ENERGY-EFFICIENT PROCESSING - PLANT ORGANISATION AND LOGISTICS

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ABSTRACT

Baseload energy use (energy consumed in starting up and maintaining an abattoir ready for production, but not that used directly in production) is a sufficiently large proportion of total abattoir energy use for it to justify a similar level of study to energy-efficient processing equipment. Factors leading to high baseload energy use include initial utility equipment selection, old age of buildings, alterations or additions to initially-compact and/or multi-storey buildings and use of relatively heavy building materials (bricks and mortar, concrete) compared to lighter materials now readily available. Plant capacity in itself may have only a small effect. Design concepts that will lead to low baseload energy use in abattoirs, and to longevity of plant energy efficiency in the face of process technology change are presented.

INTRODUCTION

Fifty years ago, in his well-known book on energy conservation, Lyle (1947) used as an example an English brewery taking in ingredients and water at ambient temperature, and producing beer also at ambient temperature. He stated that considerations based on the first law of thermodynamics suggested a zero net energy demand, and hence if the brewery could operate with anything like reasonable energy efficiency the energy demand would in fact be quite small. The reality was quite different. At that time he was unable to precisely define what a reasonable extent of energy recovery and reuse would be, and it took sometime until the advent of pinch analysis (since broadened to process integration), and exergy analysis before the question of efficiency of energy reuse could be systematically and realistically investigated.

A different way of considering the same problem can be found in the well-known Sanke diagram (Figure 1). This shows an arrow in the direction of energy flow, starting with the feed of energy across a site boundary fence, and ending with arrowheads showing the relative quantities that end up in different places. Whilst conceptually an interesting diagram the reality is that engineers must conceptualise the diagram in reverse - if there was no process need (i.e. no factory) then there would be no energy demand by the green fields site. The philosophy that is now recognised as correct is that the process must drive the energy supply and distribution system.

Irrespective of whether one takes the approach of Lyle and calculates the fraction of total energy that ends up in the product, or one uses a Sanke diagram, one inescapable fact is that processing accounts for only a part of energy use. There are always significant overhead costs, and as Figure 2 illustrates, much of this is in a so-called baseload component, which is the energy that would be used if the plant was held perpetually in a state ready for processing but no product was put through.

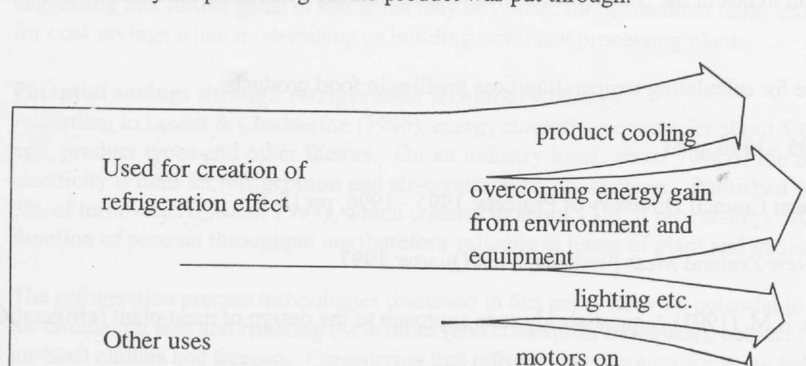

Fig. 1: Example Sanke Diagram for electricity use in an abattoir

Surveys of N.Z. meat processing plants have been carried out regularly over the last 25 years. Reporting the results of the 1989/90 survey Fleming and Kemp (1992) presented graphs showing estimates of total, baseload, and direct energy use. Interpreting their results, over 13 works the baseload contributed between 20% and 60% (mean = 40%) of the fuel use, and over 22 works baseload was responsible for between 30% and 65% (mean = 50%) of the electricity use. Other surveys since (Lovatt & Kemp 1995, Lovatt & Chadderton 1996) did not delineate the baseload and direct use components. In Australia, a survey by Graham (1979) did not present baseload and direct use data, but did group plants according to whether they had coldstores or not, thus recognising that on-site coldstores were a significant baseload factor.

