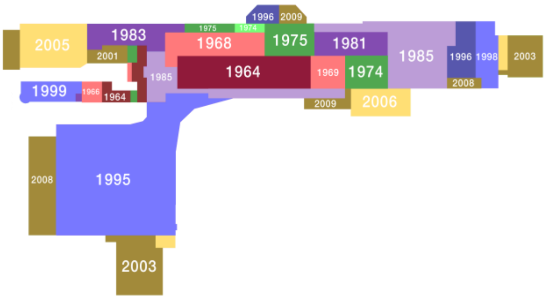

Figure 2: Phased development of East Midlands Airport 1964 – 2011

The largest airport operator in the UK, BAA is quoted as using life expectancies of: 50 years for terminal buildings, pier and satellite structures; 20 years for terminal fixtures and fittings; 5-10 years for office equipment; and 3-5 years for retail units, bars and restaurants (Edwards, 2005). In reality, the rate of replacement is reliant on many variables specific to the particular terminal building.

Terminal refurbishment options

The airport industry's leading international body, the Airports Council International (ACI), publish guidance for existing buildings to reduce CO_2 emissions including the following demand side measures: best practical fabric insulation; shading and low emissivity window coatings; modernization of Heating Ventilation and Air Conditioning (HVAC) systems; and longer-life more efficient lighting (ACI, 2009). Supply side options recommended are: wind turbines, photovoltaic panels, solar water heating, bio-fuels and combined heating, cooling and power plant. It also recommends lighting procedures and controls as an operational intervention.

Simulation of UK non-domestic buildings estimates that combined intervention packages using LCD computer monitors, small power management, LED lighting, improved wall and floor insulation, triple glazed low emissivity windows, condensing boilers, Mechanical Ventilation and Heat Recovery (MVHR), reducing infiltration and solar water heating can all help to achieve carbon savings of up to 50% and above (Jenkins et al, 2009), (Jenkins et al, 2011), (Taylor et al, 2009). A broad study of the non-domestic buildings in the UK found that extensive refurbishment packages achieving significant CO_2 savings are unlikely to be economically viable in terms of whole life costs (Jenkins et al, 2011).

SIMULATION DESIGN AND CALIBRATION

A calibrated simulation approach has been used in this case study (Haberal et al, 2005). The stages followed to create an accurate baseline model of EMA's Terminal building are described below.

1: Calibration plan

The plan entailed collecting data from the EMA engineering and sustainability departments. Remaining inputs were selected from the NCM airport thermal profile templates contained in the IES Virtual Environment software (IES, 2010). The baseline model was adjusted to reflect real annual consumption for 2010 as described in section 4.

2: Data collection from existing building

Computer Aided Design (CAD) plan drawings, construction details and information for HVAC systems and operation were provided by the EMA Engineering department. Ceiling heights were recorded in these plans or measured on site. Some ceiling void heights were estimated as they were not on record and could not be measured.

As illustrated in figure 2, the terminal has expanded continually during its life time and some areas pre-date existing records. This meant that unknown elements had to be estimated based on visual inspection. Physical inspection was restricted due to the 24 hour operation of the building. All estimates were agreed with EMA. A Pier extension at EMA built in 2007 has not been included in this exercise. It is a separate building connected to the main terminal by a raised walk-way and is heated using a ground source heat pump. It is naturally ventilated and has better fabric insulation than the main terminal.

Monthly passenger totals and Arrival/Departure schedules for typical winter and summer weeks were also provided. These schedules note the number of passengers and the time of day they arrive/depart.

Actual consumption data from 2010 was available for the terminal gas consumption and chillers electricity only.

3: Simulation data input

Building geometry and constructions were entered based upon the information provided by EMA. Actual site location was used for the solar shading calculations but the nearest available simulation weather data was for Birmingham which is 57km from the site.

The NCM airport thermal template profiles were used to control specific functional areas of the building model. Occupancy density and rate, internal heat gains, energy consumption and thermal set points are all controlled by these profiles. They are estimated by the Building Research Establishment on behalf of the UK government (DCLG, 2011). This approach was used to create an initial version of the model which was then refined to reflect the actual building.

4: Baseline simulation and calibration

The example weekly schedules and monthly passenger totals provided by EMA were used to calculate maximum occupancy density in the passenger landside and airside areas. The landside and airside areas are shown in figure 3.

