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Dynamic Insulation

Gaia Architects & Gaia Research

What is Dynamic Insulation?

Dynamic insulation is when air is drawn into a building through its insulation. It was used successfully in Scandinavia in the early '90's, largely but not exclusively, on a domestic scale. The McLaren Community Leisure Centre (MCLC) at Callander in Scotland completed in July 1998 was the largest building in the world to use dynamic insulation and the first to use it in a swimming pool environment.

The building has a sports hall, bowling hall, squash courts and a 20m swimming pool. Each space has air introduced from pressurised ceiling voids through a dynamic insulation layer.

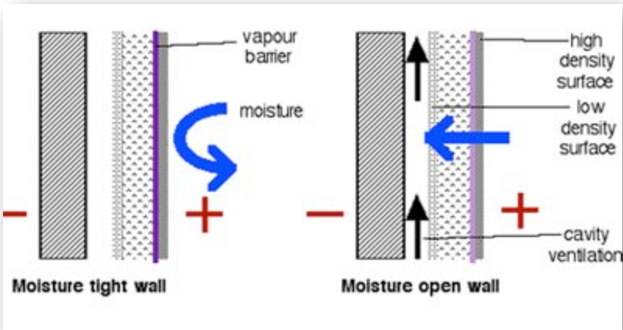
Background

This report is produced as a result of research directed by Gaia Research, which comprised a monitoring study of the dynamic insulation at MCLC. The aim of the project was to appraise and optimise the performance of dynamic insulation in dry-side and wet-side environments.

The building was monitored from September 1998 using on-site surveys and remote monitoring. This report uses data gathered from until March 2000 to assess the environmental performance of the dynamic insulation and other system elements during this period.

Theory & Principles

Energy savings in buildings are urgently required without loss of human comfort or adverse affects on occupant health. As people spend up to 90% of their lives indoors the health impacts of the internal environment are vitally important. Savings reduce pollution and also increase the cost-effectiveness of building operation. Innovative solutions for reducing energy expensive ventilation losses are important but innovation and holistic solutions are required. The strategy of increasing airtightness alone can create problems with air quality and moisture control. It can increase reliance on mechanical systems which are themselves a source of internal pollution.



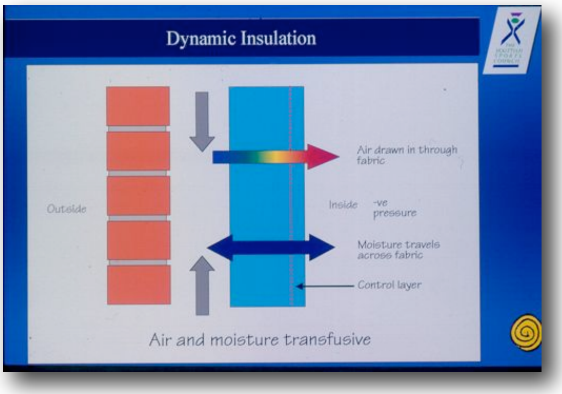
Since the 1980's there has been a development of designed naturally ventilated and moisture transfusive buildings. The moisture transfusive wall encourages moisture flow outward into a ventilated cavity and dispenses with a vapour barrier. It reduces build up of moisture resulting from activities inside a space.

It is sometimes called 'pro-flux' flow and also a breathing wall. The latter gives rise to confusion about the nature of flows across it and hence the term moisture transfusive is preferred.

Dynamic insulation is a further development of building fabric in which heat usually lost through conduction is exchanged with air drawn into a building through the insulation, which acts as a counter-flow heat exchanger. Where large areas are used to bring in air then the air velocity is of the order of a few m/h, well below the threshold for comfort.

How does it work?

Dynamic insulation relies on a controlled constant air flow through a membrane due to a pressure difference between two sides. The pressure differential, is normally created by an under-pressure induced internally, through natural or mechanical means. It is sometimes referred to as "contra-flux' flow. The under-pressure introduced internally causes air to be introduced into the structure and heat exchange occurs between this incoming air and the conduction heat loss. The temperature distribution through the wall is altered by the air flow.