Further examples of the importance of baseload are available from the work experience of the author. In a survey of refrigeration systems at two plants with similar frozen lamb throughputs it took only a few minutes of relatively simple engineering calculations to show, in the manner of Lyle, that the mean product heat load arising from the difference between live animals entering at about 40°C and meat exiting at either -15°C or 0.5°C was about 1.2 MW but the operating refrigeration capacities were 2.4 MW and about 5 MW. Thus, one plant created 2 kW refrigeration/kW of product heat load, and the other about 4 kW/kW. The immediate suspicion was that there was a major difference in types of freezing and chilling equipment used, but this was not the case in this instance, and in my experience is rarely so. The major difference is in baseload energy use (defined in the manner of Figure 2).

The treatise for this paper is that organisation and logistics of energy supply and distribution systems for meat processing plants (which are baseload-related) require as much study as does energy-efficient processing equipment. In seeking to develop the argument and analyse the causes of high baseload one quickly runs off the end of published literature to provide supporting evidence. To my knowledge, work that has been carried out tends to be in-house to companies, and has not often been at an academic level valued by research institutions. Thus, this paper will present ideas and concepts that are not well-tested scientifically. It will also draw heavily from the Australian and New Zealand experience of the author in attempting to identify causes of excessive baseload. If the reader can identify similar characteristics in plants in their own country then the presentation here, based on South Pacific experience, will almost certainly be applicable to them.

BASELOAD ANALYSIS

Surveys to estimate baseload energy use are fraught with potential pitfalls. The concept, shown in Figure 2, of plotting daily or perhaps weekly data vs production is simple, and will generally produce plausible straight lines provided product throughput varies through the survey period. However, the method can falsely attribute items to baseload. For example, typical New Zealand continuous carton freezing tunnels have their fans running 24 hours per day, irrespective of the product throughput, whereas in a batch carton freezer the fans run only when there is a batch of product present. The number of batch freezers in operation is then changed according to production level. In the case of the continuous freezer much of its energy use will appear as baseload, whereas in the batch freezer it will more likely appear as direct use. Comparisons of baseload between plants cannot be done simply.

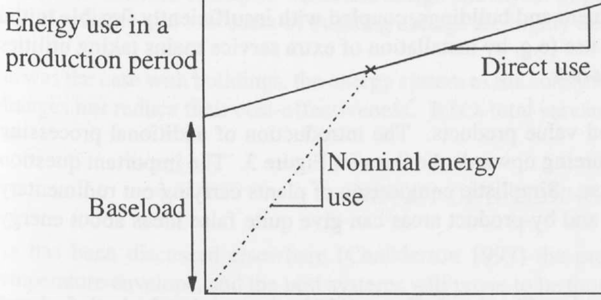

Fig. 2: Baseload, nominal and direct use components of energy use

Figure 3 shows four possible concept diagrams for energy use vs product throughput graphs. Figure 3(a) shows the impact of decisions made at time of initial capital investment, Figure 3(b) shows the likely impact of adoption of a philosophy favouring automation, Figure 3(c) shows the likely effect of plant age, and Figure 3(d) shows the likely impact of plant add-ons. In this context the word "add-on" must be carefully interpreted. There are additions to plants to introduce process equipment for the manufacture of new products, and there are additions to plants solely to accommodate changes in technology required to continue making the present product range. It is the effect of the latter that is illustrated in Figure 3(d).

Figures 3(a) and (b) closely correlate - a high investment policy usually means automation to save labour costs - at the expense of only minor increases in energy use due to the automation equipment (Lovatt & Chadderton 1996), but in cost terms there are savings. Labour-saving automation in itself is unlikely to save energy unless it is accompanied by improvement of process control systems. Although not shown diagrammatically, plant size also correlates with automation - larger plants tend to be more automated. This is evident in the data of Fleming & Kemp (1992) which show that direct use energy (J/kg of product) drops with increasing plant size (increasing degree of automation).

