WORKPLACE PERFORMANCE MONITORING: ANALYSING THE COMBINATION OF PHYSIOLOGICAL AND ENVIRONMENTAL SENSORY INPUTS

D Wilson
B Haglund

Arup, UK.
University of Idaho, USA.

ABSTRACT

The intent of this study was to investigate the combination of body physiological monitoring and the monitoring of the physical workplace as well as measuring worker / workplace performance through a questionnaire and activity log. We believed that these three data streams can be analyzed to reveal a strong correlation among them. The introduction of body physiological monitoring represents a new initiative in our quest for understanding the complex man-environment relationship.

CONTEXT

For a number of years Arup have been examining how buildings have worked post occupancy and feeding those findings back into the loop to re-fine our designs. In the early years this was either collaborative work with research organisations or external commissions for energy surveys or investigations into internal environment problems. Latterly we have increased the resources for this work and invested our own money to expand our activities in this field to understand better how buildings perform once occupied.

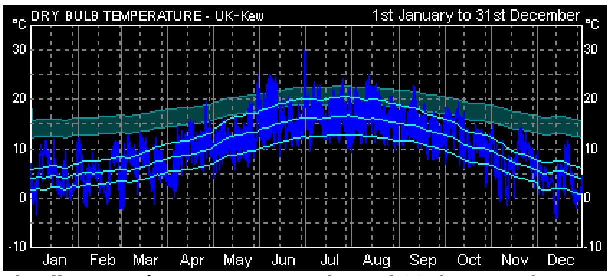
Building Performance

The primary environmental conditions that affect occupant comfort (temperature and relative humidity) in a workplace can easily be measured over time with small microprocessor-based data loggers [Vital Signs (1)]. Other performance indicators such as air movement, radiant temperature, and air quality are more elusive, but can be spot checked with handheld instruments such as hot wire anemometers and infra red thermometers.

Comfort

Current research suggests that determination of comfort is more complex than the previous comfort model which suggested a consistent comfort zone that ranged from about 20°C to 25°C [Oseland (2), Humphreys and Nicol (3)]. This new definition of thermal comfort suggests that the comfort zone changes seasonally, dependent on the average outdoor temperature — people are comfortable in warmer places in summer than in winter. Moreover, this research has shown building occupants are more tolerant of thermal conditions in buildings where they expect natural ventilation and passive solar heating to condition the space and where they have control over thermal conditions via devices such as operable windows, blinds, and electric lights.

Each person adapts to indoor conditions differently; in fact no more than 80% are expected to be totally comfortable in any single environment. In order to determine whether or not individuals are comfortable in a workplace environment you must ask them. Arup have used questionnaires developed by Building Use Studies (BUS) Ltd. to assess levels of occupant comfort as well as the extenuating circumstances that may affect their vote.



This illustration from Square 1's WeatherTool (4) shareware shows how the comfort zone temperature range (green band) adjusts seasonally for a free-running building.

Hypothesis

In this study we aim to measure the value of remote body monitoring tools that can collect physiological data in a research subject's free living environment. The following hypothesis has guided this research:

We can obtain quantitative data that describes occupant experience of the workplace and which correlates to that monitored by the building and predicts data gathered from questionnaires.

METHOD

This section introduces the wearable computer used in the project, tools for monitoring the workplace and the experiment conducted.

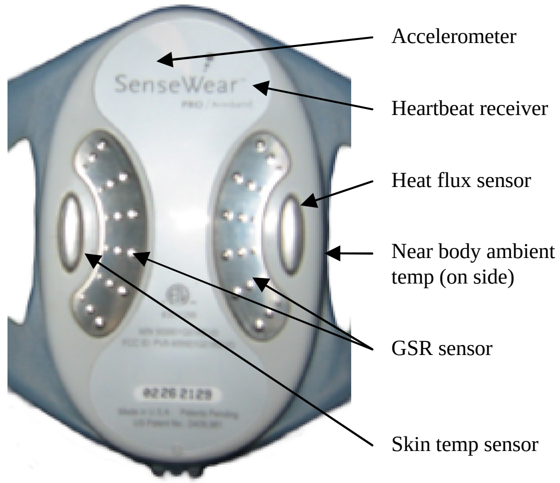
Wearable Sensors

BodyMedia SenseWear Armbands were used to obtain physiological data for three test subjects.


