The Internal Environment of the Glasgow School of Art by Charles Rennie Mackintosh

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Abstract
This paper discusses the Glasgow School of Art in the context of the wider history of the Victorian art school as a distinctive building type. It explores the precedents for the school in Manchester, Birmingham, and London, and reveals that its design was informed by predominantly environmental considerations.

The internal spaces of Victorian art schools display an unprecedented qualitative concern for the provision of light in the context of the soot-laden skies of the industrial city. The Glasgow School of Art was also equipped with a mechanical plenum system that provided clean and tempered air in variable quantities to the different spaces of the building. The innovativeness of this system has been widely disputed – this paper aims to cast light on its precedents and situate its significance in the wider history of the development of building servicing. This includes discussion of a contemporary report detailing the engineers' commissioning of the building in 1910, as well as a recent study undertaken to evaluate the environmental management of the school today.

The paper demonstrates that the Glasgow School of Art represents a key milestone in the development of our modern conception of the internal environment of large buildings, brought about in response to the atmospheric degradation of the industrial city. The sophisticated integration of the environmental qualities of the Arts and Crafts movement with thoroughly modern servicing technology is indicative not only of Mackintosh's principle of 'total design', but also of the architectural possibilities inherent in the construction of a particularly specialised building type in a specific time and place.

Key words
Lighting, ventilation, heating, environmental design, Charles Rennie Mackintosh, Glasgow School of Art

Content
9,100 words; 18 images.

Biography
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Introduction

The Glasgow School of Art, by Charles Rennie Mackintosh, was completed in 1910. It went almost unnoticed by the architectural establishment for a quarter of a century, until Nikolaus Pevsner heralded Mackintosh and the school as proto-modernist in *Pioneers of the Modern Movement* in 1936.[1] Thomas Howarth's 1952 study, *Charles Rennie Mackintosh and the Modern Movement*, was the first of many to cement Mackintosh's reputation, and the famous art school has been written about so frequently since then that any attempt to retell the story of its significance must be justified by an explanation about why it is necessary – what is different to what has been told before.[2] At the same time, we must acknowledge that as architectural historians and critics we are often trying to re-contextualise Mackintosh to make his work more relevant for us today; to 'construct' a story that might tell us something new that we can learn from buildings with which we are already very familiar. Critically, this 'construction' is not a macro-theorisation of a story about the transmission of abstract ideas, but rather instead it seeks to explore architectural evidence from the material, spatial, and atmospheric presence of the school that until now might otherwise have been discounted. This focuses on the environmental design and atmospheric experience of the Glasgow School of Art; how it was conceived, how it was constructed, and how it was maintained.

The Glasgow School of Art was constructed in two phases, the eastern portion between 1897 and 1899, and the western portion between 1907 and 1910 (Fig. 1). Broadly in section the building has three main levels of studios facing northwards onto Renfrew Street: the basement is lit from skylights (filling the lightwells between the building and the street); the ground floor level is lit by large windows to the street; and the first floor (comprising the largest studios) is lit both by taller windows and an area of glass turning to the sky above the windows. The entrance is located centrally beneath the director's room and studio. Spacious corridors doubling as galleries at each level give access to the various studios through the massive east-west spine wall, and at basement level more studios with pitched roofs are lit from skylights to the south. Off this section are hung three wings of additional special accommodation to the south: containing respectively, to the east, the caretaker's flat, staff rooms and another studio at roof level; centrally, cloak and student lunch rooms beneath a large toplit museum; and to the west a lecture hall, architecture studio and famously the double height library beneath a further studio in the roof. When the first section opened, there was only one main timber staircase descending from the entrance hall to the basement and rising in the centre of the museum opposite the director's room. Howarth explained:

> "The city authorities apparently overlooked this dangerous arrangement at the time, but when the opening ceremony was performed elaborate fire precautions had to be taken: not only were buckets of sand and water placed in all the corridors, but a complement of firemen was stationed on each landing."[3]

Mackintosh corrected his mistake with construction of the second phase, adding an extra stone staircase to the eastern wing to match the new western library tower. He also added another floor of studios to the roof of the whole building, necessitating construction of the 'Hen Run', cantilevered above the museum and connecting the new section with the old, as the headmaster's studio occupied the full structural width of the building at the point where the link would otherwise rationally have been made. But for Howarth, as for Pevsner, it was the west front of the building that best illustrated Mackintosh's prescience as an architect:

> "With its exciting horizontal rhythms and soaring verticals of glass and metal, its large plain surfaces of masonry, and rigid clean-cut angularity of form, this elevation represents not a step forward of a mere decade, but a stride of twenty or thirty years in British architectural development."[4]