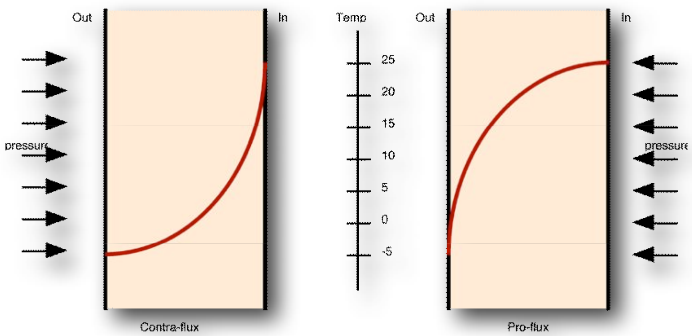


Condensation Risk

Significant damage to buildings is due to air leakage from inside to outside which occurs because of a local or general over-pressure. As the air moves to outside it cools it gives up moisture often resulting in interstitial condensation. More and more buildings are applying moisture transfusive wall design to deal with moisture passively. There is good evidence that this is a significant contribution to creating healthy internal environments and reducing dependence on mechanical systems.

By creating an under-pressure internally, dynamic insulation prevents air flow out through the fabric that might cause condensation and tends to dry out the construction instead. In buildings with a high moisture content, such as Swimming Pools, creation of an under-pressure is recognised as good practice.

With a dynamic membrane the temperature profile is influenced by the air flow so that most of the temperature exchange occurs at the internal edge of the insulation, and in the contiguous air. A constant air stream from the cold side to the warm side ventilates the construction and the building.



Because the air is always moving to the warm side, where its potential to hold moisture increases, and because at typical ventilation rates the velocity of the incoming air overcomes the outward diffusion of water vapour, condensation cannot occur. Provided that the air continues to flow then the building membrane effectively creates its own vapour barrier.

However it is important to ensure that there is a uniform air flow resistance. A resistance layer is best installed as a continuous unbroken sheet. Gaps, holes or blockages in the insulation, or along the supporting frames, which allow uncontrolled air leakage from the internal, normally, warm side, to the external, normally, cold side will distort the isotherms and could give rise to local condensation.

Dynamic U-Value

The effect of the air flow through fabric is to modify the U-value. In the case of contra-flux insulation the effective U-value of the wall is reduced by an amount which corresponds to the heat gains from convective air flow. A near zero U- value can be easily achieved. This has been validated and quantified using steady state models. The temperature of an internal wall is reduced and this reduces the radiant temperature.

Benefits

The use of dynamic insulation has several claimed benefits,including:

i. Well-diffused air supply,preheated through heat recovery in the dynamic insulation.

ii. Downward air distribution helping to reduce relative humidity levels in the pool area.

iii. Perhaps a healthier environment through well-filtered and better distributed air, when combined with careful material specification.

iv. Potential capital and running cost benefits.

Capital Cost & Energy Savings

The McLaren project fits within an overall objective to get as many people active in sports from as early an age as possible to promote good health. In order to achieve this it is important to keep costs as low as possible by attention to both capital and operating expenditure.

Provision of comfortable, attractive and well designed facilities is important in encouraging increased use and hence the necessary revenue stream which keeps costs for all at acceptable levels to sustain facilities. The potential of the technique to reduce reliance on mechanical systems is particularly attractive as a buildings' services are an ever growing proportion of the capital expenditure of commercial and leisure buildings. They take up valuable space and present an ongoing burden with respect to running costs.

Systems are on a short-term replacement cycle which makes them a substantial aspect of the life-cycle cost. They are often more prolific and less functional then they need be and can be difficult to operate economically to meet real needs. Also design is frequently driven by extremes leading to oversizing & inefficiency. Minimising a buildings' services & ensuring that whatever is installed is efficient and well controlled is a fundamental contribution to maintaining costs at affordable level.

The use of dynamic insulation is also believed to deliver energy benefits, through reducing energy expensive air change losses, by reducing stratification when introduced at high level, by reducing pressure drops and marginally due to reduced fabric heat loss because of heat recovery through dynamic membranes. Energy savings of up to 50% have been quoted for buildings using dynamic insulation but there are no monitoring results which evidence this.