Figure 3: EMA terminal – passenger airside and landside areas

Profiles created for the baseline model control the occupancy rates in these four separate areas. It was assumed that departing passengers were in the airside section (lounges and concessions) during the hour before departure and in the landside section (check-in and security) during the previous hour. Arriving passengers were assumed to be in the airside section (immigration and baggage reclaim) during the hour after arrival. Passengers were assumed to be in the landside arrivals area following this but for less time.

Separate daily occupancy profiles were created for the summer and winter seasons in each of these areas. The summer season is defined as May to September when over 300,000 passengers per month use the airport. Figure 4 shows an example occupancy profile for the airside departures area. The occupancy factor for each hour represents the percentage of the maximum density of people in that area at a specific time. Similar occupancy profiles were used for all the areas of the building accessible to passengers as shown in figure 3.

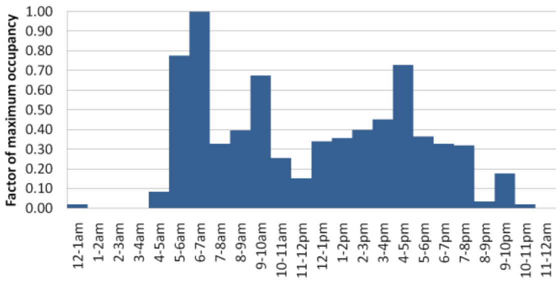

Figure 4: Example summer daily occupancy profile for airside departures area

The NCM default occupancy and internal gain profiles were used in all non-public areas. Further adjustments to the baseline model were made to calibrate it with the known consumption data. The infiltration rate was increased in accordance with estimates for buildings of this type and exposure (CIBSE, 2006). The cooling set point was then reduced to the temperature advised by EMA. At this stage the simulation results estimated higher gas consumption and much lower chillers electricity consumption than the 2010 monitoring data. Energy consumption and resultant internal gains from equipment and lighting were the greatest unknown factor. These were adjusted so that the gas and chillers electricity consumption predicted by the model closely matched the measured consumption for 2010. Test simulations confirmed that an increase of 50% produced a final baseline model that estimated gas consumption to be 4% higher than the 2010 data and chillers electricity to be 2% lower.

SIMULATION OF REFURBISHMENT OPTIONS

This case study is primarily concerned with thermal performance. Evaluated refurbishment options (interventions) focus on fabric and HVAC improvements. Simulation results for solar shading strategies are not included here as they had a negligible impact on CO_2 emissions. Orientation of the building's largely glazed north facing facade results in relatively low solar gains.

All versions of the model are simulated in forecast passenger increase scenarios. A UK government report predicts increased passenger numbers (PAX) of 7 million in 2020 and 9 million in 2030 (Department for Transport, 2009b). Occupancy density was adjusted to simulate increases providing a comparison of potential savings in future scenarios. Forecast occupant densities do not exceed the International Air Transport Association (IATA) space allowances for an 'acceptable' service shown in Table 1 (Jones & Pitfield, 2007). In this case study it has been assumed that the airport runway and apron can accommodate the extra flights/larger aircraft.

Table 1:
IATA Level of Service criteria

m^2 / simultaneous occupant	IATA	EMA 2020	EMA 2030
Check-in	1.4	2.3	1.8
Wait/Circulate	1.9	2.9	2.2
Hold room	1	2.9	2.2
Baggage reclaim	1.6	2.3	1.8
Gov.inspection	1	2.3	1.8

A morphed 2020 weather file has been used in all these future scenarios (Belcher et al, 2005). The morphed files are for Manchester which is 85km from the site. A 2030 file was unavailable at the time this study was completed. Interventions were tested in three scenarios: 2010 PAX and weather data; 2020 PAX and weather data; 2030 PAX using the 2020 weather data.

Single interventions:

Interventions have been selected on the basis that it is feasible for them to be introduced whilst the Terminal remains operational. This is vital for EMA as it operates a single Terminal. Internal roof insulation has been selected as the present high performance roof covering would not need to be replaced during the life cycle considered here.

V1: External wall insulation (200mm).

V2: Internal roof insulation (300mm).

V3: Reduced infiltration – reduces the infiltration rate 0.45 air changes/hour to 0.25.

V4: Triple glazing.

V5: MVHR.

V6: Ground source heat pump.

V7: Biomass boiler – heating and hot water.

V8: Biomass boiler with absorption chillers.