BodyMedia SenseWear™ Armband in cradle.

The SenseWear Armband utilizes a heat flux sensor, 2-axis accelerometer, galvanic skin response sensor (GSR), skin temperature sensor, and a near-body ambient temperature sensor to capture data. The SenseWear Armband also offers the option of heart rate detection through the use of a Polar Chest Strap.

The following is a brief description of each sensor and its function in the device. More detailed specifications can be found on the BodyMedia (5) website.



BodyMedia SenseWear™ Armband Sensors

The accelerometer in the SenseWear Armband is a 2-axis micro-electro-mechanical sensor (MEMS) device that measures motion. The motion can be mapped to forces exerted on the body and hence energy expenditure. By taking into account gravity, the algorithms implemented by BodyMedia can also predict the context in which the armband is being worn. We use this to establish a context of 'movement' within the workplace.

The heat flux sensor in the armband measures the amount of heat being dissipated by the body. The sensor uses very low thermally resistant materials and extremely sensitive thermocouple arrays. It is placed in a thermally conductive path between the skin and the side of the armband exposed to the environment. A high gain internal amplifier is used to bring the signal to a level that can be sampled by the microprocessor located in the SenseWear Armband.

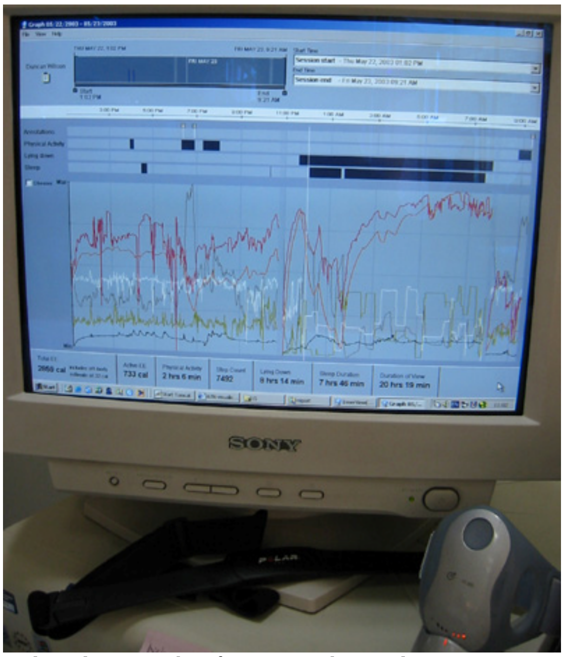
Skin temperature is measured using a thermistor-based sensor located on the backside of the armband near its edges and in contact with the skin.

The near-body ambient temperature sensor measures the air temperature immediately around the wearer's armband. This sensor also uses a thermistor-based sensor and directly reflects the change in environmental conditions around the armband; for example, walking out of an air-conditioned building on a hot day.

Galvanic skin response (GSR) represents electrical conductivity between two points on the wearer's arm. The SenseWear Armband GSR sensor includes two hypoallergenic stainless steel electrodes integrated into the underside of the armband connected to a circuit that measures the skin's conductivity between these two electrodes. Skin conductivity is affected by the sweat from physical activity and by emotional stimuli. GSR can be used as an indicator of evaporative heat loss by identifying the onset, peak, and recovery of maximal sweat rates.

The SenseWear Armband houses a custom receiver board to receive the pulses transmitted by a heart beat detection chest strap.

The SenseWear Armband is configured, re-charged and provides access to data through a desktop interface. Configuration requires the input of basic subject parameters such as name, weight, height and the set-up of test parameters such as data collection rate, data inputs required etc. A charged unit can typically (i.e. using factory defaults) record for 2-3 days continuous use. The battery unit could provide power for up to 2 weeks if required.