Indoor Air Quality

Sportscotland also considered it vital to promote 'Healthy Buildings for Healthy Pursuits". Claims are made for the ability of dynamic insulation to improve indoor air quality but evidence is poor, although:-

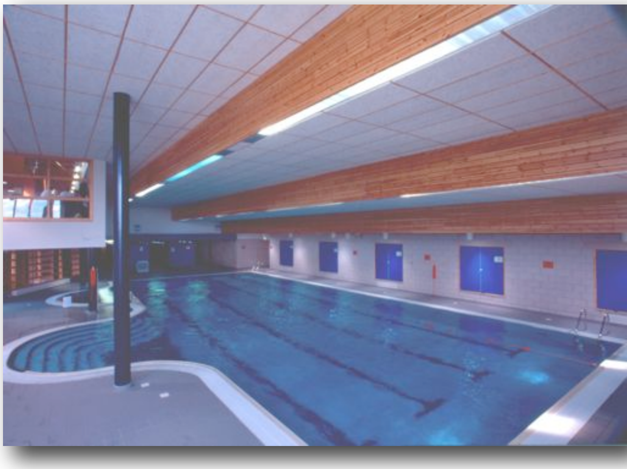
- Advantage will accrue from removal of intake ducts which are a recognised source of indoor pollution.
- Selection of benign materials will contribute to improving indoor air quality by removing pollutants at source.
- Benefits of filtration by a dynamically insulated wall are claimed but no evidence to support this has been identified. The filtration aspects of the dynamic insulation, because of the big surface and low velocity, should theoretically contribute to indoor air quality benefits, provided that:
- Gases, particles or biological activity in the insulation do not cause problems and filtration occurs at the correct scale and that this does not give rise to the build up of secondary pollutants. Research by Sällvik indicates that clogging of the fabric is unlikely to be a concern but further research is required.

Choice of insulation material can also be an important factor in relation to the bio-deterioration of buildings. Research in Finland has been undertaken to investigate the growth and decay effects of decay and mould fungi on different insulation mineral wools and cellulose. Dynamic insulation also permits large quantities of air to be delivered without causing disturbance through high velocities or a wide difference in the incoming room air temperature without giving rise to discomfort. This offers a possible alternative, for example to perforated ceilings used in operating theatres, computer suites and clean rooms.

Another aspect concerns the effect not of the dynamic insulation but of its use in combination with the use of hygroscopic materials. The use of hygroscopic materials is expected to cut down problems with mould, bacteria and viruses. It is not possible to quantify the extent of the hygroscopic effect in moderating humidity and the consequent impact on air quality but work by Anderson and others indicates that this results in a buffering effect and hence better moisture stability. This in turn has been shown to reduce the occurrence of indoor health risks.

Monitoring

The monitoring equipment was installed in June 1999. One array only was installed in the Sports Hall ceiling whilst in the Swimming Pool some short arrays were also added to increase confidence and, because the ceiling is stepped, to enable analysis of the performance at different ceiling heights. Data were gathered on a regular basis. This data, in combination with specially commissioned software, allowed a picture to develop of the performance of the dynamic installation and other system elements during this period.



March 1999

Condition & Performance of Dynamic Insulation

The dynamic insulation was effective in transferring heat, and preheating the ventilation air. Moisture levels of the samples of Warmcell, Heraklith and timber inspected were all low which suggested that it was resisting the back flow of water vapour and moist air.

Air Circulation Patterns

With the prevailing weather and plant operation at the time of the visit, major rotary air movements were observed in both the Swimming Pool and the Sports Hall, driven by down-draughts from cold external walls and windows and up-draughts from radiators and heated surfaces. These indicated bulk movements super-imposed upon more turbulent and fluctuating flows above the heated surfaces of the floors and pool, and agitated by the occupants. The rotational flow circulated air past the ceilings at many times the rate at which air was being introduced via the dynamic insulation, permitting more rapid transfer of heat and uniformity in temperature than would otherwise have been anticipated.

Air Circulation Patterns in the Sports Hall

Smoke pencil tests revealed a rotary air flow, rising along the warmer west wall with part being extracted through the grilles but much moving past, traveling north along the ceiling, with diagonal movement partly towards the colder walls at the NE corner and partly into the viewing gallery at the NW.

While temperatures in the Sports Hall were quite uniform, the downdraught made the northern-most court and the east side feel significantly cooler. At the NW there was a strong updraught, also towards the viewing gallery. The drift velocity below the ceiling was quite strong, at typically 0.2 to 0.25 m/sec in a layer about 2 m deep.

