- **Intelligent Buildings Group**
  - ⇒ Vic, Graham & Sue (plus Libor, Huosheng, Martin ?)
  - ⇒ cswww.essex.ac.uk/intelligent-buildings

- **From Robots to Buildings !**
  - ⇒ *“A building is a machine we live inside”* !

• What is Intelligent Building ?

⇒ One that autonomously ***governs*** the building environment so as to optimise user ***comfort***, ***energy-consumption, safety*** & ***monitoring-functions*** (eg system maintenance or supervision in care homes)

⇒ Works by taking inputs from building sensors (light, temp, occupancy etc), using information to control effectors (heaters, lights, windows etc)

• IB Generations

1st. numerous independent *self-regulating* (automatic) sub-systems

2nd. as 1st but connected via specialised *network* (eg BACnet, ESHA Lonworks, CEbus, X10) and various physical media for remote/centralised control (simple sequencing)

3rd. as 2nd but *self-governing* (autonomous) systems ie learn, make their own rules (and perhaps collaborate) etc

- **Characteristics of IB system**
  - ⇒ situated in real-world (senses & acts directly on physical world)
  - ⇒ in dynamic, unpredictable, complex world (eg involves people and natural phenomena – difficult, if not impossible, to model)
  - ⇒ uses inaccurate, imprecise sensors & imperfect control
  - ⇒ ideally, requires small, cheap hardware (comparable to building devices)
  - ⇒ ideally, should be reliable, extensible & interconnected

Observation: All similar to requirements of mobile robot.

Question: Could we use mobile robot control techniques?

- Sue's starting point was to determine:

⇒ if a behaviour-based system (ie goal driven reactive operation) is capable of controlling an intelligent building.

⇒ whether there exisits a set of basic behaviours that equate to IB needs.

⇒ the form that an embedded IB adaptive agent could take.

⇒ the form that a macro-architecture (multi-agent) could take.

• System Requirements

⇒ Sue's interests in bringing benefits of technology to disadvantaged groups.

⇒ Chose to apply her work to care for older people and those with disabilities

Got specifications from:

⇒ Balkerne Gardens Trust (residential home for older people)

⇒ UK Alms House Association (sheltered housing)

⇒ Hamilton Lodge (long term residential home for those with sever disabilities)

⇒ NHS Estates (hospital provision – currently in discussions with them)

Specifications not presented here (as this is a large document produced by Sue!).

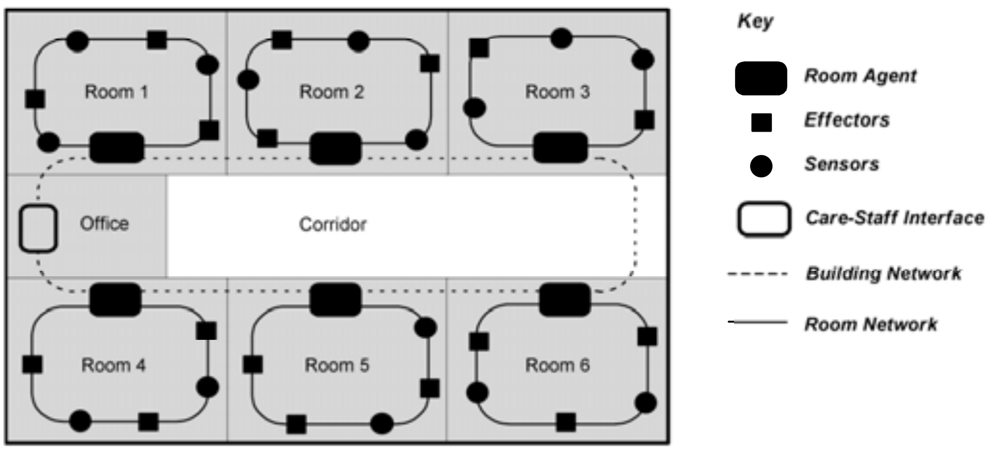
• Proposed Solution

⇒ **Model** - based on view that that physical and logical unit of an intelligent building is a single room (the justification being that that rooms are basic building blocks of larger buildings and communities)

⇒ **Building Level** – Use MAS with each room containing an agent; the *room agent* (a small embedded processor)

⇒ **Room Level** – room agent based on combination of a *behaviour* and *instance* based architecture (the latter to provide a learning capability)

• Building Level



• What is in the Rooms ?

Sensors	Controllers
temperature	heating
light	lighting
pressure pad	alarm
appliance	appliance
window	window
smoke	door
movement	
person ID	
call alarm	

There would be other global sensors (time, external light level, other agents etc)

Room Agent

Behaviour approach chosen because:

⇒ good bet as works well with similar situated agent (eg mobile robots) and was challenge of the Ph.D

⇒ minimal embedded architecture (ie no planner, expert reasoning etc)

⇒ guaranteed set of base behaviours (ie safe)

⇒ adaptive (ie interplay between behaviours allows differing solution in changed world)

Instance approach considered because:

⇒ compatible with behaviour architecture

⇒ potentially small enough for embedding

⇒ on-line user driven learning (real-time)

• The Behaviours

"*a law for attainment or maintenance of goals*"

Two types:

Fixed – do not change or adapt over time (the standard approach in behaviour systems)

Dynamic – the agent learns by forming new instances of behaviors based on monitoring actions of user (very much the subject to ongoing research and experimentation).

