Occupancy Analytics – a new science for energy efficient hospital design.

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Abstract.

This paper introduces an innovative approach to the management of energy consumption and carbon emissions in the design of a new hospital in the UK. Conventional design practice focuses on the asset specification of the facility to control energy performance. Yet, there is clear evidence to demonstrate that UK hospitals are failing to achieve the performance required by the UK Government's Carbon Reduction Commitment.

The new approach set out in this paper, (which is being implemented on the 3T's Redevelopment and Brighton & Sussex University Hospital NHS Trust, and sponsored by Professor Duane Passman), promises to reverse this situation by addressing the fundamental reasons that lead to it, and in doing so establish a new benchmark in hospital energy and carbon performance. It involves the development of a new science founded in an analysis of occupancy. Through this work new data is created which is essential for the accurate design of engineering systems.

The results of the work undertaken so far have been substantial in their impact. A major finding was that conventional design practice grossly over-estimates occupancy. Inaccurate assessment of occupancy will result in engineering design being misinformed, systems over-designed, and controls systems unable to meet the needs of the users. Consequently energy will be consumed needlessly and far in excess of that expected by the designers and user alike. The strategy forecasts a reduction in carbon emissions for the new hospital of 34%.

Key words: Hospital design, Occupancy, Energy Modelling, Carbon Performance, Energy Use.

1.0 Background context

The performance of UK hospitals and the services that they provide has been receiving much scrutiny for some years. There have been reviews concerning value for money of the built asset (DoH, 2008) as much as there has been in terms of the efficiency of the services provided. Commentators have challenged space efficiency and raised questions as to the significant amount of under-utilised space ((Appleby et al., 2010) (C. Ellis et al., 2011)Environmental performance has also been challenged when assessed relative to the Carbon Reduction Commitment (CRC) (SDU, 2009), where carbon performance is diametrically opposite to that required by the CRC.

The latter challenge presented by the CRC is substantial because it requires a dramatic reduction in energy consumption and the associated carbon emissions. The challenge is all the more greater because there has been a decade or more of investment in hospital infrastructure in the UK, with some of the highest asset specifications in the world, and yet these appear to have made little difference to the In-Use energy and carbon performance. But as others have observed: it is the occupants that consume energy not buildings.

The need to develop a mature understanding of how facilities are used by the occupants has been raised by Bordass who has been a consistent commentator in this area for some years. In his 'post-occupancy' studies (Bordass, 2001) observed that all too often the supply side (designers) fail to understand the operational impacts of their strategies on the users and conversely users fail to understand how to use the facility most effectively to leverage the value of those same strategies. This situation has been described as the 'Great Divide' (H. Davies and P.Jones, 2003).

Bordass (op cit) contends that the supply side does not understand enough about its products In-use, and so does not truly appreciate what needs to be changed, a point also raised in the Leigh report (Leigh, 2008). This also means that designers often remain ignorant of *how* hospital facilities are used in practice as well as the associated impacts of that use on energy and carbon performance. Consequently they are obliged to develop theoretical models of use (formulaic principles and 'rules of thumb'). The author argues that this is a key reason why forecasts of building performance bear little correlation with the performance that is actually achieved In-Use. Studies by CIBSE ((Menezes, 2012) report that this disparity can be as much as five times that forecast by the design team.

The author argues that the same assumptions used by engineers to calculate the facility engineering services requirements are also embedded in the processes used by hospital planners, and indeed the assumptions made by the latter are exactly those used by the former. Whilst there is little direct evidence that acute healthcare facilities are over-engineered, there is certainly evidence to suggest that they are likely to be. The most poignant evidence found by the author is that from the NHS Estates, Health Facilities Note of 1998 (Estates, 1998) which stated that most building services plant in the UK is over sized. It then described how various healthcare specific factors lead to this situation. Whilst over-sizing can be expected for a variety of reasons, it is the extent of over-sizing that is the primary concern. But what is the evidence of over-sized facilities and engineering systems?

1. Concerning space utilisation the latest data from the Department of Health (2010-2011) now reports the amount of unused or under-utilised space is 1.72m m^2, which equates to £1b annual expenditure (E.C Harris, 2011). 1.4m m^2 of this surplus

relates to acute facilities. This is equivalent to the whole J. Sainsbury's retail and storage footprint.

2. Concerning over-engineering, the latest UK data that the author has found is that from 2000 which is a study carried out at BSRIA on 50 building. It showed that 100% of ventilation plant and 86% of chiller plant was oversized in these buildings (Crozier, 2000). A later case study in Australia (P.C Thomas and Moller, 2007) on two commercial buildings found the same evidence of over-sizing and studied in some detail the consequences of over-sizing. In a US study (Graham, 2009)they found that 100% of all buildings studied (over 200) never achieved more than 50% of their design load performance. (In the Australian study it was found that this figure was less than 30%).