As in the Swimming Pool, this promoted good mixing of the incoming fresh air with less of a temperature gradient than might have been expected.

The incoming air created a tendency of the rotating air to fall away from the ceiling, but this was counteracted by the large body of warmer air underneath; with additional warm air rising from the heated floors. Radiation from the floor also helps to make the ceiling warmer. It was thought that an increase in the output or set point temperature of the underfloor heating zone might reduce the discrepancy; although it could have other unpredictable effects.

Sports Hall Pre-Heat

On a sunny day, solar heat gains into the roof space provided valuable air preheating. However, in summer this may cause overheating. It was thought to be worth considering switching off the supply fans when the roof space temperature was over, say, 24°C. The windows could be used for ventilation but care would be required to prevent unwanted and uncontrolled air movement.

Condensation Risk

The rotary air flows had the incidental advantage of feeding drier air into the downdraughts which travelled over the colder walls and windows, reducing condensation risk.

Positive Pressures

The Swimming Pool and Sports Hall were at significant positive pressures with respect to the outside air and adjacent spaces, leading to exfiltration of warm moist air from the pool into the reception area and changing rooms; and of cooler, drier air into the first floor street. The positive pressures appeared to originate from:

a. Less leakage in the roof voids than the 50% assumed in the engineering design calculations. However, visual inspection suggested that leakage through joints in roofing and block work was likely to be significant.

b. Seemingly less extract ventilation capacity than the design levels, particularly in the Swimming Pool.

c. It concluded that it may be worth experimenting with the air supply to the Wet Changing area switched off.

Variable Speed Control

During the survey, the variable volume Swimming Pool supply and extract plant was always operating at full speed, while lower speed operation might have been anticipated. Inspection of the O&M manual indicated that the controls were set to increase the speed to maximum if the RH exceeded 60% but to only start reducing it if the RH fell to 40%. If this is correct, then the operation would inevitably contain major hysteresis and low speed operation would be unlikely, except perhaps when the pool was covered. Further investigation of the control strategy was thought to be desirable. It might be possible to increase the RH set point because the humidity levels at the condensation-prone perimeter are lower than at the extract points in the Wet Changing area and below the cupboards on the west side.

Sports Hall Temperatures

While temperatures in the Sports Hall were quite uniform, the downdraught made the northernmost court and the east side feel significantly cooler. Potentially, a relative increase of the output or set point temperature of the underfloor heating in this zone might reduce the discrepancy; though changes in the air circulation patterns could have other unpredictable effects. On the sunny 10 March, solar heat gains into the roof space provided valuable air preheating. However, in summer this may cause overheating. Subject to operational experience, it may be worth considering switching-off the supply fans when the roof space temperature is over say 24°C.

Swimming Pool Air Temperature

Complaints of low Swimming Pool air temperatures, were borne out by measurements of typically 24 to 25°C on the east side. Fortunately the airflow patterns meant that this has not led to condensation. On the other hand, the Wet Changing area was rather hot. The possibility of altering the control and balance of the heating system to reduce the underfloor input in the

changing area and increase it in the poolside underfloor heating and perimeter radiators was thought worthy of consideration although, the effect on air circulation patterns is uncertain.

It was noted that several of the perimeter radiators were turned down (the TRVs chosen have a maximum setting of 26°C, or 28°C if a displacer cap is fitted, the plant provides them with water at a maximum currently set at 58°C). It was determined that temperatures above this were not available using TRV's and hence an alternative strategy was required.

The use of the heater battery caused confusion. It had been understood that this was intended for use when the heating capacity was insufficient to create a temperature of 30°C and to provide preheat capacity up to 10-15°C in the event of problems with the dynamic insulation. There was concern that it was being used excessively.

Building Review to Dec 1999

At the end of this period of monitoring a number of interlocking issues were identified which related to design, installation, management, commissioning, control, maintenance and reliability. These were brought to the attention of the management to assist in optimising the performance of the building in environmental and energy terms.

It led to recommendations for a number of key priority actions including attending to the Swimming Pool extract, equipment lockouts, routine maintenance, night operation and proposed operating schedules for day, night and seasonality.