BodyMedia Research Software - graphing tool

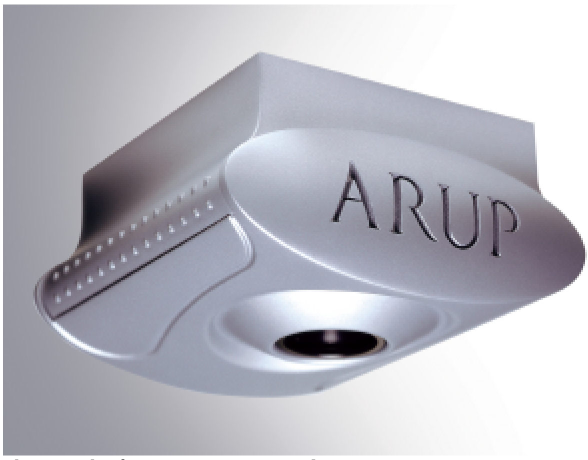
The desktop interface also provides tools for data analysis and export. The research software provides a visual environment for graphing real and derived data as per the examples shown in the results. The software also provides a channel for exporting the raw / part processed data in CSV format. An earlier version of the software also provided output in XML.

Workplace Performance Monitoring

HOBO (6) and Testo (7) data loggers were employed to measure environmental data [temperature, lighting, relative humidity]. HOBOs were also used to sense the operating conditions (e.g. on/off/standby) of equipment (computers, lights, heating systems, operable blinds and windows). The data loggers were set to record conditions at one minute intervals to match the sensing intervals of the BodyMedia Armbands.

Hobo RH/Temp/Light/Ext and Testo H-1 dataloggers.

A prototype people counting device [Irisys (8)] was used in the experiment to monitor the number of people within the area of the workplace being monitored. The people counter is a 16x16 pixel array based infrared sensor. The proprietary software has a collection of algorithms which permit measurement of velocity, location, size and number of ‘objects’ in a scene. The device was set-up to monitor staff entering the work area (crossing a virtual line) and was used to give an indication of the number of non participants in the workplace while the experiment was being conducted.



Photograph of Irisys prototype people counter

Experiment Design

The initial experiment was conducted in a top floor office space that is day lit and naturally ventilated. Three individuals in the space were selected to wear the BodyMedia Armbands and to log environmental conditions, their job functions, and their reactions [well-day lit, no electric lights on, too hot, opened window, worked at computer, left for lunch, and such] to the environmental conditions in the office. They were also asked to fill in a post occupancy questionnaire to rate their overall impression of the workplace.

The daylighted and naturally ventilated office.

Data loggers were placed at the north and south-facing windows and on the three subjects' desks to sense indoor and outdoor temperature and relative humidity as well as computer on/off/standby; task lamp operation; and sunlight penetration.

RESULTS

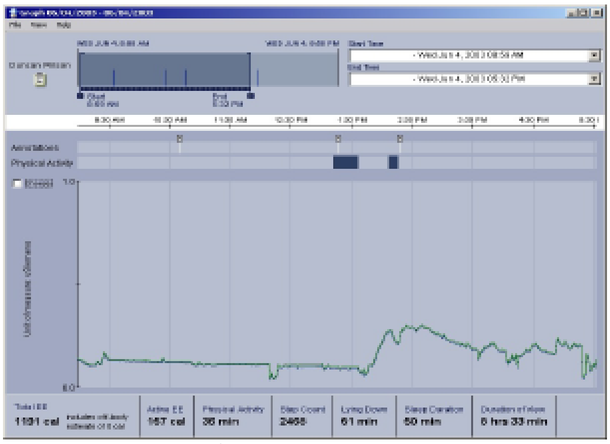
Physiological Data

The BodyMedia Armbands were set to record at one minute intervals the following data:

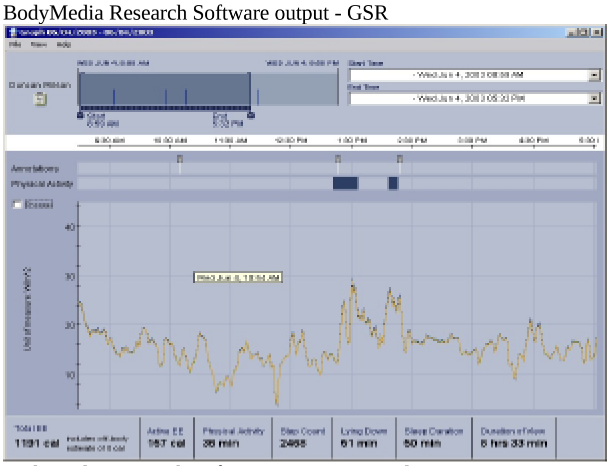
1. GSR (high, low and average)
2. Heat Flux (high, low and average)
3. Longitudinal / Transverse acceleration
4. Near body / Skin temperature
5. Energy expenditure (derived)
6. Step counter (derived)

The image below shows a typical output over a normal working day (9am – 5.30pm) and the graphs which follow show each of the key outputs monitored:

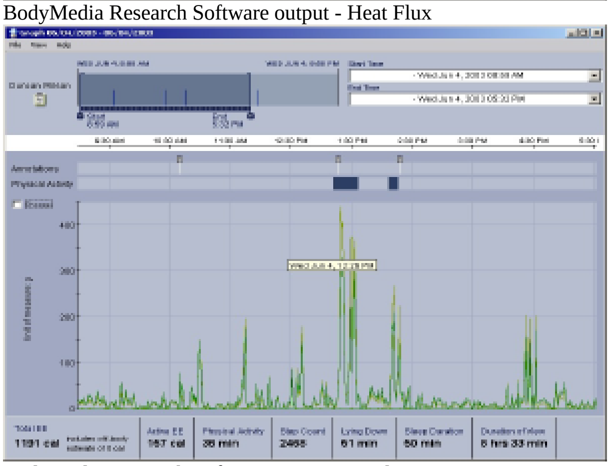
BodyMedia Research Software - graphing tool with menu showing



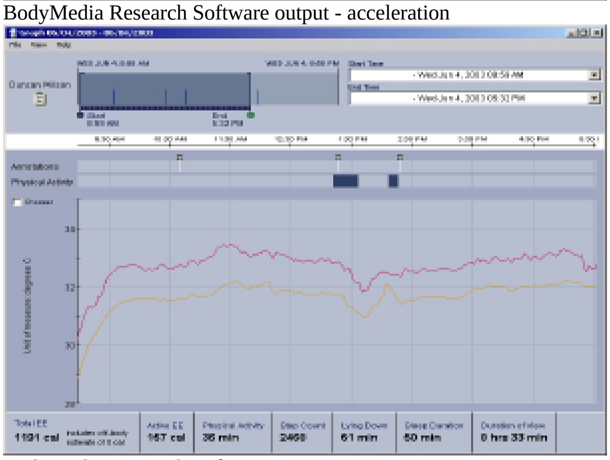
BodyMedia Research Software output - GSR



BodyMedia Research Software output - Heat Flux



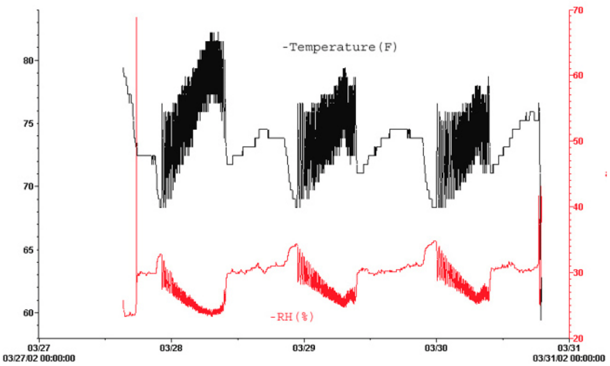
BodyMedia Research Software output - acceleration



BodyMedia Research Software output - temperature

Room Data

Three daily cycles were measured to obtain a contextual view of the environmental dynamics of the office. Outdoor and indoor conditions were measured to determine adaptive comfort conditions and sun penetration and cloud cover.