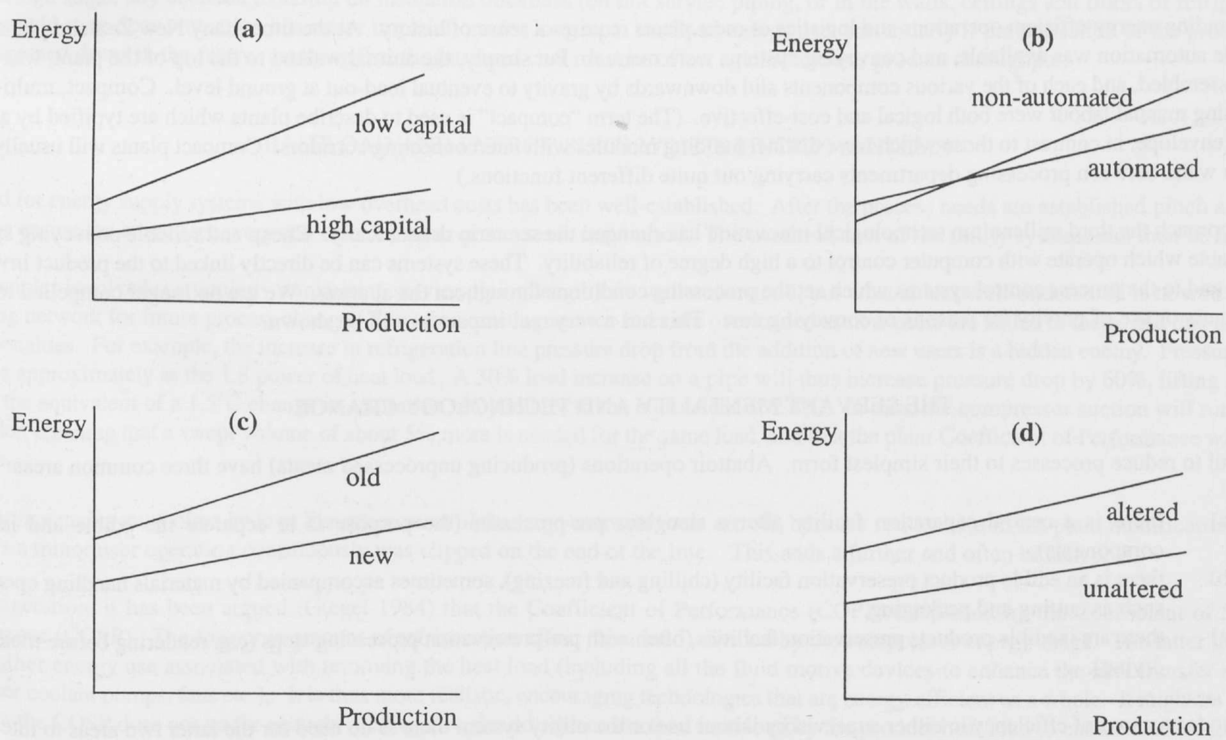

Fig 3: Effect of plant parameters on energy usage patterns. (a) level of initial capital investment, (b) level of automation, (c) plant age, and (d) extent of building alterations and process technology change for making existing products.

Plant age can have two effects - firstly the ageing effect in itself - insulation tends to deteriorate so the energy required to keep hot utility lin hot, and the energy required to keep refrigerated rooms cold will gradually increase with time. The second effect of age is that the original pla design and processing technology will steadily date, and hence changes will be made to introduce new technologies which appear cost-effectiv Alternatively, changes may be forced by the never ending web of regulations that control abattoir operations, and such changes may occur lon before equipment systems reach the end of their useful life. In both circumstances, more space is usually required, and this cannot be foun without adding-on to the building envelope. Changes to the processing equipment and buildings, coupled with insufficiently flexible initi design of the utilities systems lead to add-ons which increase baseload energy use (e.g. by installation of extra service mains taking utiliti to plant additions). Thus, the concepts illustrated by Figures 3(c) and 3(d) interact.