The issue of over-provision of hospital space is one that is of increasing concern to NHS Trusts because of the current constraints of capital funding in developing new facilities. The need is to achieve improved utilisation of space assets to leverage latent capacity. The challenge is that traditional measures of utilisation are based on whether the planned use of facilities provides adequate space for the activity intended. This is what Department of Health, Health Building Notes which are used in planning are predicated upon. But the author will demonstrate that actual utilisation based on real time usage is very different from these generic standards. It is from these standards that Room Data Sheets are developed, which are used in hospital planning and where occupancy requirements are specified. It is these requirements that are used by engineers to calculate internal heating cooling and ventilation loads.

The consequence of the aforementioned situation is the substantial over-sizing of engineering services as previously highlighted. This should be of no surprise to HVAC engineers because their own design guides warn of this situation arising should occupancy and equipment estimates be incorrectly calculated (CIBSE, 2006).

With this evidence we should not be surprised either in the results of the NHS Sustainability Development Unit Carbon Report previously referred to. The author's argument is that the fundamentals of energy efficient, low carbon acute hospital design are not being achieved in the UK because the basis of design is fundamentally flawed. Authority for this assertion comes from the Innovation and Growth Team report, Low Carbon Construction (IGT, 2010), where they urge HM Government that a '*fundamental change in the process to deliver low carbon buildings is required*' because the government estate for the greater part continues to fail to achieve the desired performance. This Royal Academy of Engineering in their report 'Engineering a Low Carbon Built Environment' (RAE, 2011) cite the reason for the poor performance of contemporary buildings because of the loss of building science, a point also raised by the now ex president of CIBSE in his presidential address in 2011 ((Manning, 2010)

Yet as much as there maybe limitations on the supply side, so too are there on the demand side, where, as has already been pointed out, the customer often has difficulty in defining appropriate, business orientated metrics. Where hospital facility performance is related to how the facility is used, this is where the author believes that the basis of performance measurement can be derived, particularly as it relates to energy and low carbon performance. The author's argument is that if the impact of working practices can be attributed to energy consumption and by extension to carbon emissions, then this would be a sound basis for a facility performance metric that users would understand. Furthermore, if these working practices could be defined in such a way as to enable data to be created that would provide the foundation for a new basis of engineering design, the value to the engineering profession would be significant. It would avoid the wholly erroneous assumptions made by the engineering profession in the design of HVAC and controls systems and provide a new basis for engineering science. It was from this reasoning that the author created the concept of Occupancy Analytics™

1.1 A new building science

The arguments for developing a new approach to acute hospital design are compelling. The author's proposition is that there must be a new form of engagement with users that can become the basis of a new dialogue. It would be where the forecast operational impacts of design strategies can be used to inform and optimise those strategies. Likewise users need to understand the potential operational benefits of different design strategies. In addressing these issues, the author envisions that new information and data can be developed to inform the design process.

It is in this latter point where the opportunity arises to develop a new building science, and so rid the design process of the gross assumptions that lead to energy inefficient hospital design. These assumptions being:

1. How the building and clinical equipment will be used, and most notably the diversity of use of that space and equipment.
2. The operational processes that determine occupancy.
3. The operational processes that lead to energy consumption and the associated carbon emissions.

This following sections of this paper reports on the results of the author's work with his Integrated Decision Support (IDS) Team on the 3T's redevelopment at the Brighton and Sussex University Hospitals NHS Trust. In the development of the new science it is important to acknowledge the close cooperation with Professor Augenbroe and his team at Georgia Tech University, in the United States. It is also important to acknowledge the role of Professor Duane Passman who sponsored the implementation of this work on the 3T's Redevelopment Project.

2.0 Occupancy Analytics™

Occupancy Analytics™ is a study of how people use buildings. It is enables the prediction of building occupancy and specifically the probability of occupancy density at different times of the day in different parts of a facility. It enables the analysis of forecast patient demand and resource availability in terms of staff, facilities and equipment.

To restate: The primary goal is to establish the connection between how building users work in the hospital (their working practices), as set out in Operational Policies[1], with the energy and carbon impacts of those working practices. The author believes that unique in his work is the creation of a Health Activity Model (HAM) derived from forecast patient demand, Operational Policies and other project data. The HAM is a unique collection of data sets used to drive an Occupancy Analytics simulation model.

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[1] Operational Policies establish to the working practices and the supporting resources required for those practices. In essence they provide the logical basis for a study into occupancy and the movement of occupants around a facility.

Occupancy Analytics™ uses this simulation model to process information from the HAM. The occupancy simulation model is configured with the process constraints and variables. Typical variables would be concerned with variances in the process – the length of time to process a patient in part of a process, for example. Through statistical analysis the upper and lower bound probability of patient demand can be forecast.

