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Mobile Architecture and Built Environment Laboratory (MABEL) – a Building Performance Evaluation Tool
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This paper describes the Mobile Architecture and Built Environment Laboratory (MABEL) and its application for systematic building performance evaluation for compliance testing, commissioning, strategic and operational facility management and continuous improvement in the built environment.

The first part of the paper introduces the application areas of on-site building performance evaluation and discusses the shortcomings in this regard in current practice. It emphasizes the need for on-site investigations to generate information on ‘as built performance’ for the feedback loop between design, operation and occupancy of new buildings, retrofit or adjustment.

The second part introduces the Energy-Comfort-Behaviour Framework for ‘across-the-board’ building evaluation and discusses MABEL’s role in this scheme. MABEL’s objectives, procedures and the performance measurement matrix are explained and discussed.

1.0 Introduction
Building Performance Evaluation (BPE) is employed to ensure that a building and its service systems are able to provide the required services to the building occupants and that its operational parameters comply with given design and performance standards and objectives. These evaluations are performed to support efficient operation and effective functioning of a specific building. It results in adjustment of control and operational parameters of the building, its service systems and operation.

A wider application for Building Performance Evaluation is the generation of performance information for specific design measures and technologies with relevance beyond the operation of the specific building. This information is then fed back into future design work and it can initiate development by providing assessment of technologies, design options and complete building concepts. Such application results in general design knowledge for improving design practice, standards and building policies.

Hyde (2000) states that such knowledge generation is required as good professional practice by the Royal Australian Institute of Architects (RAIA), as well as the American Institute of Architects (AIA), but is seldom performed systematically.

1.1 The Systematic Design Feedback Loop
The literature on Building Performance Evaluation (e.g. Hubank, 2004; Freiser and Schramm, 2005) suggests that a formal and systematic feedback loop is required linking briefing, design, construction, commissioning, evaluation and improvement in order to improve building performance for specific buildings and the entire building stock. Such a feedback loop is shown in Figure 1.

During the building’s life span, the loop is stepped through not only when the initial design is developed, assessed and improved, but multiple times by the various stakeholders during design, construction and operation. Especially in the occupancy phase, which is the longest and most important phase in a building’s life, a building undergoes frequent change and adjustment. Here systematic and repeated building performance evaluation is required for efficient building operation and strategic facility management.

Also, the identification of best practice systems and evidence-based knowledge about advanced design solutions can only be achieved by systematic evaluation of actual performance of innovative and traditional designs in real world settings after design and construction.

In the feedback loop suggested by Hubank (Figure 1) Building Performance Evaluation is located in the sequences ‘measure’ and ‘analyse’ and the evaluation framework is originated in the sequences ‘require’ and ‘design’, where the briefing and objective development takes place.

1.2 Performance Evaluation in the Design Process
In the design process, simulation studies of various sophistication levels (computer or paper-based) are employed to predict performance of the future building. A simulation model is an abstract

![Feedback Loop into the Design Process](Figure 1)
representation of a technical system and its formulation involves simplifications and assumptions. Therefore the match between simulation result and later real world behaviour of the investigated building is relative to the accuracy of the model and the entered data.

Besides the degree to which the model and simulation input represents the system, the fact that it is often calculated with ideal behaviour and zero percent failure rate compromises the application of simulation for design evaluation under real world settings. This means that in such investigations all systems are working as planned and are perfectly adjusted. Even if sensitivity investigations are conducted for a range of selected parameters of the simulation model, the unpredictability of the real world must be considered. It can be expected that real world performance be affected by many more influences than can be anticipated and modelled in simulation studies.

1.3 Design Briefs, Rating Schemes and Standards

In the initial commissioning phase, before a building is first occupied after construction or major retrofit, Building Performance Evaluation is employed for testing if planned operational characteristics and performance objectives are met. In practice these objectives are partly results of the building owners and designers’ individual aims developed in the briefing process (see Figure 1 ‘require’), mediated by the architect and other consultants, but also of prescriptive standards and professional guidelines.