As mentioned earlier, add-ons also arise when companies seek to make added value products. The introduction of additional processin departments will usually add to both baseload and direct use energy demands, forcing upwards the lines on Figure 3. The important questio in such circumstances is whether the extra product value justifies the energy use. Simplistic comparison of plants carrying out rudimenta abattoir operations, and those making added value products in both the meat and by-product areas can give quite false ideas about energ efficiency.

Lovatt & Chadderton (1996) were able to detect an age effect in their survey results. Fleming & Kemp (1992) showed that for both fuel an electricity, baseload increased with plant capacity at beyond a pro-rata rate, thus indicating that the larger plants in their survey were relativel poor performers in baseload terms. However, the large plants were generally the older plants, and the effect observed may have been part due to ageing.

Another factor which may be influential in explaining the trends in the data of Fleming and Kemp is the plant loading factor. Many plants, an particularly some of the large ones, were operating below capacity at the time of the surveys, and this reduced direct use without an equivale drop in baseload. Major advantages are often claimed for plants using multi-shift slaughtering, but these are also usually the plants operatin closest to capacity, and they also tend to be the smallest.

Electrical baseload can be lower if cold storage is hired off-site, but this merely shifts some of the electricity use to a different company an does not change efficiency. Similarly, small plants which have no by-products processing facilities can appear to have low baseload, and indee can often totally avoid the baseload costs of operating a steam boiler. This baseload may be borne by their rendering service provider, witho the advantage of being able to use recovered heat from rendering for meeting hot water demands.

It is the view of the author that these sorts of factors are often insufficiently considered when survey results are discussed, and as a result th small new plant can be wrongly seen as a panacea for all previous problems. Wrongly designed, the small plant has equal potential to its large counterpart for excessive and ever increasing baseload energy use.

PRODUCT MOVEMENT

Understanding energy-efficient operations and logistics of meat plants requires a sense of history. At the time many New Zealand plants we built little automation was available, and conveying systems were manual. Put simply, the animal walked to the top of the plant, was kille and disassembled, and each of the various components slid downwards by gravity to eventual load-out at ground level. Compact, multi-store plants using manual labour were both logical and cost-effective. (The term "compact" is used to describe plants which are typified by a singl building envelope, in contrast to those which have distinct building modules with interconnecting corridors. Compact plants will usually hav common walls between processing departments carrying out quite different functions.)

As we approach the third millennium technological innovation has changed the scenario dramatically. Cheap and reliable conveying system are available which operate with computer control to a high degree of reliability. These systems can be directly linked to the product invento systems, and to the process control systems which set the processing conditions throughout the abattoir. We are no longer compelled toward compactness or use of gravity for reasons of conveying cost. This has a very real impact as will be shown.

THE SERVANT MENTALITY AND TECHNOLOGY CHANGE

It is useful to reduce processes to their simplest form. Abattoir operations (producing unprocessed meats) have three common areas:

(a) there is a central separation facility after a slaughter pre-processor (the purpose is to separate the edible and inedibl components),

(b) there is an edible product preservation facility (chilling and freezing), sometimes accompanied by materials handling operatio such as cutting and packaging,

(c) there are inedible products preservation facilities, often with pre-preservation processing steps (e.g. rendering before meat mea drying).

Other than for reasons of efficiency in either supervisory labour use or the utility system there is no need for the latter two areas to interact a all. In fact, it is usually highly desirable for them to operate quite independently - a difficult task to accomplish in a compact, multi-storey plan

It is also useful to visualise the building needs. In (a) there must be some isolation of the product from the external environment, but since bot edible and inedible product are present the hygienic considerations are more rudimentary than in (b) where it is necessary to maintain continuou and effective product isolation from the environment. In (c) the constraints are the least stringent - in the most extreme cases the building i more to provide a satisfactory work environment for people than to protect the product. Nevertheless, it is vital that the building system in n way restricts processing and that the building does not impede the uptake of new technology by adding to the costs involved.