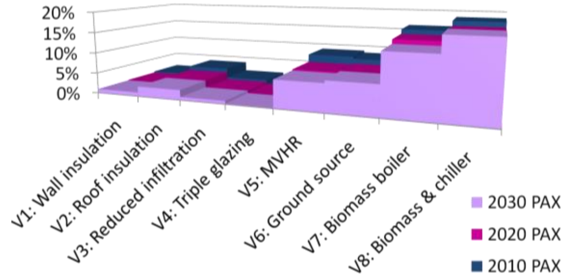

Figure 5: Simulated percentage annual CO_2 savings for single interventions

Relatively low savings on the total carbon footprint are achievable using single interventions. This is largely due to electricity contributing 82% of the total emissions in the baseline model. Results presented in figure 5 show that all fabric improvements achieved CO_2 savings of less than 5%. HVAC improvements (V5-V8) could achieve larger savings. Effectiveness of all interventions is decreased very slightly in 2020 and 2030 scenarios as cooling demand increases due to higher occupancy rates and the milder weather conditions. The exception to this is the combined biomass system (V10) which increases savings marginally from 2020 to 2030 by using the less CO_2 intensive biomass fuel to replace the electricity consumed by the chillers in previous versions of the model.

Significant space heating emission savings can be achieved by the HVAC interventions as can be seen in figure 6. Improving roof insulation can also help reduce savings by over 20% due to the building's large plan form. The future scenario changes have a minor impact on the performance of these interventions. The savings from the combined biomass system reduce slightly as the cooling consumption is included in these figures.

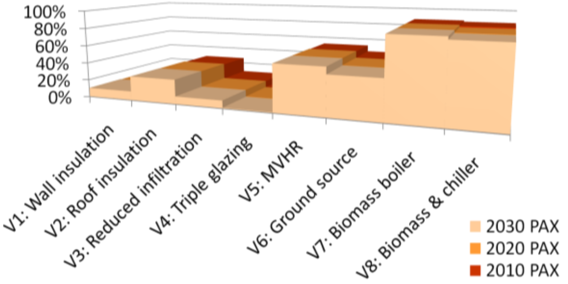

Figure 6: Simulated percentage annual space heating CO_2 savings for single interventions

Renewable Energy

There is large potential for the use of renewable energy at airport sites due to the low-rise infrastructure and large open spaces. However, building integrated solar and wind systems have not been evaluated in this case study. Further research is required to establish the most effective use of renewable power supply for airport terminals and sites as a whole. Wind turbines are already in operation at EMA and importantly for this study, the airport has planted its own biomass crop which enhances the sustainability of a biomass option. Growing biomass on site allows the operator to ensure that the fuel used is part of an on-going cycle. It also reduces the associated CO_2 from transporting the fuel to site.

Combined interventions and reduced electrical demand

The first set of combined interventions includes the compatible options that reduced the life-cycle cost of the building as described in the next section of this paper. The second set includes all the compatible interventions that achieve the greatest CO_2 savings.

No consumption data was available for specific lighting and equipment. A better understanding of actual consumption and potential for efficiencies in the extensive range of lighting and equipment is required before effects can be accurately simulated. However, a version of the building with a reduction in these areas was simulated to illustrate the effect this could have on emissions and loads.

Combined interventions are listed below:

C1: Improved NPV - includes single interventions V3, V5 and V8

C2: All fabric & HVAC - includes single interventions V1, V2, V3, V4, V5 and V8

C3: Reduced gains – as C2 using equipment and lighting gains from the NCM profiles (effectively reduced by a third).

Results presented in figure 7 for the combined interventions are shown in comparison with the best performing single intervention, the biomass heating and cooling system. The combined fabric and HVAC interventions achieve the greatest CO_2 savings for the base 2010 year. However, in the 2020 and 2030 scenarios CO_2 savings are slightly less than those achieved using only reduced infiltration, MVHR and the combined biomass system (version C1). The improved fabric insulation in combination with the higher occupancy rates and milder simulation weather data in version C2 mean that cooling loads and associated emissions are increased.