The work was inspired by initial work in this area by Augenbroe (Augenbroe et al., 2009). This work established the principles of using organisational simulation to inform HVAC design. Other work that has been carried out in order to understand the dynamics of occupancy has been in relation to the design of office buildings, notably (Kwok and Lee, 2009) buy using stochastic methods. As far as the author is able to establish, there have been no studies that point to a reliable method to enable the direct correlation between these models and reality. (Wang et al., 2011), describes the use of probability theory to develop such a model, but clearly recognised the limitations of such models and described the challenge in these terms:

> *"Occupant behavior, as a basic factor in building performance, still remains a big issue because of its stochastic nature in time and space."*

Creation of a predictable occupancy model is of course essential if such models are to be used for the foundation of engineering and controls design. The use of Operational Policies avoids the need to develop theoretical models of occupant movement within a facility. A further innovation is that the output data from this is then processed into what the author refers to as a 'Whole Facility Energy Model'. By this means a direct correlation between how a hospital facility is used and energy consumption pertaining to that use is established.

In the other studies cited there was no attempt to ground the work in reality as the author has achieved at the 3T's Redevelopment. The importance of this was emphasized by Mahdavi (Mahdavi, 2011) when he concluded in his work: 'People in building performance simulation'*:*

> "*The reliability of results obtained from building performance simulation application, depends not just on the validity of the computational algorithms, but also on the soundness of the input assumptions."*

With no grounding in reality, such as one has within an Operational Policy, such models must be questionable in terms of their accuracy. Surely they can only ever be considered theoretical models? Despite this, all authors share a common objective, which is to develop a sound basis of design for the predication of occupancy related heating, cooling and ventilation loads in facilities, but as Mahdavi points out (op cit):

> *"While there has been significant progress concerning methods and practices for specification of building geometry, materials properties, and external (weather) conditions, the resolution of input information regarding occupancy (i.e., people's presence and behaviour in buildings) is still rather low."*

Mahadavi also raises warnings about reliance on these theoretical models:

> *"Aggregate models of user presence and behaviour would be rather problematic , if the detailed configuration of building services systems (for HVAC) is the main*

concern (Author: which it is for the 3T's project) *For example….the range and variability of required thermal loads at the local level must be reliably gauged. This cannot be based on spatially and temporally averaged occupancy assumptions. In such instances reliance on realistic models may be critical."*

Occupancy Analytics sets out to address this fundamental need – that of a creating a predictable and reliable model for forecasting hospital occupancy, able to be used as a basis of design for engineering systems. The need is not just to inform the occupancy related heating, cooling and ventilation loads for a building, but as will be seen in the next section, the data derived from occupancy can be used in many ways to inform the basis of design of a hospital.

2.1 What is the evidence that using Occupancy Analytics™ produces more accurate results than conventional practice?

We have seen that simulations are only as reliable as the parameters and computational logic on which they are based. Invariably these parameters involve assumptions because the data to inform them does not exist. Any assumption will carry with it a degree of inaccuracy, which may well be a departure from what could happen in reality. Occupancy Analytics ™ sets out to reduce the dependence on assumptions by using Operational Policies that set out how the facility will be used, as well as the working practices that are to be followed. The model then establishes the data requirements needed to model those activities.

The key challenge in any simulation is to understand what needs to be modelled (i.e. level of complexity), and how it is modeled relative to the outcome that is desired. On the 3T's project we conceived two levels of abstraction:

Level 1: Inter-departmental flux

- Purpose: To understand peak departmental (zones) occupancy, and by extension peak hospital occupancy.

Level 2: Intra-departmental flux

- Purpose: To understand accommodation occupancy within each department, and the occupancy peak within accommodation types (sub-zones).

2.1.1 Level 1

On the 3T's project, the major focus has been at Level 1, because a key project objective was to understand peak departmental occupancy such that it could provide a new basis of engineering design. At this level of abstraction, we found that there was comprehensive staff and patient data available to support the analysis. Furthermore the inter-departmental relationships were well understood, and consequently departmental management teams were able to provide the data required for the modelling. The resultant occupancy was expressed in terms of the probability of occupancy within each department at every hour of the day, based on both 10 and 90 percentile extremes.

2.1.2 Level 2

The Level 2 analysis was inevitably more complex, because there are so may variables that determine patient and staff flux within a department. As our objective was primarily to understand occupancy distribution within the department, we reasoned that we could distribute patients based on the overall occupancy profile established at Level 1 for each department (zone). The distribution of patients was estimated as follows:

- From the Operational Policy in terms of the processes that are to be used to manage the patient journey through the department. We identified both 'static occupancy' – people at desks for example, as distinct from 'dynamic occupancy' where people move around according to a process. From this study we could understand, for example, the possible patient demand on consulting rooms and other patient spaces.
- The composition of occupancy established in the Level 1 study. This was expressed in terms of occupant types expressed in terms if numbers of patients, companions, and staff at each hour of the day. Staff were distributed according to assumptions as to what proportion of staff would be in each of the accommodation types (sub-zones) such as consulting rooms, admin, waiting, staff rest and so on.