The Australian Council of Built Environment Design Professions (BEDP, formerly the Australian Council of Building Design Professions – BDP) Policy Statement for the Built Environment recognises that ‘it is no longer effective to determine the quality of the built environment by minimum construction standards alone’. Therefore performance-oriented standards are in force today. Besides energy usage and environmental performance requirements, the minimising of pollution to soil, air and water as well as the use of non-renewable resources and health and safety are major considerations of such policies. Recent ‘best practice’ developments in this regard are provided through rating systems such as Green Star (2005) or NABERS (2003).

The BDP Environment Design Guide provides a starting point in the development of an effective environmental design process. One paper in particular, describes developing the building energy brief as ‘the scope of works to be undertaken, the management and reporting mechanism’ (Oppenheim, 2002).

An increasing and perhaps more popular state of mandating an environmental design brief for buildings is through the development of rating tools. Such tools as Green Star, have grown in popularity among clients seeking a rating approval for their building. Rating schemes are well placed to guide and put the project on track and in the right direction. However, there remains a definite lack of evidence-based reporting on actual implementation of sustainable concepts. In fact the stakeholders of a project are often left uninformed about the successes or failures of sustainable design implementation, where buildings perform unsatisfactory although their design received high ratings.

1.4 Rating the Rating Tools

At this point in time, we are in the early days of ‘rating the rating tools’. It is still to be proven, if high rated buildings operate substantially better than standard buildings. Although the intentions are well placed, it appears that only a few of these schemes rely on actual collected data and measured performance. Those that do reference standards, which in return, require measurement for compliance.

2.0 Energy-Comfort-Behaviour Evaluation Framework

The previously described applications reason the development of a systematic approach for Building Performance Evaluation. The remainder of this note will describe a building evaluation framework involving MABEL.

Three main techniques are applied for building performance diagnostics:
- Environmental Measurement
- Operational Monitoring
- Occupancy Survey

The Energy-Comfort-Behaviour framework combines the three diagnostic techniques. MABEL is a facility for environmental measurement and operational monitoring. It has been integrated with occupancy survey techniques.

The first method 'Environmental Measurement' measures physical parameters (e.g. temperature, humidity) in the environment and relates them to environmental assessment models (e.g. comfort models).
in order to assess the environmental quality. The second method 'Operational Monitoring' looks at the function and behaviour of the building and building service systems (e.g. ventilation and air conditioning units) in order to ensure the functional and efficient operation of the building and its technical systems. The third method measures the environmental quality as perceived by the occupants using 'Occupancy Surveys' and statistical analysis techniques.

3.0 MABEL – Mobile Architecture and Built Environment Laboratory

MABEL is a versatile and comprehensive in-situ testing facility for built environments. It is a diagnostic toolkit providing multi-dimensional testing of the key performance criteria of power, light, sound, thermal comfort and indoor air quality.

The purpose of MABEL monitoring is to:

• generate evidence to identify best practice technologies for environmentally sound building operation
• provide internal environment performance diagnostics for commercial, industrial and residential buildings
• establish performance levels of five important environmental criteria: power, light, sound and thermal comfort and indoor air quality
• establish a set of realistic standards that can be measured and met for ESD building performance
• provide data to a client or consultant that verifies compliance and/or contributes to building improvement
• provide data sets for building energy rating and simulation tool verification, and
• perform in-situ product evaluation.

The following steps are conducted in the MABEL project procedure for Building Performance Evaluation. The steps are outlined in the following sections:

1. establish objectives and deliverables
2. establish measurement design and schedule
3. determine instrumentation, location and positioning of measurement
4. collect data, perform measurement
5. construct database; analysis and organisation of the results
6. present and convey results, and
7. building performance verification; apply the results.