- **Fixed Behaviours** (all systems have these – experiments show this works well)

⇒ **Economy Behaviour** – responsible for conserving energy where possible.

⇒ **Manual Behaviour**– maps the occupant’s explicit commands directly onto devices in the building (ie allowing the building to be at least as competent as one without the agent).

⇒ **Emergency Behaviour** – specifies what must happen in an emergency.

⇒ **Safety Behaviour** – prevent controlled quantity going outside some limit.

- **Dynamic Behaviours** (provide the learnt actions – focus of current work)

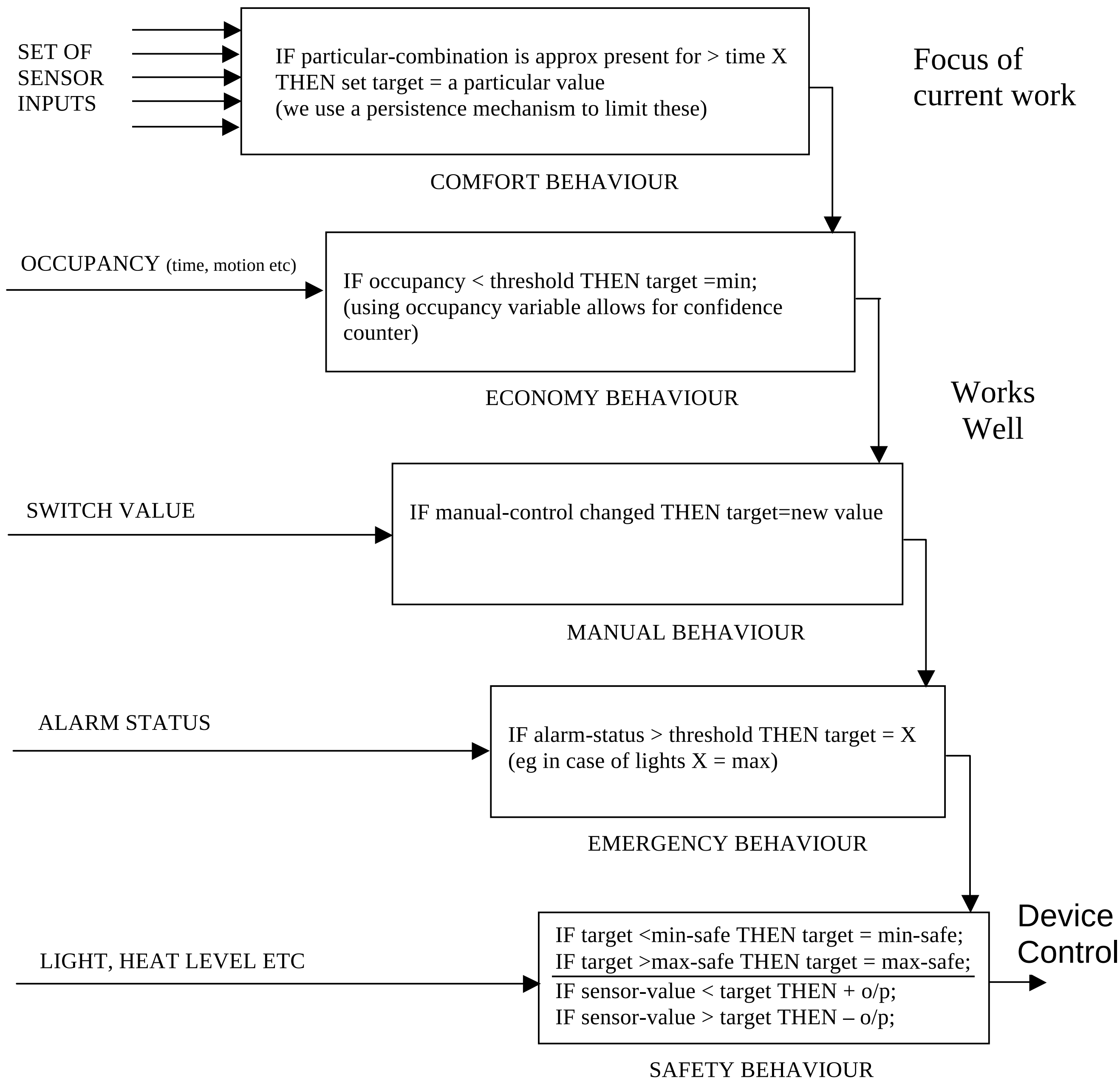
⇒ snap-shot of sensor values when user adjusts control used to form an instance in the form of *if-then-rule* (new instance only created if input vector beyond some distance from nearest neighbour)

⇒ new instance only activated after persistent use (ie only if the number of examples in a period X exceeds some threshold Y – done by incrementing counter).