Building Review to March 00

A further visit was made to the site towards the completion of the monitoring programme and with the realisation that standard re-commissioning was not going to take place in time to fulfil the project objectives. Much of the time was spent checking the operation of the H&V services and their controls in advance of the end-of-defects snagging meeting.

The dynamic insulation appeared to be working effectively, although the ventilation supply air gives too much of a cooling effect in the swimming pool. It appears to be keeping itself and the fabric dry, except in parts of the sports hall roof which are subject to localised drippage.

The increase in radiator heat output and extract ventilation capacity - together with the decreased supply fan speed - had improved temperatures and reduced draughts, but there are still some residual problems. The rotary air flows observed in 1999 had the incidental advantage of feeding drier air into the down-draughts which travelled over the colder walls and windows, reducing condensation risk. Now their velocity is lower, the effect is less marked and a small amount of condensation was observed. This could be reduced at times of risk by increasing the ventilation rate.

The positive pressures in the swimming pool area are not as severe as before; and indeed there is a slight negative pressure with AHU6 off. It will be worth experimenting with having AHU6 off (or alternatively at reduced speed) for longer periods, certainly overnight and possibly all the time. The variable speed control currently does not work effectively because the extract fan EF2 is handling only about half the design requirement at maximum speed; and the humidity control sensor is in the wrong place. These faults need to be corrected.

The underfloor heating was maintaining the sports hall temperature at the set 16°C. Concerns remain about a clear strategy for operation of the dynamic insulation in summer if unwelcome air movement is to be avoided. Low temperatures persist, but with some improvements now the radiators are working fully. Further increases may be possible if the pool floor heating can be made to work better. However, temperatures over 27-28°C are unlikely unless there is more heating capacity.

To a degree, the project objectives have been thwarted by ongoing problems associated with the conventional building technology. Problems were identified by the monitoring at an early stage in the building operation. It has taken over two years for a thorough investigation to be completed. Problems identified two years after occupation of the building include major fans installed the wrong way around, flow design problems, incorrect positioning of control sensors and a number of problems arising from inadequate maintenance. At the time of writing this report the building is being recommissioned.

As the building was not operating optimally during the project no air quality monitoring was justified.

The building monitoring was stopped at this stage when so much valuable data could still have been obtained.

Appraisal of Original Objectives

The architects of the MCLC chose to incorporate dynamic insulation on the understanding that a number of its claimed benefits would support them in pursuing healthy buildings and affordability as intrinsic elements of sustainability for community buildings. The following appraisal reviews the original intentions.

i. Structural soundness

The roof is a especially vulnerable element in Swimming Pool design. The dynamic insulation is successful in reducing the risk of condensation and the moisture content of the roof timbers is very low. Risks of over pressurisation of the swimming pool hall must be addressed through appropriate management.

ii. Healthy and satisfactory indoor climate

'Healthy buildings for healthy pursuits' is a priority interest of one the projects sponsors - SportScotland - and was a significant factor in development of the technique. Sensations of air quality remain subjective and it is difficult to be compare with a similar building.

iii. Minimising Plant

At McLaren plant reduction was largely resisted to ensure failsafe innovation but the experience and the monitoring programme have identified opportunities to reduce plant and will enable future designs to benefit considerably.

iv. Energy Efficiency

A preliminary study was undertaken to coincide with the installation of the monitoring equipment. This was to check the performance of the dynamic insulation and to make a brief assessment of the pattern of energy use and the potential for energy savings prior to final installation of the equipment. This process identified means of reducing the energy consumption and made a significant input to a cost review. Of particular note was the decision to change the fans installed to half their design duty with an option to turn down the ventilation rate to as low as 0.5 ac/h.

The initial study identified scope for energy savings largely through attention to operation and control settings - as at the time of the visit plant and systems appeared to be running liberally. The energy costs were higher than anticipated, accentuated by omission of certain significant energy consuming elements from original estimates. The excess energy consumption was largely a consequence of conventional systems and in part a consequence of air to the Swimming Pool ceiling void being supplied at maximum volume, while variable volume operation was intended. The energy consumption varied enormously during the first year and was on occasions very high. During the second year the energy consumption was substantially down. Whilst it is not unusual for a building operation to take some time to settle down, it was evident that there was things that could be done to bring the energy consumption down still further.

v. Affordability as factor for community facilities

The capital cost has been compared with a similar facility built at the same time. McLaren costs were £757.10/m2 inclusive of site preparation. However, attention was given to the bowls hall at which was a particular inexpensive element at only £500/m2. After taking account of this the comparable cost was £853.91/m2. An equivalent building in the region cost around 3% more at £878.43/m2. Energy management requires constant vigilance and the management has still to address this as an aspect of the mismatch between outgoings, including staffing, and income.