Environmental Significance

In 'Poetics of Workmanship', David Brett deploys Frampton's 'rehabilitation' of the tectonic'[6] to analyse the 'poetics' of the construction of the Glasgow School of Art, dividing Mackintosh's palette into stonework, timber and metalwork. From the outside inwards, Mackintosh deploys stone in the "walls and entrances", timber in the "hallways and stairways", metal in the "railings, brackets and fittings" and finally, and perhaps most intriguingly, "glass, ceramics and enamel", which have "a small but important role to play: they are the principle means by which bright colour enters a building", accents of which "are used throughout his public buildings as way-markers and insignia" or in private houses to bring "a note of expectancy into dark interiors".[7] This study will assert that in fact the means by which Mackintosh manipulated the environmental qualities of the building – the admission of light and air – have a greater significance than has previously been recognised. The means by which the many different interior environments of the Glasgow School of Art were shaped and perfected are as significant as the physical fabric, and can reveal just as much about nineteenth century conceptualisations of architectural experience, propriety, the divisions between public and private space, and the intrinsic symbolic meaning or 'poetics' of Mackintosh's architecture.

The 'materials' or criteria of this evaluation are light, ventilation, and warming (or cooling). This study can broadly be divided into two parts, as the means by which the school was ventilated and warmed (or cooled) were broadly one and the same; a mechanical air plenum system that provided tempered air in variable quantities to the different spaces of the building. We have to be careful, however, not to assume that the lighting and the air system were independent considerations in Mackintosh's design; rather they are entirely *inter*dependent in the atmospheric experience of the school, and this is furthermore arguably what is so architecturally significant about the spatial richness of the Glasgow School of Art.

Daylighting

The requirements for lighting in an art school were already clearly laid out by the time the school in Glasgow was conceived. In the third chapter of the 'Directory, with Regulations for Establishing and Conducting Schools of Art', published annually between 1856 and 1902, a general outline was indicated for the accommodation of a school of 50 students, to be scaled upwards as appropriate. This was accompanied with various notes about the lighting requirements of the different rooms. The 1888 edition called for:

(a) One Elementary room 20 x 30 feet. This room should not be less than 16 feet high, and may be lighted by skylights as well as by side windows.
(b) One room for study from Life or Life-size casts, not less than 20 x 24 feet. This room should be lighted from the north side by a single large window, the top of which (carried up in a dormer if necessary) should be at a height above the floor equal to ¾ the depth of the room, or if the pitch of the roof be steeper than 60°, a skylight should be made in conjunction of the window, so as to gain the same effect in lighting.

(c) One modelling room 20 x 15 feet.
(d) One master's room 12 x 15 feet. This room should be lighted by a side light from the north, if possible.
(e) One cloak-room for females 12 x 8 feet 6 inches.
(f) A kitchen and bedroom for the attendant, each 12 x 10 feet.[12]

While guidance was specified for study from life or from life size casts, guidance for appropriate lighting for painting and sculpture was noticeably absent. The infamous twenty-three stage National Course of Instruction, intiated by henry Cole in 1853, had little time for such mediums, considered to belong firmly in the realm of 'fine', rather than 'practical', art. More detailed guidance specified that:

(a) The rooms for study should be not less than 15 feet high to the wall plate, if ceiled flat, or 12 feet high to the wall plate if ceiled to the collar-beams or the common rafter.
(b) The windows should be large, and in Art Schools, free from mullions or small panes.[13]

This model for an art school was first realised in the new studios for the Art Training Schools, constructed to the rear of the Museum of Manufactures (now the Victoria and Albert Museum), in South Kensington (Fig. 2). The studios were constructed on the second and third storeys of a new wing of the Museum behind the North and South Courts, completed by Francis Fowke in 1863.[14] A single volume of studios, 200 feet long, and lit from a dual aspect (both north and south) on the second floor was supported on iron girders that also heated and ventilated the building. According to the Tenth Report of the Department of Science and Art:

> "The building has been constructed throughout with fireproof floors, the girders supporting which have been made hollow, and thereby employed to carry the hot-water pipes for heating the several stories. These troughs are carried through external walls, and terminate in iron grated boxes through which a constant supply of fresh air is obtained. The windows are made very large, and with wide intervals between them to suit the requirements of lighting for the school, and with a like object to the upper floor the windows are continued a considerable

> way into the roof as skylights, an arrangement by which a command of light is obtained at any required angle of elevation."[15]

Arguably, the fact that the studios only formed the second and third storeys of a wing of the new museum means that it cannot accurately be described as the first new art school built *expressly* for the purpose. The model was further developed, however, in the Manchester School of Art, the first purpose built school of the major industrial centres, which opened in April 1881 (Fig. 3). Pevsner described the building as:

> "Gothic and symmetrical, with a central entrance, but take the period details away and you have Mackintosh's Glasgow School of Art of 1898, i.e. with an ornate treatment of the centre, but otherwise all frankly large studio windows."[16]

The similarity with the Glasgow School of Art should hardly be seen as a surprise, and yet has mostly gone unnoticed. The plainness and functionality that Pevsner highlights was necessitated by financial constraint, though the prospect of a brick-fronted school was seemingly so abhorrent that the money was eventually stumped up to present the front façade in stone.