One must conceptualise the building as no more than a device to physically enclose the processing plant - changes to new technology will usually mean that both the physical size and shape of the enclosure require change, and that the utility demands are different. The uptake of the new technology must be accomplished with minimal interruption to other processing areas and without the need for major re-routing of service or product flows. It is at times of process change that the disadvantages of heavy construction, multi-storey plants are most obvious. There are numerous examples where the design and layout of process equipment has been severely compromised to fit into existing space. In-built flexibility and low costs of building change are highly desirable features.

As was the case with buildings, the energy system exists solely to support the processing. It should in no way restrict the ability to make process changes nor reduce their cost-effectiveness. It is a total servant.

IMPACT OF BUILDING MATERIALS AND CONSTRUCTION

As has been discussed elsewhere (Chadderton 1997) the preservation system for edible product operates in a tightly constrained time-temperature envelope, and the best systems will prove to be those in which the "directness" of refrigeration/product interaction is maximised (thus enabling the highest possible level of control of the product). Conditioning and ageing time provide one limit to the rate of product cooling, and safety and spoilage considerations create the other. To avoid excessive product handling between different environments it is necessary to be able to manipulate the temperature, and sometimes humidity of an in-plant environment quickly and efficiently. Anything that contributes "side loads" represents an overhead cost.

Consider the example of a batch chilling room. Prior to product entry it will be sanitised - usually with water-based cleaning systems, often using heated water. The inevitable consequence is heating of all structures in the room. The worst of these is often the floor - there can be 2-5 tonnes of concrete per tonne of product in a chiller room, and this will often require recooling over a significant range in temperature. This is a baseload cost. Putting typical New Zealand data against this problem, if a 100 mm thick concrete floor heats to 20°C (as a result of the use of hot water for cleaning), and recools to 2°C daily for 200 days per year, the annual cost of recooling the floor is about $NZ25/m^2. To this must be added the cost of water heating, the extra size of the refrigeration system to handle the floor cooling load, and the interference of the floor heat load with the desirable task of cooling the air. Over the lifetime of the chiller the energy cost is many times the capital cost of the floor. Also consider the costs of making alterations to the high thermal mass chiller to incorporate new technology.

This is but one example but there are many other instances where heavy building construction raises energy costs by exhibiting unhelpful thermal mass (also known as thermal inertia). There is a real demand for low thermal mass building materials. The problem has often been solved for walls and ceilings by the use of foam panel insulation construction, and has also been solved for floors of shipping containers which use similar panel construction. If low thermal mass floors have been successfully installed in abattoirs on a large scale the details of such installations would appear to be well-kept secrets.

At the design stage, any decision to skimp on insulation thickness (on hot service piping, or in the walls, ceilings and floors of refrigerated areas), or cold store door protection has major implications for long term baseload energy use, particularly if the utilisation of the processing area concerned drops in the future, meaning that the baseload cost must be offset against a lower product throughput.

BASELOAD AND ENERGY SUPPLY/DISTRIBUTION SYSTEMS

The need for energy supply systems with low overhead costs has been well-established. After the process needs are established pinch analysis is used to ensure the energy recovery and reuse by other processes is maximised. The overhead cost of the utility systems can then be tackled.

The principles involved (particularly minimising service piping length) are well understood, but what is less well-understood is how to design the piping network for future process change. Too often existing service lines are overloaded as new users are added to them, and this imposes severe penalties. For example, the increase in refrigeration line pressure drop from the addition of new users is a hidden enemy. Pressure drop increases approximately as the 1.8 power of heat load. A 30% load increase on a pipe will thus increase pressure drop by 60%, lifting it from perhaps the equivalent of a 1.5°C change in saturation temperature to the equivalent of 2.4°C. In turn, the compressor suction will run about 1°C colder, meaning that a swept volume of about 5% more is needed for the same load, and that the plant Coefficient of Performance will drop by 1-3%.

Large service mains must often be kept live when most of the large users on them are off, because somewhere in the plant modifications over the years a minor user operating continuously was clipped on the end of the line. This adds a further and often hidden cost.