⇒ dormant behaviour removal (ie remove if its use falls below threshold Y in period X - done by inc/decrementing a "life" counter)

• Agent Architecture

Illustrative view of room agent (A working "Toy" model was demonstrated in September 98).



• Current Work

⇒ Scaling up instance architecture

⇒ Refining mechanisms for identifying, filtering and merging similar behaviours.

⇒ Refining ways of limiting pool of instances (eg rate of reinforcement)

⇒ Investigating ways might combine information from agents and sensors when subject to uncertainty (eg temporal confidence counters).

⇒ Considering how to structure multiple embedded agents and the information they need to pass (the original proposal, Sue's M.Sc, called for a hierarchy of agents, however, we are going to revisit this).

⇒ Building a better IB model

Notes on Comments & Thoughts

1. Need to add temporal considerations to future work (it is currently included but implicitly rather than part of any explicit explanation).

2. The new-diagram integrating the fuzzy rules with the architecture needs to show that there are N-similar units tagged on sideways to this (forming the other devices controllers …. and attaching to some of the same sensors). Also, sometime, Vic & Sue need to discuss this as it almost certainly is not the way Sue implemented it in software !

3. The fixed behavious having a fixed priority structure (as in the new dia) went down well for arguments on safety and absolute guarantees of system behaviour.

4. 4. The dynamic behaviour part of the architecture didn't declare how we were going to manage instance priorities (ie not necessarily a hierarchical mechanism as in the fixed behaviours). We need to consider the merits of an alternative mechanism in the dynamic section (maybe based on Sue's ideas for using a TDM (time domain mux) arbitration.

5. The theorists seemed to argue for generalisations and coming from the spec up. We should remember that merging dynamic behaviours is in effect a form of generalisation mechanism. Also, we should remember the arguments deployed by Graham that we are actually trying to do the opposite of generalisation (particularisation!!!) by deliberately creating a system that can adapt to the idiosyncrasies of individuals

6. There may be legislation on what one can do to safety systems (eg fire) in terms of connecting in parallel to sensors. Perhaps we should call this by another name as it is not safety in the sense that which "building safety" managers responsibilities are defined. There was a question on reliability of the system due to sensor failure. It was suggested we should consider multi-sensors.

7. We might add to our future work list maybe confidence counters for both "pseudo reasoning" together with masking out duff system/sensors (Sue has already suggested this …. and we did mention it in seminar).

8. Need to consider , if quantization, best way of reducing instance sets (or whether need to look at algorithms, eg K-Nearest neighbour, in PS ref). Should stick to simplest approach as we are trying to fit into embedded systems.

9. Maybe need to consider adding some prior knowledge to rule formation (eg if for dynamic heating instance then …. Start heating 30mins before time instance created ?)

10. Need a software front-end tool to extract knowledge from the building manager to set up **fixed** behaviours to embody rules/regulations (eg this door must be kept shut between these times …. or tailor behaviour to specific people).

11. For dealing with temporal aspects need to investigate the use of sequences (eg when the last three events occurred in this sequence the user did the next action). How do we do this to remove absolute time dependence (state machines?), How long do sequences need to be (2, 3 more ? … variable …. Another example of parameters that need to be experimented with, assessed, optimised).

12. activity profile or 'normal day' in which deviation from the normal can signal a problem (ie detecting or monitoring changes in patterns of behaviour on the cycle time of a day - part of the temporal processing, or processing of sequences ?).

13. Pick a few examples of notable Ibs, for eg: European bank for Reconstruction & Development, Broadgate, London; Plaza Towers, Illinois; Deaconess Hospital, St Louis.

14. Traditional groups such as Reading are only peripherally concerned with adding anything like artificial intelligence capabilities to building systems and much more concerned with the ability of the building to respond to changes in use etc. We are clearly faced with a more established paradigm of intelligent building that that is considerably different. It is worth making these differences very obvious since this will establish that we are involved in a completely different enterprise to that currently being pursued by them. Of course they might begin to take an interest in our approach once they hear about it but their definitions of intelligent buildings should be contrasted with our own (if we have one!?).

15. Multi-user … rule migration ?

16. Knowledge diffusion - something like the following: if rule X was fired when input vector Y was encountered for person P then maybe the X/Y relation would hold for person N. Or alternatively: If rule X was useful in situation Y it might be useful in situation Z where the only differences are the person? Read Karl Popper's 'Objective Knowledge' for a well founded philosophical viewpoint that develops the view that there is objective knowledge and it can be found in books and other things. Popper calls it world 3.

17. Sensor space navigation model - multi-dimensional "parameter space" (eg energy) that IB agents "navigate (move) through", thereby linking behaviour based robotics to IB systems. As in mobile robots the space needs to be bounded so the robot can learns the regularities associated with that bounded world. In our "parallel world" (yes, here it is again!), our IB space would be bounded to. The time axis would be bounded at a year (as this seems to be the min unit that contains cyclic symmetry ... ie yearly patterns in weather) and the other axis' would be bounded by practical limits. Thus, we have a bounded space that our IB agents can navigate and learn within. I really think this is a potentially powerful concept (and worth a paper in itself).