3.1 Establish Objectives and Deliverables

For future buildings performance, targets are set based on guidelines, standards and on previous experience. For existing buildings, problem areas are identified by analysis: for example, energy consumption records or occupants' complaints or perceived low performance in other areas. In a growing number of cases building owners, managers and tenants aim to upgrade functioning buildings and their indoor environments in order to achieve a better rating, higher rents or simply a more productive work environment than can be achieved under prevailing conditions.

If the testing of compliance with improvement objectives and performance targets is intended these objectives also define the necessary scope of a MABEL measurement study. Beyond this, MABEL is usually employed using the complete range of assessment areas (see Table 1), to uncover performance shortcomings and potential improvements by detailed environmental and operational diagnostic.

Power

Energy efficiency is a result of good design and optimal operation. MABEL determines energy use and CO₂ generation of equipment and assesses its energy efficiency. System defects are uncovered employing monitoring of operation characteristics and energy consumption figures, as well as other diagnostic techniques available in the MABEL measurement regime (e.g. flow rates measurement, air change assessment, etc). The building envelope is analysed based on building physical calculations and with in-situ measurements (e.g. thermal imaging camera).

Lighting

Good quality of lighting, natural and artificial, in our environment supports visual task performance and well-being of occupants. Visibility of work tasks and room experiences are influenced by lighting conditions. High luminance of surfaces, especially when surrounded by darker areas, can cause glare and thereby, disruptions and disability.

The MABEL measurement scheme includes luminance photographing (brightness) to assess light distribution and glare probability within the view field of occupants. Visibility is assessed with light meters at the work plane and at the computer screen. Further light grid measurements within an office area are taken to assess light distribution in daylight and artificially lit conditions (daylight autonomy assessment).

Based on MABEL results lighting equipment can be optimised and recommendations for effective retro-fit measures (e.g. sun blind, glare screens, light fittings, control schemes) can be developed.

Thermal Comfort

It is common knowledge that thermal comfort is not only dependant on the air temperature, but on a variety of other environmental parameters, such as humidity, air velocity, radiative and surface temperatures, as well as on the occupants' clothing and activity. Thermal comfort is a transient and situated perception.

MABEL uses comfort carts, which measure the parameters of thermal comfort at three levels (floor, seat and head) and comfort indices are calculated on this basis. Additionally radiative asymmetry for example at cold facades can be assessed. For identification of
heat bridges and the determination of heat loss through the building envelope, a thermal imaging camera is employed.

Thermal comfort results are used together with CO₂ and volatile organic compounds (VOC) levels to assess the effectiveness of ventilation building infiltration and are integrated with occupant surveys to assess work productivity.

**Indoor Air Quality/Ventilation**

Air quality has great impact on human well-being and performance. Although building occupants often adapt to low air quality and may not perceive the deterioration, high CO₂ concentrations lead to fatigue and loss of concentration. VOCs in high concentrations are believed to be the cause of more serious health conditions. MABEL measures CO₂ and VOC concentration in areas (e.g. at workstations) as part of the regular comfort assessment scheme. The ventilation rate and ventilation effectiveness are determined with specialised equipment employing tracer gas decay analysis techniques.

Besides general work environmental comfort evaluation (CO₂ and VOC), MABEL is used in buildings to understand the ventilation characteristics of naturally hybrid and mechanically ventilated buildings. Inefficient control schemes of ventilation systems are identified and recommendations for improvement are suggested.

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Table 1. Environmental Measurements and Assessment of the MABEL Facility
Sound

Evidence shows (Visher, 1996) that sound conditions, perceived as noise and disruption, have great impact on the occupants’ comfort perceptions. Noise, especially information rich noise (speech) is disruptive for cognitive tasks and communication. Speech privacy and intelligibility are further issues related to the sound environment.

The MABEL measurement scheme comprises noise measurement, reverberation time assessment and sound noise source identification, as well as the in-situ assessment of noise qualities of building parts (e.g. partitions).

MABEL is employed for the assessment of acoustic qualities of various office environments, conference rooms, as well as for the acoustic optimisation of church, concert and lecture hall facilities.