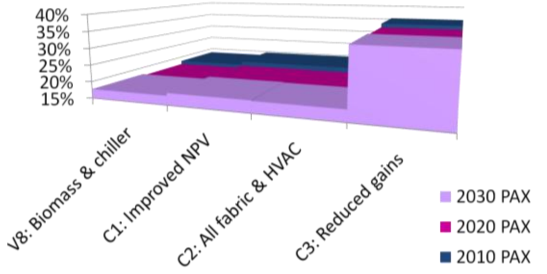

Figure 7: Simulated percentage annual CO_2 savings for combined interventions

The effect of the combined interventions on the annual heating load can be seen in figure 8. The 2010 peak daily heating load for the single biomass intervention is 1400kW higher than that of the version incorporating all of the fabric and HVAC improvements. An opposite effect is seen with the cooling load. This has important implications for the sizing of heating and cooling plant and the refurbishment strategy as a whole. The results in figure 8 suggest that a new boiler system sized for the 2010 baseline building would be required to meet much lower part loads if fabric improvements were introduced in the future. This would results in less efficient operation of the boilers. The opposite effect would impact on the chillers plant which could mean it was unable to meet the future increased loads.

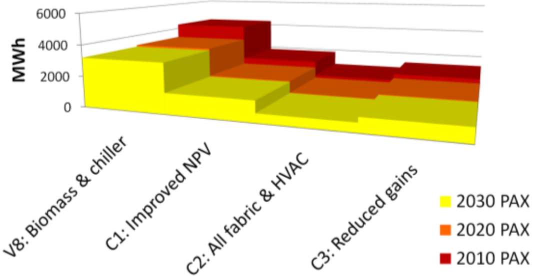

Figure 8: Simulated annual heating load for combined interventions

LIFE CYCLE ECONOMIC AND ENVIRONMENTAL PERFORMANCE

A life cycle of 20 years has been used for this evaluation in accordance with EMA practices. The baseline building has been projected to include replacement of the boilers after 5 years and glazing and cladding after 10 years. These retrofits are assumed to replace existing elements with no improved performance. This baseline case has been used to compare CO_2 reductions and present values.

Carbon footprint savings

Improvements made at staggered intervals reduce cumulative emissions savings. Environmentally, it would be most effective to introduce refurbishment measures as soon as possible. In reality it is more likely that incremental savings will be made as improvements are introduced at the end of elemental life-cycles. Figure 9 shows the life cycle CO_2 savings for combined interventions when introduced at different stages. These projections are based upon the combined set of interventions C2 noted above. This includes improved wall and roof insulation, triple glazing, reduced infiltration, MVHR and the combined heating and cooling biomass system. If all were introduced in the first year, 28,209 tons of CO_2 would be saved over the life cylce in comparison with the basline model. The alternative pathways introduce these interventions at different stages of the life cycle. Pathway D in this example would achieve less than a third of the potential life cycle CO_2 savings.

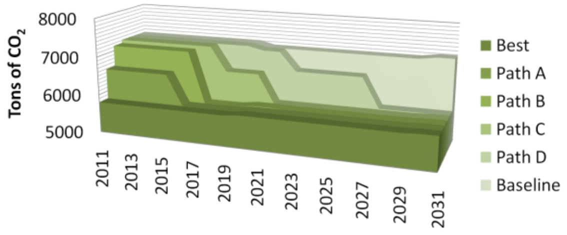

Figure 9: Comparison of cumulative CO_2 emissions for alternative refurbishment pathways

Facility Net Present Value: Baseline and post refurbishment

The NPV of the facility estimates its net value over a defined life-cycle in present terms. This type of assessment is commonly used by organisational decision makers to compare the economic implications of capital investment options. Calculation of the facility NPV before and after refurbishment uses estimates of relevant capital and revenue costs.

References for capital costs were taken from price books commonly used within the UK construction industry (Langdon, 2011a), (Langdon, 2011b). Outline capital estimates include for materials, labour, preliminary costs (calculated as 12% of the project cost) and Value Added Tax (calculated at a reduced rate of 5%). No allowances have been made for tax incentives in these estimates as a more detailed breakdown of capital costs would be required to calculate these.

Revenue fuel cost estimates are based on simulated consumption figures and do not use the actual fuel prices paid by EMA. Fuel prices were referenced from the Department for Energy and Climate Change (DECC, 2011). Government enforced CRC Energy Efficiency Scheme payments of £12 per metric tonne of annual CO_2 emissions are included in the revenue costs (The Environment Agency, 2010). The UK Government Renewable Heat Incentive (RHI) subsidises renewable thermal provision and has been accounted for in these calculations (Hunt, 2010).

Reliable estimates for maintenance costs were not available for this case study. Maintenance costs would be very low for the fabric improvements but could increase considerably for the HVAC options. Biomass systems in particular can have high maintenance requirements which would influence the final NPV. General inflation rates have not been included in the NPV calculations as they do not affect the present values. Real inflation of fuel costs has not been included either as it is very difficult to predict with any degree of accuracy.