In reality the distribution within sub-zones would vary according to a large number of variables that would impact each department's processes. Nevertheless the variances would be within the lower and higher bound probability of occupancy that was modelled at Level 1.

2.1.3 The evidence

The evidence from 3T's is that the design team estimated peak occupancy at 6000 people. They never explicitly calculated this total, but it was derived from data estimated in the Room Data Sheets produced by the hospital planning team. These findings compare with the Occupancy Analytics study, which forecasted peak occupancy at about 2300 people. The diversity of use of each zone was forecast for each hour of the day, and it is this diversity that was significantly different to that estimated by the design team.

For the reader with a knowledge of building engineering systems design they will no doubt appreciate the impact that this difference on occupancy would have on the sizing of the engineering systems. The impact would be substantial and the energy analysis bears this out, as will be discussed later in this paper.

These results were validated by sampling four departments. These were:

- Oncology and Haematology
- Fracture
- Imaging
- Nuclear Medicine

These departments were chosen because we also wished to develop alongside the validation process a dialogue in terms of challenging their Operational Policies. In so doing we planned to explore with them how these changes would impact energy consumption and carbon emissions. In this regard it was important to work with departments that would be receptive in such a dialogue. These people became members of a User Reference Group.

The results were assimilated into a Briefing Pack for each department represented on the User Reference Group. Clinical specialists and departmental managers attended workshops to understand three critical components of the work:

1. Review the input data.
2. Review model logic and variables.
3. Review results.

Input data

The HAM database was reviewed with all of the key datasets. Standardised data processing sheets enabled the structured gathering of data based on the agreed process logic. The precise datasets processed in the model, will not be described here, because of the need to protect the author's intellectual property.

Data values were gathered from for example, Patient Admission Systems, and specialist Clinical Information Systems. Further reviews with clinical specialists were carried out to ensure the veracity of the data and to ensure that it could be used within the HAM database. At each workshop the data was reviewed and tested against other information sources. Growth factors were then processed from the Trust's own forecasts of patient growth for different modalities.

A Pre-workshop Briefing Meeting enabled users to understand these factors and to challenge the data that had been collected and used within the model. The Briefing Pack, which was tailored for each department explained the data used in some detail. Subsequent to the briefing meeting, the Trust's senior analyst met with each department once they had reviewed the data, and this provided the department's management team with the opportunity to provide updated and in some cases different data sources to enhance the quality of the data.

Model logic

The model logic was derived from statements within the Operational Policies and through interview with clinical specialists. The information enabled the direction of flux to be modelled within the simulation engine. Patient pathways were identified and these were identified in the simulation as input data values.

For all of the key values, a measure of standard deviation (SD) was established. The SD establishes a measure of variability in the process. Consultations with the clinical specialists enabled the SD for each of the key values to be defined.

By this means a whole process model of the hospital was created for the Level 1 analysis. It provided the process framework within which to model all inter-departmental processes. The simulation run enabled the following occupancy analysis:

- 24 hour occupancy profile for all hospital departments, for patients, staff and visitors. The model manages the flux of support staff and the transient site population that would move through the building.
- Corridor, stair and lift occupancy analysis.
- Equipment utilisation analysis.
- Consulting room utilisation analysis with associated staffing resources.

The Validation Workshops reviewed the model logic, and the results were presented both with the original data (that used for the validation review) and also with a new data that was provided. We wished to build confidence in the results and the transparency of the process was designed to encourage this.

Results

For every department an occupancy profile was produced, typical to that illustrated in Figure 1.