3.2 Establish Measurement Design and Schedule

The measurement design and the schedule when the measurement is taken depend on the problem and the building investigated. Two main measurement modes are offered. In the 'survey mode', which is mainly used for the evaluation of environmental conditions, detailed spot measurements are conducted at various selected locations in the building. The survey mode is designed to investigate comfort conditions in workspaces, therefore work disruption cannot be avoided and the measurement design and schedule is to be aligned to needs of the occupying organisation. In the 'operation mode', long-term measurement is employed to investigate the performance of building service systems.

3.3 Determine Instrumentation, Location and Positioning of Measurement

The locations as well as the types of measurement are determined and documented (see Figure 3). The positioning of instrumentation and the type is decided according to the project objective and the current situation in the building. The regular MABEL measurement scheme generates redundant information for the main comfort parameter, so that results can be tested and backup is available in case of failure and loss of data during the measurement.

3.4 Collect Data, Perform Measurement

The data in the 'survey mode' is collected in 15 minute intervals at each location at 10:00, 13:00 and 16:00. At the same time the weather conditions are measured with a weather station on-site. It is the objective of measurement to assess a situation close to the condition, when problems are perceived during normal operation. Therefore, measurements are performed during office and operation hours at the workstations of the occupants.

3.5 Construct Database, Analysis and Organisation of the Results

The various MABEL instruments generate a number of computer files in proprietary formats. These files are translated into text-files, readable with spreadsheet.
calculation programs and specialised analysis software. The data is processed with macros and specially implemented programs in order to calculate advanced comfort and other environmental indices and to depict the data in appropriate ways.

3.6 Presenting and Conveying Results

After measurement, the results are presented to the client and the project design is described in a project report. The measured values are evaluated and discussed briefly. The dissemination of results is discussed with the client. In case consent is given, results can be used for publication and research. Specific results are made anonymous before publication, if required. Figure 4 shows a thermal comfort chart, as example for result presentation.

The dimensions of the entire Building Performance Evaluation scheme are depicted in Figure 5. Such holistic evaluation method, as shown is the figure, is currently still under development, as the scientific background for the scaling of the individual dimensions is not available at this stage.
3.7 Building Performance Verification Applying the Results

In some projects the application of MABEL results extend beyond the described reporting. For example measured values of outdoor conditions and ventilation rates have been used as input for simulation studies to the simulation model (AccuRate) and validated using the measured indoor conditions. The validated model was then used for extensive investigation and parameter studies to assess design options for the investigated building.

4.0 Conclusion

This paper outlines the application of building performance evaluation for compliance testing, commissioning, strategic and operational facility management and continuous improvement in the built environment. It reasons the need for on-site measurement and discusses shortcomings in current practice in this regard. It relates environmental performance evaluation to application of standards, guidelines and rating tools.

The Operation-Comfort-Behaviour framework of building evaluation is introduced and the role of the Mobile Architecture and Built Environment Laboratory (MABEL) is explained. MABEL is a facility for performing built environment diagnostics within this framework.

In the second part of this paper, MABEL’s project procedures are explained briefly and the current measurement matrix is given in order to demonstrate the range of environmental measurement areas, which can be assessed with the MABEL facility.

In summary, our environmental design processes require feedback loops and the dissemination of evidence-based performance knowledge. Such are well placed and supported in public forums supported by our governments. Rating systems and briefs require an understanding of the technology of measurement and its deliverables before ‘mandating’ results and setting the targets. A measurement protocol is required as a follow-up of rating evaluations focusing on operational building performance. Many performance variables within our environments are transient and require measurement in the built environment.

The Mobile Architecture and Built Environment Laboratory (MABEL) measures environmental and operational parameters across the various sectors of built environment investigation (power, sound, light, thermal comfort and indoor air quality). Evaluation of these parameters produces insight to the cause and effects of our indoor environment and thereby gives rise to best-practice and continuous improvement in our buildings.

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Biography

Dr Mark B Luther is a senior lecturer in the School of Architecture and Building at Deakin University.

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