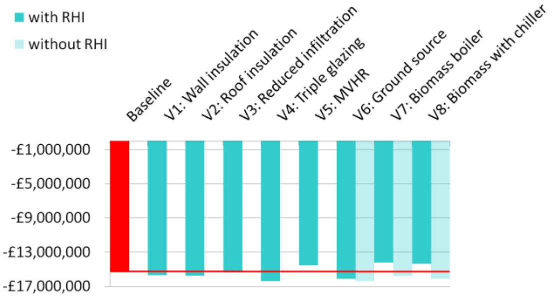

Figure 10: Estimated NPVs of Terminal with single interventions

Results in figures 10 and 11 are shown as a negative value as they represent costs to the airport operator. The lower the negative NPV is, the more the facility will cost to operate in this life cycle. Of the fabric improvements, only reducing the infiltration rate does not decrease the NPV further. This is however a difficult investment to estimate. Pressure testing, leak detection and draught proofing have been allowed for in the capital cost estimate. A similar amount of uncertainty is associated with the MVHR capital estimate. Installation costs could greatly increase if major reworking of the existing ventilation duct work is required.

Economic viability of the biomass systems is improved through access to the UK government's Renewable Heat Incentive. These systems represent very large capital investments in comparison with traditional systems and as shown in figure 10, without access to the RHI they would not improve the facility NPV. Combining improved fabric and HVAC performance actually decreases the building's present value when compared with the best performing single intervention. This is partly due to the greater capital cost but also to the RHI subsidies. A biomass fuel purchase cost of 2p/kWh has been used compared with the 2.5p/kWh subsidy available from the RHI. The difference of 0.5p/kWh should help to offset some of the capital and maintenance costs of these systems.

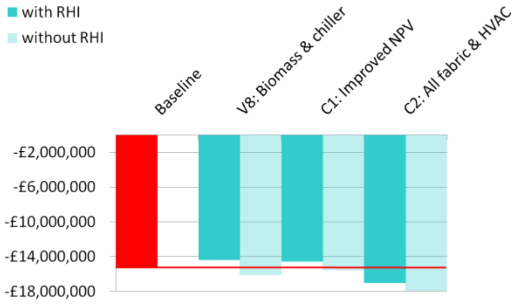

Figure 11: Estimated NPVs of Terminal with combined interventions

CONCLUSION

This type of investigation can play an important role in the early financial decision making stage of the design process. In a UK context this is defined as stage 'A' by the Royal Institute of British Architects (RIBA) and also relates to the 'business justification; stage of public sector project management procedures (RIBA, 2007). Whole building simulation techniques allow for energy use, CO_2 emissions and associated costs to be projected and reasonably assessed for large scale refurbishment projects. This can help the built environment and sustainability teams of airport operating organisations present a robust business case for some interventions.

From an economic perspective, it is difficult to justify the introduction of fabric improvements before the natural life span of the building elements are complete. Annual fuel costs and enforced payments to the UK government's mandatory CRC Energy Efficiency Scheme for annual CO_2 emissions would not be reduced sufficiently to make the fabric improvements economically viable. Only the use of MVHR seems to be economically viable without the access to government subsidy. However, as mentioned previously, it is difficult to estimate the capital cost of MVHR systems. Simulation results for HVAC interventions show a much greater reduction in CO_2 emissions. It is also clear that fabric improvements will have little overall effect unless the gains from equipment and lighting can be reduced considerably. This becomes even more relevant in the estimated future passenger and weather scenarios.

Access to the RHI improves the NPV of the case study facility and on the basis of the simulated consumption figures the introduction of biomass systems would generate large life-cycle savings. The biomass options could be a truly sustainable if the fuel can be grown on site or sourced locally. Results from the models including combined interventions suggest an implication for RHI policy. Estimates imply that there could be a financial incentive to be inefficient if biomass fuel can be sourced for a price per kWh that is lower than the subsidy return, especially when operating buildings with high annual energy demands. In these circumstances, making the building more efficient reduces the financial return from the RHI.

Future work will assess the potential for lighting and equipment efficiencies, the integration of renewable energy sources and the effect that these have on the energy performance of airport terminals as a whole. Research will continue to incorporate estimates of future passenger increases and weather conditions.

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