Conclusions

• If correctly applied dynamic insulation has the potential to reduce insulation requirement, reduce fan power and reduce energy consumption, at the same cost as conventional approaches.

• Simultaneously it can provide a clean internal environment through a combination of well filtered air and reducing the need for input ductwork with associated cleaning requirements. As such it provides a potential exemplar of a sustainability driver in building design, alongside passive solar design and passive moisture design. Principal proponents are likely to be clients, government and individuals/ practices seeking the benefits of sustainable construction.

• At McLaren pieces of conventional technical equipment were not in the condition that they should have been and this inhibited the monitoring with respect to optimising and subsequently monitoring performance. The total system performance has not been assessed in a way which allows for an improved understanding of the relationships between pressure differences, temperature differences, fan power and pre-heat. Assessment of the performance of the heat pump has also not been possible.

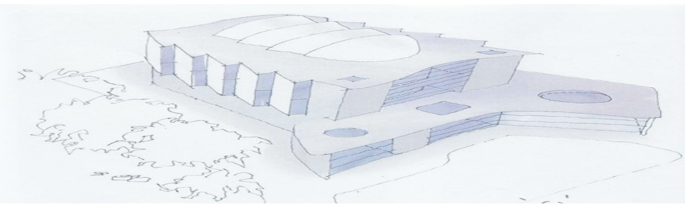
• Optimising the plant operation was not possible within the timescale of this project. However much has been achieved to assist the client and architect to ensure that the dynamic insulation achieves the principal design objectives and the monitoring has been an invaluable resource in achieving this.

• The monitoring process has been a crucially important diagnostic tool, and a necessary basis of support in both the energy strategy and the identification of latent defects for such an innovative project. Choice of insulation material remains an issue with respect to hygroscopicity - which is largely unquantified - and also latent health implications.

• Despite teething problems with many of the building systems virtually none of these either occurred in - or affected the operation of the dynamic insulation, which appears to be working as the design intentions. However, it is clearly not optimised and may be undermined by the combination of technical and training issues.

• A principal concern is a generic issue with innovative projects. Whilst the dynamic insulation has not been a problem and may well have been a benefit during the first two years when much of the system has not been fully operational, there is a tendency for all problems to be blamed on the innovative aspects. This has sometimes adversely affected attitudes and hindered progress.

• Of the practical aspects of the construction it is notable that a motivation for investigating air and moisture transfusive fabrics was a concern for confidence in the building integrity. The integrity of the construction has been shown to be equally important. The basic design principles are straightforward but their achievement is dependent on effective detailing. The technique draws attention to the importance of the construction process and team approaches to design, construction and feedback.



• Future designs also need to consider and design for long term access if it is needed and to plan for commissioning to ensure that buildability criteria have been met.

• The operation of dynamic insulation in summer remains unresolved in circumstances where air movement is a significant issue. This is due to heat gains in the roof exacerbating overheating. In some circumstances it might be possible for the dynamic insulation and natural ventilation strategies to be interchanged.

Dynamic Insulation Now

The use of dynamic insulation in housing is now common in Scandinavia for commercial housing and also in specialist health related circumstances. In the UK this was investigated by Gaia Architects in the development of five dynamically insulated houses designed for use by allergy sufferers in a project being supported by an RIBA Sustainability Research Award. Gaia Architects have subsequently designed dynamic insulation into two dry sports halls in Scotland and assisted on designs for office buildings in England.

Application in further swimming pools is considered to be a major opportunity with specific advantages being perceived as both structural and performance based. The latter particularly related to the low humidity aspects which enhance comfort. A final seminar in July 2000 discussed the prospects for application of dynamic insulation and concluded that it had a future in a wide range of building types in both pure and hybrid forms.

Acknowledgments

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