Birmingham School of Art, completed in September 1885, also demonstrates this contemporary paradox of function and propriety. In the extension of 1893, the critical junction between façade and roof opens to the sky in a chamfered wall-to-wall north-west skylight, and the wall separating the room from the corridor is punctured by pointed gothic windows and arched double doors suggestive of the external façade. The interior of the art laboratory is an in-between space, part enclosed, part open to the sky, and separate from the interior of the rest of the building (Fig. 4). Similar spaces can also to be found in the Glasgow School of Art, where the composition room above the library is lit by large plate glass skylights juxtaposed against the small rectangular rolled glass panes (so typical of Mackintosh) in the bay window beneath (Fig. 5).[17]

The similarities between Birmingham, Manchester and Glasgow Schools of Art are more than coincidence. In 1893, a deputation from the Glasgow School of Art visited the schools at Manchester, Birmingham and London in preparation for drawing up their own brief for a new building[18], and Mackintosh's design was selected at competition because it deviated the least from a sketch plan prepared by Francis Newbery, headmaster at the time, in consultation with the authorities at South Kensington.[19]

Perhaps the most easily identifiable development in the provision of light in Glasgow is in the wide provision of plate glass for the studio windows (a return to the South Kensington model), which had been absent from both the Manchester and Birmingham schools (as the cost of manufacturing this kind of glass was still prohibitively expensive). However, unlike South Kensington, the studio windows in Glasgow would for the most part face only north. The fact that opposing orientations of light were not adequate for creating the right effect (as in the second floor studios in the longer wing at South Kensington), is evidenced by a handbook written by Richard Hatton, headmaster of the Newcastle School of Art, in 1895, where he suggests refinements to the instructions for lighting from the Department:

> "Then another consideration is that if lighting. The Suggestions of the Department, given above, speak of a north light for the life-rooms and master's room only. This is misleading. It is distinctly inconvenient for any of the windows to admit direct sunlight; and it is therefore best for the building to face the north or the east. If the eastern flank of the building face east-north-east or between that and east, it will probably be found that the sun will not enter the windows of that side after 10 a.m., the hour at which most classes commence. All the windows on a side at right angles to this, facing, say, north-north-west, will be free from direct sunlight till 5 p.m."[20]

Generally, levels of illumination in Glasgow School of Art far exceed current guidance. At the front of the main north facing studios on the first floor, daylight factors reach 12% on the horizontal working plane (Fig. 6). Wood paneling "off the saw", likely stained dark green, around the base of the studios provided a neutral backdrop free from glare for the composition of figures or still life, while a light plaster frieze above, "finished off the float", ensured maximum penetration of light from the 22 foot high windows to the back of the studio, where daylight factors never fall below 4%.[21] While the average of 8% is impressive by modern standards, we must bear in mind that the sky in Glasgow would often have been considerably obscured by smoke. Similarly, in the library, which has been considered by some to be impracticably dark (in reality a product of the contrast between the dark wood interiors and the light from the windows), daylight factors measured on the west-facing desk surfaces perpendicular to the windows are around 10%.[22]

The loss of light due to smoke pollution are perhaps best quantifiably illustrated by the smoke charts developed by Max Ringlemann in Paris in 1890, and introduced to Britain by the turn of the century. These consisted of four increasingly dense grids of black lines (representing in turn 20, 40, 60 and 80% blackness), which were to be held at arms length and compared in tone with the part of the sky in question. There were two aspects of the nuisance to be identified; firstly the absorption of light caused by soot held in the atmosphere, and secondly the loss of light caused indoors by the fall of soot affecting transmission through glass.[25] According to Nicholson, the average loss of light at any given time in the worst-affected regions of Britain due to the former aspect was 45%.[26] It is possible, however, that this would have been much worse in cold and humid weather conditions, or winter temperature inversions, and would have been significantly worse indoors without regular cleaning of windows. In order to describe the qualitative aspects of this smoke and fog pollution on London's climate, Dean Hawkes has cited Dickens' lengthy atmospheric descriptions in 'Bleak House'.[27] However, by the beginning of the twentieth century at least, it was clear that the problem was much worse in the demographically smaller industrial cities of the north, with one study identifying the annual soot fall in the centre of Glasgow as 820 tons per square mile, in comparison to 426 tons in London.[28]