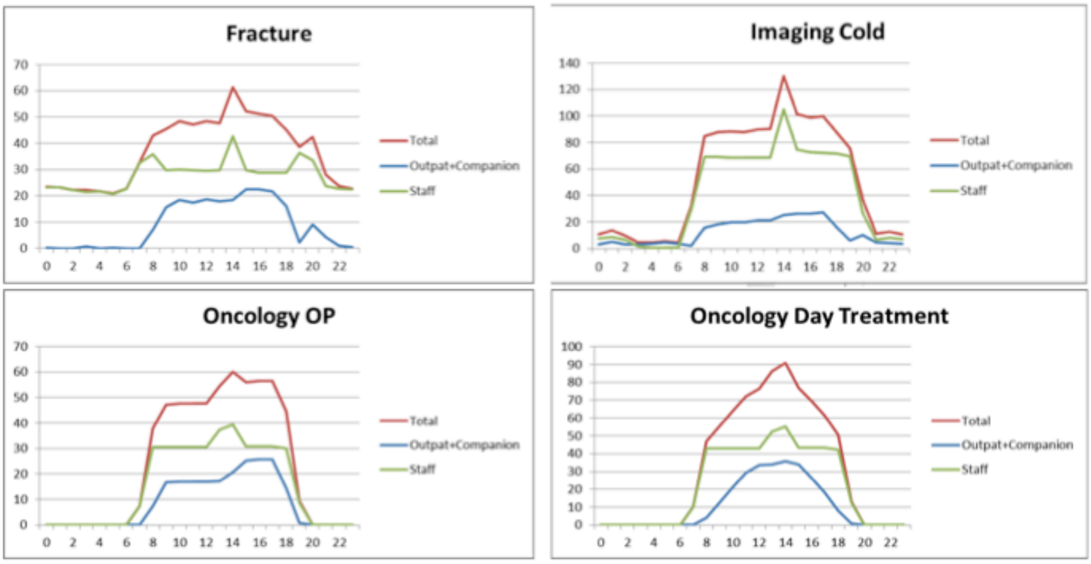

Figure 1 - Departmental occupancy profiles

Due to the variability in the parameters, the simulation generates an outcome in distribution. In general, we have presented the data in 'MLU' format, in which 'M' is an abbreviation for Mean; 'L' is an abbreviation for lower (10) percentile, 'U' is an abbreviation for upper (90) percentile. Alternatively, some of the data are presented in 'MS' format, in which 'M' is an abbreviation for mean, and 'S' is an abbreviation for standard deviation.

These two formats can be converted to each other using a convenient formula:

$$L = M - 3S,\ U = M + 3S,\ \text{and}\ S = (U-L)/6.$$

Occupancy Analytics in Brighton Sussex University Hospital															
Department			Hour of Day												
			8	9	10	11	12	13	14	15	16	17	18	19	20
Simulation Results	Imaging Cold	M	77	84	85	85	85	85	119	89	88	88	84	76	19
		L	63	72	73	73	73	73	92	75	75	75	72	61	0
		U	89	96	97	97	97	97	145	104	102	102	97	91	49
	Imaging Cold Pat	M	8	15	16	16	16	16	17	19	20	19	16	9	0
		L	2	11	12	12	12	12	14	15	15	15	12	3	0
		U	12	19	20	20	20	20	20	24	24	24	19	15	0
	Imaging Cold Sta	M	69	69	69	69	69	69	102	70	68	68	68	67	19
		L	61	61	61	61	61	61	78	60	60	60	60	58	0
		U	77	77	77	77	77	77	124	80	78	78	78	76	49
	Imaging Hot	M	73	71	72	72	72	71	100	67	65	65	64	65	27
		L	62	62	62	62	62	61	78	58	57	57	56	57	10
		U	84	81	82	82	82	81	123	76	74	74	73	73	55
	Imaging Hot Pat	M	0	1	2	2	1	1	1	2	2	1	0	0	0
		L	0	1	1	1	1	0	1	1	1	1	0	0	0
		U	1	1	2	2	2	1	1	2	2	2	1	0	0
	Imaging Hot Sta	M	73	70	70	70	70	70	99	65	64	64	64	65	27
		L	62	61	61	61	61	61	77	57	56	56	56	57	10
		U	83	80	80	80	80	80	122	74	72	72	72	73	55

Figure 2 Occupancy Analytics results

In the example in Figure 2, for the Imaging department, the data should be interpreted as the total occupancy number in that department during a specific period. For example, at 8 AM, Imaging Cold has occupancy with MLU respectively 77, 63, and 89. It means that in average from 8 AM to 9 AM, there are 77 occupants in the department. There is a 90% probability there are more than 63 patients, and a 90% probability there are less than 89 patients in Imaging Cold.

The most significant challenge to the process concerned the amount of time that patients were held in the process for. In the HAM we refer to this as the 'Dwell time'. This factor has a major impact on room utilisation and also determines the peak occupancy within each department. In whole hospital facility terms this also impacts the peak occupancy. It eventually became clear that the clinicians were including substantial 'Wait time' in these assessments of 'Dwell time'.

Having agreed to separate 'Wait time' from 'Dwell time' the discussions with the consultants responsible for each department concluded that the results of the simulations were very close to their experience to what they would expect. The 'Wait time' has clearly identified process inefficiencies and it will be this analysis that will be used to inform the Level 2 studies.