For refrigeration, it has been argued (Giegel 1984) that the Coefficient of Performance (COP) be replaced by the Coefficient of System Performance (COSP). The former is amount of refrigeration effect (heat load) divided by the compressor energy usage. The latter includes all the other energy use associated with removing the heat load (including all the fluid motive devices to enhance the heat transfer such as condenser coolant pumps, fans etc.),. It is thus more realistic, encouraging technologies that are energy-efficient as a whole. It might be argued that even the COSP does not go far enough. Perhaps we should replace the total heat load by the product heat load to ensure that we give due recognition to process technologies that minimise "side loads". Let us call this the Coefficient of Useful Performance (COUP).

As an example, consider the 2.4 MW refrigeration system mentioned earlier, and remember that this was the better of the two plants by a healthy margin. It had a COP of close to 2.0 (i.e. the compressors used about 1200 kW). Plant room ancillary equipment accounted for a further 150 kW or thereabouts, and the fan power in chillers, freezers and coldstores was 450 kW. Of the total heat load of 2400 kW half (1200 kW) was product heat load. Thus:

$$\text{COP} = 2400 / 1200 = 2.0$$

and

$$COSP = 2400 / (1200 + 150) = 1.8$$

or

$$COSP = 2400 / (1200 + 150 + 450) = 1.3$$

depending on how strict a definition of COSP is applied. The COUP is:

$$COUP = 1200 / (1200 + 150 + 450) = 0.67$$

The plant has a theoretical (second law) Carnot cycle COP of 4.5 so the overall efficiency is 15%.

As an aside, taking into account the comments of Chadderton (1997), if all blast freezing could be replaced by plate freezing, 300 kW of fa power would be saved, and about a further 150 kW of other heat loads would no longer arise. Compressor power would drop by about 22 kW, and ancillary equipment in the plant room might drop by 25 kW. Thus:

$$COUP = 1200 / (1200 - 225 + 150 - 25 + 450 - 300) = 0.96$$

which is about 50% higher than previously, and raises the efficiency relative to Carnot to 21%.

The importance of poor initial choice of equipment cannot be under-rated. Long term N.Z. experience has shown that typical COP values fo two stage compression refrigeration plant in the N.Z. meat industry are of the order of 2.0 to 2.5, but that single stage plants are typically 25 lower. Given that a refrigeration compressor may consume at least the equivalent of its capital cost in energy each year, there is significa incentive to use two-staging. However, low initial costs considerations can mean that single stage compression is inappropriately installe Further, compressor performance decline at part-load is generally worse at the higher pressure ratios found in single stage plants.

THE CENTRAL HUB MODULAR CONCEPT

The need for low building thermal mass, for buildings that facilitate replacement of processing systems with new versions that have dissimila space requirements, and for short service pipework has been established. How then can a plant be laid out to accomplish the vario requirements?

A useful starting point is the central hub, illustrated in Figure 4, in which the entry point is the "separation" area defined earlier, and from whic edible and inedible product flow in opposite directions. The key features of this concept is that it is single storey, and that each processin module is physically separate from those before and after so replacement buildings of different size and shape can be installed if a process