Lighting by Night

Lighting at night would arguably be as important in the art schools as daylighting, as technology extended education into the night, allowing apprentices and other skilled tradesmen to enroll for the first time. Here, the fittings installed at Glasgow again would be at the cutting edge of available technology. The new building was wired from the Corporation Galleries, and a favourable rate negotiated with the Corporation for electricity between 7.15 and 9.15 in the evening only (after the 4 – 7 pm peak demand). The estimates for the wiring ranged from £696.10.0 to £1050.0.0, and the lowest estimate by Hugh Osborne was duly accepted.[29]

Experiments were conducted before the electric lights were permanently fixed. The majority of the 272 light fittings in Glasgow were 16 candlepower filament lamps. There were in addition thirteen 32 candlepower lamps, fifteen 50 candlepower lamps, and nineteen arc lamps installed (50 candlepower is approximately the equivalent of a modern 40 watt incandescent bulb). One estimate for the luminosity of an enclosed arc lamp of the kind that would be installed at this time is 300 candlepower (or the equivalent of a modern 240 watt incandescent bulb). These arc lamps, therefore, would have been incredibly valuable and of high demand in the school (especially given the relative dimness of the incandescent lamps at the time), and presumably for the most part used to illuminate the subjects of classes in the studios. Arc lamps consisted of two electrified carbon rods placed close together between which the electricity would 'arc', emitting a far brighter and hotter light than regular filament lamps, and therefore appearing to give off a much colder light by appearance, as the colour temperature approached that of daylight. By 1910, however, there is no evidence of their distinctive large fittings in the interior photographs taken by Henry Bedford Lemere. It is possible that more economical and improved incandescent bulbs replaced them: indeed some of the photographs show multi-bulb fittings for these complete with directional reflectors (Fig. 7).

Warming and Ventilation

Broadly, we can divide the causes of atmospheric pollution that required ventilation into two categories: the detrimental influence of the outside air and its impurities on the interior; and the more immediate sources of unpleasant 'odours' caused by poor personal hygiene or other unacceptable contaminants on the inside. In art schools, designed before the advent of electricity, the soot associated with gas lighting would have had more of an impact on the atmosphere than in other building types, as the illumination requirement was greater, and in some rooms – painting studios and workshops in particular – the by-products of the chemicals used to mix paint or fix materials could be dangerous if allowed to accumulate in still air.

The school at Glasgow, Reyner Banham narrated in 'Architecture of the Well Tempered Environment', "used a Plenum ventilation system – which is not surprising in William Key's home town – whose ducts appear, uncommented, in practically all the standard photographs of the studios and work-spaces of the school."[30] This is about all that is not disputed about the building's prototypical air-conditioning system.

In his 1990 doctoral thesis, George Cairns also concluded that the plenum system and the proximity of Key are more than coincidence, as John Keppie and William Key worked together on the Victoria Infirmary in Glasgow, installing a forced air and ventilation system in 1896. Robert Tindall and William Key jointly lodged patents for what Cairns describes as the first true air conditioning system in London in 1896.[31] This system fulfilled all of the criteria of the definition of air conditioning developed by George Wilson in 1908 (that Willis Carrier would later subscribe to) but one; ventilation supply, heating, cooling, and 'washing' the air, however it could only further humidify, not dehumify, the air.[32]

William Key was an engineer from Tradeston Gas Works on the south side of Glasgow. He was an instrumental figure in the development of pressured-plenum systems of mechanical ventilation (employed extensively in hospitals) in competition with vacuum systems as championed by Robert Boyle, which were encumbered by the double flaw of requiring high level installation of mechanical equipment in buildings (or long ducts in which to extract air down to the basement), and leakage into the low-pressured interior of draughts from the outside.[33] The advantage of the pressured system was that it could be installed close to the ground in buildings with ductwork logically dispersed vertically off a main horizontal plenum. While it required a lot more power to drive the same volume of air into a building, it had the further advantage of preventing cold draughts from leaking in.

It is clear, however, that the use of fans at Glasgow was not new, nor was the combination of fans and plenums. The Capitol Building in Washington was installed with a dual fan and plenum system in 1855.[34] At roughly the same time, the idea of ventilation by heated shaft was also advancing, from the precedent of Joshua Jebb's Pentonville Prison in 1840, to Dr David Boswell Reid's less successful coke-fired exhaust experiments at the new Houses of Parliament beginning in 1836.[35] The result of Reid's experiments was the sophisticated system he designed for St. Georges Hall in Liverpool in 1851. Fans eventually came to replace fires as the primary means of driving air, however, increasing flow rates dramatically as well as reducing fuel consumption.