It will be at Level 2 where the intra-departmental processes will eventually be studied in detail. Discussions with the consultants for each department at Level 1 identified that there is often a clear mismatch between patient demand (often caused in Outpatients through the way that appointments are made) and resource availability. We concluded from this work that more work is required on the Operational Policies because they are all 'silent' in a number of important areas of working practice. To be effective the policies need to accurately reconcile, people, equipment and clinical resources, and if in practice these are not, then extended 'Wait time' will result. This in turn will impact peak occupancy.

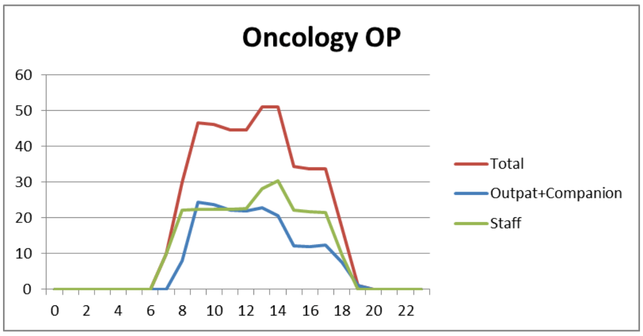

Figure 3 - Original Oncology Outpatient occupancy study with 45 minutes 'Dwell time'

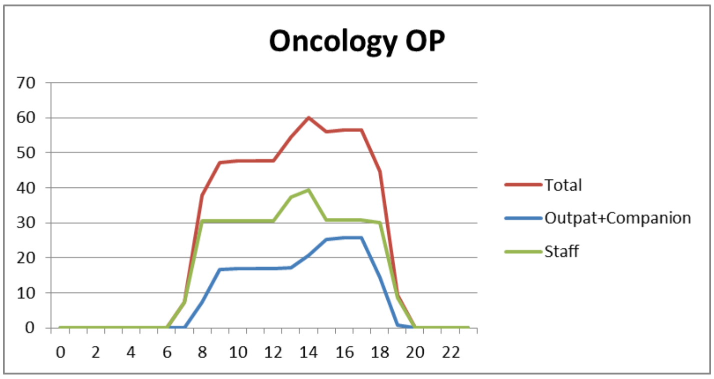

Figure 4 - Subsequent Oncology Outpatient occupancy study with 90 minutes 'Dwell time'

Comparison between Figures 3 and 4 clearly illustrate the impact of extended 'Dwell time' on the peak patient profile, which will then impact consulting room availability as well as the number of clinicians that are required.

2.2 What do these results mean in terms of the impacts on planning design for the hospital?

Occupancy Analytics ™ provides a novel approach to understanding space utilisation in hospitals. The author argues that it provides the evidence-base for efficient health planning, which as was explained earlier, is a challenge to the conventional approach to space planning based on formulaic methods. The analysis showed that in many instances there was a 90% probability that there would be significant under-utilised space. The illustration in Figure 5 is typical.

Opportunity Analysis													
Department	Descriptions		Hour of Day										
			8	9	10	11	12	13	14	15	16	17	18
Oncology OP	1)	Mean number of patients	5	15	14	13	13	14	12	7	7	7	5
	2)	Mean number of available rooms	20	10	11	12	12	11	13	18	18	18	20
	3)	90% chance that there are at least X number of unused rooms	15	5	8	8	9	8	9	15	15	14	18
	4)	10% chance that there are more than Y number of unused rooms	25	15	14	16	15	14	17	20	21	20	23

Figure 5 - Probability analysis for a space utilisation study

Compared with the data in Figure 2, this analysis correlates the forecast patient demand at each hour of the day with the availability of 'patient spaces'. These are defined as:

1. Consulting and Examination rooms
2. Therapy / Treatment Rooms
3. Counselling rooms
4. Treatment / Day bed spaces

Using the 10 and 90 percentile data we calculated the probability of empty rooms at each hour of the day. When these results were aggregated for all Outpatient departments we identified between 650 – 1000m^2 of potential under utilised space. The variance arises from variances in 'Dwell time', which have yet to be finally agreed, subject to final resolution of Operational Policies.

The analysis identifies much potential to drive space out of facilities and prevent the over-sizing of them. It also provides the basis on which to develop an understanding as to how to achieve better space utilisation from existing facilities. On the 3T's project further studies have now been carried out to investigate how existing facilities could be merged into 3T's to make use of the forecast under-utilisation.

2.3 What do these results mean in terms of the impacts on the engineering design for the hospital?

These results would impact every aspect of the engineering design: ventilation, heating and cooling. They also provide valuable insights into equipment utilisation and the associated impact on energy consumption. The impacts of these differences on engineering design are forecast to be substantial:

- HVAC cooling energy: 30% reduction (where cooling loads account for 15% of the total forecast energy load)
- HVAC fans energy: 80% reduction (where the fans account for 17% of the total forecast energy load)
- Hot water energy: 57.5% (where hot water energy accounts for 7% of the total forecast energy load)

If implemented the impacts would be on capital provision of plant as well as reduced operating costs.