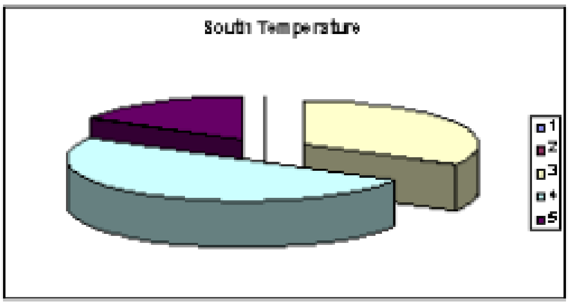


This Hobo plot shows air temperature and relative humidity near a heated air supply register during a three-day interval.

The data loggers also used temperature and light readings as a surrogate for operational status of computers, lamps, and window blinds.

Post Occupancy Questionnaire

The responses to the questions in the questionnaire can be plotted as pie charts to gain a better understanding of their significance. It's important to develop correlations between the measured and perceived conditions in the office.



Temperature sensation in a south-facing office space. The five-point scale ranges from hot (1) to neutral (3) to cold (5). Although temperatures were within the comfort zone most occupants rated it as a bit cold or too cold.

DISCUSSION

Qualitative vs. Quantitative

It is our belief that the BodyMedia Armband data allows us to compare the qualitative data that describes the thermal conditions and the qualitative data gleaned from logs and questionnaires. Fluctuations in skin temperature and near skin temperature should predict the subjects' perception of their environmental conditions. There is a tendency that subjects will act to change conditions only under strong environmental pressure, while the BodyMedia Armband records more subtle changes. A good correlation between the building environmental stress recorded by the armbands and action to open or close windows, or remove or put on clothing can be made. These can be compared to interior and exterior temperature and humidity readings to check for conformation to adaptive comfort theory.

Issues for a Field Engineer

The software behind the analysis of armband data has been influenced by 'sleep researchers' and as such the patterns of activity that the device derives include a 'sleeping state'. During the experiment several false positives were recorded where subjects appeared to be sleeping at their desks. In reality this misclassification was perhaps made when people were spending prolonged periods of time 'concentrating' in front of their desktops.

The data output from all devices was combined with relative ease since all where functioning at 1 minute intervals. The only issue surrounding the data was the large volume collected over the three day period (over 4000 time intervals for 40+ channels is over 160,000 multivariate data points). The use of data visualisation and data mining tools were explored however the majority of the analysis for this project was conducted using the BodyMedia Research Software and Excel.

Wearability

The SenseWear Armband has been designed to be wearable [Kasabach (9)]. The co-development by industrial designers, engineers and medical staff have ensured that the product has both form and function. The device is worn on the back of the arm.

SenseWear^{TM} Armband on arm (courtesy of BodyMedia).

The SenseWear armband proved to be a device that was:

- Comfortable and discreet to wear
- Easy to configure
- Simple to use

From a researchers perspective the wearable was successful because:

- Participants were happy to wear it for prolonged periods of time.
- The device accurately recorded the data required.
- Did not intrude on the subject's normal work practice.

The only equipment issue that arose during the trial was the lack of reliability in the use of the heart beat strap. Whilst conduction was maintained during high levels of physical activity (running, in the gym etc.) the heart strap tended to 'dry out' and lost its ability to record heart beat in a more sedentary work environment.

CONCLUSIONS

Correlation between the quantitative and qualitative data acquired during the experiment shows that the BodyMedia Armband was successful in recording levels of comfort in a workplace environment. In addition the device itself proved to be a successful wearable computer in that it collected the required data successfully and reliably and it was received without complaint by those asked to use it.

Further testing on recent Arup projects will be carried out under an umbrella project at Arup on Workplace Productivity. The results of these tests will focus on establishing the viability of using the BodyMedia Armbands as part of the post occupancy analysis toolkit.

A secondary area of further work will involve exploring the use of data mining and visualisation techniques to process the large volumes of data being collected. The aim of using such techniques will be to explore and identify further relationship between inputs.

REFERENCES

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