It was a combination then of improved building technology and a greater sensitivity to personal hygiene that drove the development of new methods of adequately ventilating the new, more complex types of public buildings that characterised the civic realm of the second half of the nineteenth century. In Glasgow, the pioneer Wilson Weatherley Phipson had installed a revolutionary fan and heating system at the University (designed by Sir George Gilbert Scott) between 1866 and 1870. This was a fan driven system, but with localised boiler heating in dispersed chambers feeding groups of classrooms and lecture halls, and extraction assisted by the heat from the boiler flues running up the centre of the extract shafts.[36] After his work at Glasgow Phipson's career took off, and he was responsible for installations at the Royal Albert Hall in 1871, the Natural History Museum in Kensington in 1873, and the Royal Infirmary in Liverpool in 1889.[37]

The use of fairly sophisticated technology quickly spread to more commonplace building types as well. The medical profession in Britain had raised concerns about the health implications caused by overcrowding within school buildings as early as the 1860s.[38] The American surgeon John Billings's 1893 guide for architects, *Ventilation and Heating*, also detailed various strategies for various building types, including schools and hospitals. He recommended careful analysis of existing practise and practical experiment as a means to perfect air quality.[39]

In Birmingham these concerns manifested themselves in the architecture of the Board schools; each of Chamberlain and Martin's schools was equipped with a plenum ventilation system and an enormous chimney (an example of which, albeit at Edgbaston waterworks by the same architects, was apparently the inspiration for Tolkien's 'Two Towers'[40]). The quality of air was a major concern in overcrowded, gas-lit classrooms, especially in an age when tuberculosis was still very common.[41] Evidence of the unsatisfactory nature of the School of Art's accommodation (originally housed in the Birmingham and Midland Institute), meanwhile, can be seen in a letter from a female student to the Committee of the School of Art appealing for more classroom hours, dated 17th November 1880. She wrote:

> Will you… give back to the advanced students the privilege of working in the School all day on Tuesdays and Thursdays? We should not interfere with the Elementary Students, as we never work in their rooms. The male students are so few we could not be in their way and as we should leave the building at the same

> time, the presence of a few ladies could not make the atmosphere any worse at night, *than it is always* and even if we stayed till 5 o'clock it would leave from 5 till 715 for ventilation.[42]

While the author of this letter claims that the arrangement she suggests could not 'make the atmosphere any worse' at night, it is significant that this is mentioned at all. When the new school was built, it was installed with a radiator system supplied by the Trowbridge firm of Haden and Sons (who had developed warm air circulating stoves for churches[43]), and lit by 'Bower' gas lights, which necessitated a complex ventilation system to remove unwanted heat and fumes.[44] The 'warm' radiators[45] were combined with a network of ducts that circulated air from the boiler room to a series of grates in the basement corridor, and grills in the skirting boards of the museum and the external walls of other rooms. Stale air was drawn out close to the ceiling on the inside walls, or through flues above the gas lamps in the studios on the top floor, and then returned in an extract plenum along the spine to the large stack located on the spine above the southernmost staircase. William Martin modified Joseph Chamberlain's first design for the school after his death to 'obtain increased light and ventilation to the various rooms,' increasing ceiling heights generally and enlarging 'areas for light' around the perimeter of the building.[46]

However, when the school was extended, a separate heating system to the original building was installed, supplied by Henry Hope at a cost of £1,367. The Corporation Gas Department took responsibility for the gas, ventilation and lighting installations for what seems a bargain price of £365.[47] The forced air plenum system was far larger than the system in the first part of the school, with man-sized ducts underneath the basement feeding air from a second fan and boiler installation underneath another chimney (which also drew air down to the basement) to vertical risers located in the buttress-like features between the windows (Fig. 8). The extracts and foul air plenums were again centrally located on a spine wall, connecting back to the chimney at roof level (Fig. 9). This system matches one described by the French engineer Paul Planat as "aspiration from above", with supplementary draught supplied by the warm air from the flue extracts above the gas lamps in the top floor studios.[48] When the time came for the school to be extended then, it seems that the original ventilation strategy was reconsidered, suggesting that complaints about the quality of the atmosphere had not been sufficiently improved in the original building.

Description of Apparatus at Glasgow

While Banham and Cairns's conjecture is attractive, it is unlikely that Key was involved in the design of the ventilation system at the School of Art in Glasgow directly, as the Glasgow firm of James Cormack and Sons Ltd. oversaw the installation for the sum of £1454.0.0 (though Key and John Keppie did work together again on a heating system for William Whitie's Mitchell Library of 1906[49]).