Right sizing of engineering plant

The engineering challenge will be to understand all of the factors that affect the 'right sizing' of the engineering plant. Conventional practice estimates the sizing based on the peak heating, cooling and ventilation loads. These calculations make many assumptions concerning future growth of demand as well as variable contingency factors allowed for within each of the design, procurement and construction phases. The results of the Occupancy Analytics studies provide the client with a 'base line' on which to 'right size' engineering plant and equipment. Informed decisions can now be made with the client and the supply chain to determine what design, construction and operational risk allowances should be built into the capacity to provide an appropriate safety margin.

A new basis for building controls design and operational optimisation

Whilst peak occupancy loads are the most significant factor in the 'right sizing' of engineering plant, another important factor that Occupancy Analytics ™ informs is the controls strategy based on the diversity of use of space. The author's work with the design team on the 3T's project identified that the assumptions made on diversity of use were significantly different (i.e. less) than what we forecast in the simulation by studying occupancy at each hour of the day. It is clear from other studies, notably by Granlund OY, in Finland (unpublished) that conditioning of spaces is often taking place when they are not occupied. The control systems were consequently not aligned to use. The illustration in Figure 6 below explains the situation very well.

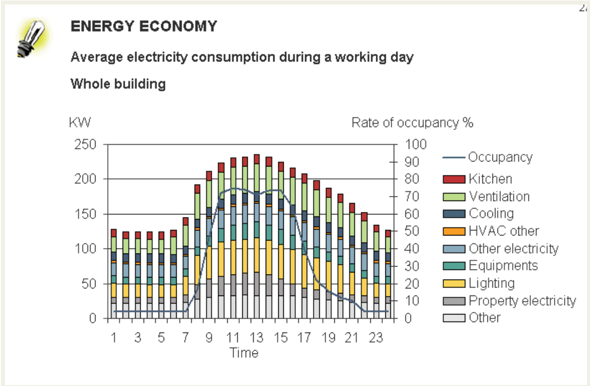

Figure 6 - Granlund OY analysis of the mismatch of consumption and occupancy

The Occupancy Analytics ™ work provides a new basis for the design of controls systems such that they are aligned to use. RIUSKA is the energy analysis software that was used to by the author's IDS team to develop the 'Whole Facility Energy Model'. This model forecast all energy consumption based on the occupancy data. A controls profile was designed for the model, such that the impacts of energy consumption based on occupancy could be assessed. The cooling profile is illustrated in Figure 7 below.

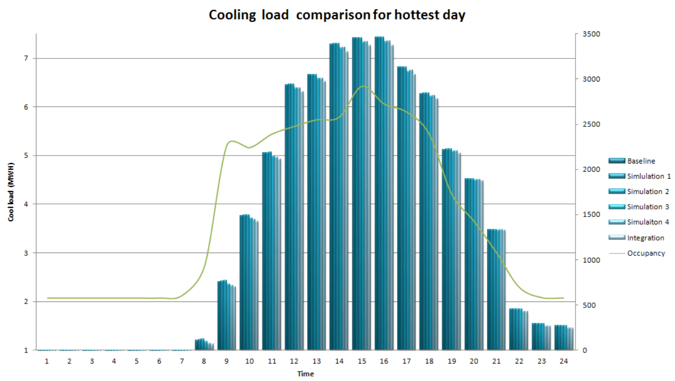

Figure 7 - Cooling load energy consumption correlated to occupancy

The engineering challenge would normally be to engineer the controls system to respond to occupancy. The design engineers would argue that a high level of modulation would be required to achieve the occupancy diversity forecast in the Occupancy Analytics™ study. This could be expensive and would require a life-cycle cost analysis to evaluate the impacts of this.

The author's approach is to develop a controls and monitoring strategy is one that involves the building occupants that work in the facility. The proposition that the author put to the users was this:

> "Is it not in your interest to control patient flow and to avoid occupancy peaks, because of well-being, improved Infection Prevention and Control, improved patient care and dignity, and better space utilisation? It is certainly in the Trust's interest to drive down energy consumption, reduce carbon emissions, and so reduce both capital and operating costs, and for these reasons we should work together for mutual benefit."

The author proposed that the controls system strategy be designed to meet the needs of the users as much as to meet the need to optimise the performance of the engineering systems. This will be the subject of another paper.

2.4 How will the results impact the forecast energy performance?

Overall carbon emissions would be reduced from a design team forecast of 172kg/m2 to 90kg/m2 equating to a 34% reduction against the design team estimate. Also of significance is that as direct consequence of the reduced occupancy loads, with less demand on the CHP plant, there would be a net contribution to the BSUH Estate of 22kWh/m2 which amounts to half of all forecast electrical equipment demand within 3T's.