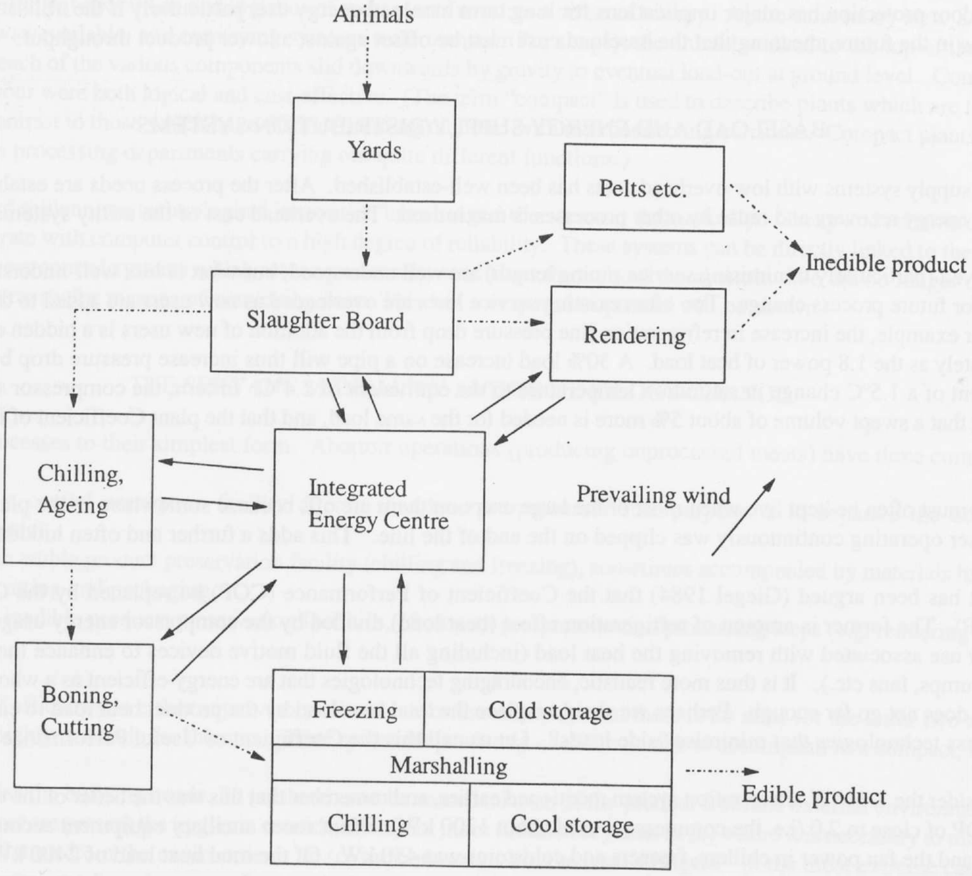

Fig. 4: Concept of a central hub design.

technology change dictates. Low thermal mass insulation panel construction is used to both minimise building thermal mass, and to minimise costs of alterations. Cheap and reliable conveying technology moves product from one processing module to the next through interconnecting corridors. The service mains from the energy centre to each process area are designed solely for the needs of that area. The pipe runs are short, and if the demands of one area change new pipework to that area can proceed independently of any other area. Priority is given to minimising pressure drop in refrigeration pipework at the expense of hot water or steam pipework, as the costs of pressure drop are greater for the cold pipes.

The only area in which compactness might be sought is in the freezer/cold store area, in which minimisation of external surface area to reduce heat infiltration is a concern. Installation of thicker panel (at least 200 mm) would certainly help offset this. Further, if thick panel is used, heat gain to the refrigerated rooms in non-production periods becomes very small, and smart control systems for reducing fan power can be most effective. Such systems, which can really reduce baseload energy use in refrigeration, are less appropriate for rooms with high infiltration gain.

This design is the antithesis of the conservative approach of keeping the "dirty" energy plant clear of the "clean" processing areas, particularly if coal is used. Energy centres tucked away on the edge of a site are the worst creators of baseload.

Of recent times in New Zealand the concept of a central hub modular design has been tested to some extent - in one or two decades more it will be obvious for all to see whether such an approach to design has proven successful.

CONCLUSIONS

Key elements of meat plant design that increase the likelihood of high baseload are old age of buildings, building additions made to initially-compact and/or multi-storey plants, and use of relatively heavy building materials (e.g. bricks and mortar, concrete) compared to lighter materials available today (e.g. polystyrene foam insulation panel). Plant capacity is not a significant factor, but extended periods of operation below capacity is. Reduction in baseload energy use requires a different view of the design of the utilities systems to that which has been historically used. This may include use of a central hub layout concept and/or processing modules constructed of light weight materials. The Coefficient of Useful Performance may be a valid concept for rating and comparing refrigeration systems.

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