The system consisted of fifteen steam coils connected to the boiler to heat incoming air and two fans supplied by the Sturtevant Company, who had offered the combination of fans and heat exchangers for installation in buildings as early as 1869.[50] It is possible that the Sturtevant Company (which had opened offices in London as well as Boston[51]), were consulted in the detailed design, as the system installed at the school displays similarities with a dual fan installation described in the Sturtevant catalogue of 1896 as a "Duplex Heating and Ventilating Apparatus" (Fig. 10):

> "The fans are built as exhausters, each with only a single inlet, and that on the side opposite the engine. These two inlet sides face each other, so that the entire space between the fans and connecting with these inlets can be readily enclosed and connected with the heater, which is usually symmetrically arranged and placed immediately behind the fans."[52]

At the art school, external air was drawn into the fan room from the light wells either side of the main entrance. Before it reached the fans it was drawn through air-filtration and humidifying screens made of horsehair and over the steam coils for warming.[53] However, unlike the standard Sturtevant installations (as illustrated in various American schools in the catalogue), rather than distributing air along plenums radiating from the fans to risers in all corners of the plan, the air was distributed neatly along the basement corridor, from which it fed risers located centrally on the spine wall of the building (Fig. 11).

As the fans and radiators would be required at all times of the day they could not be supplied with the same electricity from the Corporation Galleries employed for the lighting (which according to the Corporation's conditions could only be used in the evening). The fans were therefore powered by separate electric motors, which were also used to power radiators to heat the models' 'thrones' in the morning and evening life classes.[54]

Evaluation

Of the total budget for the first phase of the art school of £17049.8.8 (including architects' and measurers' fees), an unusually large outlay of £2150.10.0 was spent on heating and lighting systems, and when the school was extended to the west in 1907-1010, a further £716.0.0 was spent to complete the air system.[55] In response to an untraced letter from Francis Newbery during what we might today call the 'commissioning phase' of the school, the architects detail alterations and fine-tuning being made to the air system (suggestive of the fact that the installation was not as commonplace as the clients had been initially led to believe). The sophistication of the system is underlined by the response, "quite impossible", to the request for a new door to be made through the spine wall:

> "Nov 12th. 1908
>
> The Glasgow School of Art
> Extensions + Alterations.
>
> Dear Mr. Newbery,
>
> We have your letter of 9th. Nov. referring to the following items.
>
> 1st Hot air inlets. The question of these inlets was discussed by Messrs. Cormack when the Heating + Ventilating of new portion of building was under consideration and the suggestions then made by you are being carried out by them.
> We shall be obliged if you will make a statement of the defects you have found out since the existing portion of the School has again been in operation as well as a statement of any suggestions of improvements that may have occurred to you. We can then lay the whole matter before Messrs. Cormack + Sons for consideration + advice.

2nd Regarding the formation of a third door to Life School Rooms we are sorry to say this seems to us quite impossible as the wall is already built and is practically honeycombed by inlet and extract shafts.
However we will be glad to do anything to get this door constructed if you find it absolutely necessary. It might be helpful if you could call here at an early date to see the plan of this wall as it is actually constructed."[56]

Of course, the famously variable climate of Glasgow and the unusual day-to-day life of the art school would have resulted in changing demands on the heating and ventilating system from day to day as well as month to month. However, following this letter, and Newbery's response (again unfortunately lost), the architects wrote to James Cormack. & Sons about the feedback they had received. It is probably safe to assume from the architect's concern about "sticking down radiators where ever heat was required" that it was Mackintosh himself who dictated this letter (indeed it is tempting to speculate that Mackintosh may have had a hand in proposing the system for the first phase in order to do away with the need for the aesthetically displeasing and unseemly large radiators that would otherwise have been required to warm the enormous volumes of the studios). The engineers are requested to reduce the clear opening of some of the ducts and "further heat" the air in others (though quite how this could be achieved independent of the main steam coils is not elaborated). That the dissipation of heat from the air was not accurately predicted as it circulated further away from the boiler provides more evidence of the fact that this was no standard installation, a point reinforced by Mackintosh's suggestion that the contractors further test the functioning of the new air system to demonstrate that it met with the Building Committee's specifications:

"19. Feby. 1910.

Messrs. James Cormack. & Sons.
Heating Engineer
Abercorn Street.