In comparative terms against European benchmarks, the whole facility performance is forecast to be 280 kWh/ m^{2}, which is well within the benchmarks of the latest Finnish and Norwegian hospitals which are forecast to operate at less than 320kWh/m^2. However, if the published forecasts (Karlsonn, 2011) of the propose new Karolinska Solna hospital are achieved in practice, then this will set a new benchmark performance of 100 kWh/m^2. Finally, in terms of Encode (DoH, 2006) the forecast performance is 28 GJ/100m^3/a, which is a significant improvement on the Department of Health benchmark for an acute hospital of 35-55 GJ/100m^3/a.

APPLEBY, J., HAM, C., IMISON, C. & JENNINGS, M. 2010. Improving NHS productivity: More with the same not more of the same. 11–13 Cavendish Square, London W1G OAN
Tel 020 7307 2400: The Kings Fund.
AUGENBROE, G., LI, Z. & HEO, Y. 2009. HVAC Design Informed by Organisational Simulation. *Building Simulation 2009.* Glasgow, Scotland.
BORDASS, W. 2001. Flying Blind: Everything you wanted to know about energy in commercial buildings but were afraid to ask. London, UK: Association for the Conservation of Energy.
C. ELLIS, E. BALDWIN & DICK, R. 2011. NHS SERVICE AND ESTATE EFFICIENCY REPORT: SEIZING THE OPPORTUNITY. London: E. C. Harris.
CIBSE 2006. Guide A: Environmental Design. *Internal heat gains.* 2006 ed. London: CIBSE.
CROZIER, B. 2000. Enhancing the Performance of Oversized Plant. *Application Guides S.* Old Bracknell Lane West,
Bracknell,
Berkshire RG12 7AH: BSRIA.
DOH 2006. HTM 07-02: EnCO2de: Making energy work in healthcare. *In:* DOH (ed.). Quarry House
Leeds: Department of Health.
DOH 2008. Treasury's Value for Money Assessment for PFI. *In:* HEALTH, D. O. (ed.). Quarry House, Leeds LS2 7UE: DoH.
ESTATES, N. 1998. Reducing energy consumption in oversized plant. Health Facilities Note 27. *In:* ESTATES, N. (ed.). London: HMSO.
GRAHAM, C. I. 2009. *High Performance HVAC* [Online]. United States: National Institute of Building Sciences. Available: http://www.wbdg.org/resources/hvac.php [Accessed June 2012 2012].
H. DAVIES & P.JONES 2003. **BRIDGING THE GREAT DIVIDE**. *CIBSE/ASHRAE Conference.* Edinburgh.
IGT 2010. Low Carbon Construction. *In:* DEPARTMENT FOR BUSINESS, I. A. S. (ed.). London SW1H 0ET: Crown Publications.
KARLSONN, J. F. 2011. SUSTAINABLE HEALTH CARE ENVIRONMENTS – DESIGNING ENERGY EFFICIENT
AND HEALTHY INDOOR CLIMATE. *In:* SOCIETY, A. S. E. (ed.) *SOLAR 2012.* United States.
KWOK, S. S. K. & LEE, E. W. M. 2009. A study of the importance of occupancy to building cooling load in prediction by intelligent approach. *Energy Conversion and Management*, 10.
LEIGH, M. E. 2008. Building for the future: Sustainable construction and refurbishment on the government estate. London: The Stationery Office Limited.
MAHDAVI, A. 2011. People in building performance simulation. *In:* J.L.M HENSON & LAMBERTS, R. (eds.) *Building Performance Simulation for Design and Operation.* London & New York: Spon Press.
MANNING, R. Collaborate and Deliver. CIBSE Presidential Address, 2010. The Chartered Institution of Building Services Engineers, 14.

MENEZES, A. 2012. *The Performance Gap* [Online]. Chartered Institute of Building Services Engineers: CIBSE Energy Performance Group. Available: http://cibse-epg.org/downloadable/groupOutput/carbon_bites/cb11.pdf [Accessed June 2012 2012].
P.C THOMAS & MOLLER, S. 2007. HVAC system size - Getting it right. Level 9, L block, QUT Gardens Point
2 George Street, Brisbane, Qld, Australia 4000
Telephone: +61 7 3138 1393: Cooperative Research Centre for Construction Innovation.
RAE 2011. Engineering a low carbon built environment. *In:* HARYOTT, R. (ed.). 3 Carlton House Terrace
London
SW1Y 5DG: The Royal Academy of Engineering.
SDU, N. 2009. Saving Carbon, Improving Health. *In:* PENCHEON, D. D. (ed.). Cambridge CB21 5XB: NHS Sustainable Development Unit.
WANG, C., YAN, D. & JIANG, Y. 2011. A novel approach for building occupancy simulation. *Building simulation,* 4.