Dear Sirs,

We had a meeting with the Building Committee of the School yesterday and had a long interview with them regarding the heating of the School.
It is manifest room that interview that generally speaking the heating is fairly satisfactory although in some of the rooms there is too much heat, while in others, especially the library, considerably too little.
We pointed out to them the undesirability of sticking down radiators where ever heat was required, except in Class Rooms (life) where a greater heat was required than 66° [19°C] when the outside temperature was at 30° Fah [-1°C].
We explained to them the effort you were making to get the apartments which were furthest away from the boiler up to the above heat which was what you arrived at when you designed the scheme and which was the standard you agreed to when you took the contract. This appeared to them reasonable and they agreed that you should be allowed to work the system that you might show that the installation was according to contract.
For this purpose we suggested that you should have charge of the heating for a week or a fortnight as you might require and that it should be under your control for this time. As some of the rooms are overheated it may be necessary for you to diminish the entrances to the ducts in these rooms and as some of the rooms are too cold it may be necessary for you to so further heat the air entering these rooms as to bring them up to the required temperature.
According to the interview we had with you we are satisfied that you are agreeable to undertake this and we shall be glad to hear that you are to and what is the soonest date at which it will be convenient for you to make these tests.
When you are doing so we would suggest that you make a schedule of the whole of the rooms of the school and that the outside temperature be taken and the temperature in each of the rooms and that you make a record of these taking them 3 times a day, say at 10 am, 1pm + 5pm or at such other times as may be convenient to the school authorities.
The temperature will be taken in such a position in the rooms as will give the mean temperature.
It would assist us also if at the same time you would take the heat at the boiler at the times you take the temperature of the rooms, and note also the consumption of coal as it is a most important item in the matter.

You might at the same time give us information regarding any other points you think important here and I will be glad to hear from you at once regarding the above points and trust that you will give this your immediate and personal attention.

Faithfully yours,
Honeyman, Keppie & Mackintosh"[57]

From this evidence we can see that some modifications were necessary to the system as first installed. The library in particular is recorded as being too cold, and it seems that the Building Committee required more detailed guidance in order to understand how to make adjustments to the balance of heating. The testing took place over a week from Wednesday 2nd to Tuesday 8th March 1910. The architects noted that over this period it was unnecessary to employ any more than five coils to maintain a suitable indoor temperature, with the temperature outside ranging from 41 to 48 degrees Fahrenheit (5 - 9°C):

"Honeyman, Keppie & Mackinotsh,
Architects,
4, Blythswood Square,
March 16th. 1910.

Messrs The Building Committee,
of the Glasgow School of Art.
Dear Sirs,
As arranged with your Committee, we have had the heating officially worked by the Contractors from Wednesday 2nd. March to Tuesday 8th. March. During that time the lowest temperature outside was 41° and the highest 48°.
As you are aware there are 15 sets of coils in the Heating Chamber, and during the period tested it was unnecessary to use more than 5 of these, so that with the temperature as above there is a reserve of 10 coils. As it was found unnecessary to keep on the 5 coils all the time and when the heat was once raised 2 or 3 coils as the case might require were shut off. There was no difficulty in keeping the temperature at a degree suitable for working in, and with the reserve that you have in hand we are of opinion that the installation is fully up to specification.

> We found that the duct leading to the Library was of metal and that there must have been a considerable fall of heat at that point. This we have had covered in, and packed with slagg wool and the air is now delivered to that room at several degrees higher than formerly.
>
> The Library window is glazed with sheet glass, and as that is thinner than plate there is a greater fall in the temperature of this Room, when the heating is off, than in the other rooms which are glazed with plate and in many instances double glazed. It might be found necessary later on to double glaze these windows with new sashes, but in the meantime and awaiting the thorough drying of the Building we think it inadvisable to proceed with this at once.
>
> We have had a note of the coal consumpt from January 31st., to March 5th., and find that an average of 13 ½ tons per week is consumed. We are inferred by the Contractor that this is a very moderate consumpt of coal.
>
> It has been suggested that the various circulations 6 in all should be controlled with screw down valves. 2 of these in the Heating Chamber and 4 in the rooms, and we have ascertained that the cost of this will be £22. 10. We are of opinion that this is a desirable addition and the reason why it was not originally included was on account of an objection by Mr. Mollison when this was formerly proposed.
>
> We hope you will find the result of these tests satisfactory. It is unlikely that the scheme can be tested under more severe conditions until next winter, but we are satisfied with the reserve you have in hand that you have sufficient power unless in perfectly abnormal conditions to keep the School in excellent working condition.
>
> Faithfully yours,
>
> (Signed) Honeyman, Keppie & Mackintosh."[58]

The average temperatures recorded in the library and studio 24 on the ground floor are equivalent to 16.3°C (61.3°F) and 15.8°C (60.4°F) respectively, while in the larger studio 42 on the first floor the average recorded temperature was 21.1°C (70°F). This difference is accounted for by the fact that studio 42 was one of the life studios (Fig. 12).[59] James Macaulay has argued that the installation of the air system should hardly be seen as a surprise given the architects' own contention in their description of the design that "this system is almost too well known to require advocacy and has been applied with success to many well-known buildings in Glasgow."[60] However, given the fact that the installation was seemingly *so* over-specified we might question this assertion – it would not be the first time that an architect had displayed an overly exaggerated confidence in their experience of a particular technology in order to discourage any questions as to its economy compared with a more standard alternative. The rejection (and then suggested addition) of screw valves is further evidence that the engineers did not know enough about how the system might work to be fully confident in ensuring their initial scheme was executed as designed.

Banham also described the school's system as being of secondary importance compared with Key's system at the Royal Victoria Hospital in Belfast, though the former is in fact an earlier system, and very much integral to the architecture, with a complex network of plenums assembled along an east-west 'spine' wall acting to condition all the spaces in the building. In this way, the installation at the School of Art is completely integrated with the wider environmental design strategy of the building (dividing spaces between north and south as appropriate for lighting and thermal comfort), while the wards of the Royal Victoria Hospital are planned linearly as a consequence of the single underground ventilating duct.[61]

However, while the system appears to have been more than able to supply enough heat to overcome the coldest of Glasgow nights, the constant maintenance it would have required – both to the fans and filters themselves as well as the trap doors in the plenums (used to fine-tune the amount of air distributed to different parts of the building) – would no doubt have been a major drawback. It seems the system was almost too successful in its complexity, as it was replaced by a piped hot water system in 1920.[62]

Total Design

While the north façade of the Glasgow School of Art has attracted much attention for its 'proto-modernity', perhaps a more telling display of Mackintosh's evolution as a designer from 1897 to 1910 is revealed in the south façade of the building that rises high above Sauchiehall Street at the bottom of the Garnet Hill (Fig. 13). Here it can be seen that the western portion is extensively more punctured than the eastern, and in plan the potential for sun penetration of the corridors (and consequential opportunity for behavioral adaptation to the climate) is markedly more pronounced. While the first phase reads as a pragmatic response to the brief, although radical in its lack of ornamentation, in the second phase "each part of the building was then subjected to examination and re-examination as details design or building work proceeded, a process of tactical confrontation with the potential of each particular situation."[63] Smaller spaces benefit from solar gains that are exploited to great advantage (for example the window carrels in the corridors opposite the studios, or the drawing desks in the loggia looking out over the Clyde) (Fig. 14).

Mackintosh's work as a graphic artist and designer of furniture, collaborating with his wife Margaret Macdonald, Herbert McNair and Margaret's sister Frances ('The Four' exhibited at the Vienna Secession in 1900), would have made him well aware of the fashionable European aesthetic theory of Gesamtkunstwerk (literally 'total work of art'), coined by Richard Wagner to describe his seminal operas, encompassing music, fine art, literature and performing art in one totality. Mackintosh was not alone in adapting the philosophy to architecture. The Greene brothers, Joseph Hoffman, Henry van de Velde and Frank Lloyd Wright among others all embraced the idea, as did the Wiener Werkstätte collectively and of course the Bauhaus, who adopted it almost as their founding principle. But Mackintosh stands out for his ability to conceive of 'total design' not only as a physical aesthetic but to extend it to the invisible, experiential and atmospheric qualities of architecture. Desmond Mountjoy, a close friend and part-time cultural commentator and art historian composed a short essay on the Mackintoshes and their Glasgow lifestyle in 1910, just as the art school was completed. He wrote:

> It is far away in that mist-encircled, grim city of the north which is filled with echoes of the terrible screech of the utilitarian, and haunted by the hideous eyes of thousands who make their God of gold. Vulgar ideals, and the triumph of the obvious, are characteristic of the lives of the greater proportion of its population; and yet, in the midst of so much that is incongruous and debasing, we find a little white home, full of quaint and beautiful things, with a big white studio.[64]

Mackintosh's growing understanding of the importance of the local environment to the habitation of his buildings can also be clearly read in the houses he designed in the period, and the controlled manner in which they take advantage of their north-south orientations. Fred Smith amongst others has commented on the east-west spine wall that is present in

Windyhill, Hill House and Scotland Street School, which plays such a central role in the environmental regulation and disposition of the spaces inside.[66]

The key to the architectural experience of the School of Art lies in the experience of moving between the internal spaces of the building with their unique atmospheric fine-tuning, suggesting the use of different spaces for different activities. Take for instance consideration of light; perception of lighting 'quality' will differ significantly depending on whether the question is considered in relation to a particular task (drawing, reading, or more casual activities such as eating). Entering the School of Art from Renfrew Street the visitor proceeds up a flight of stone steps that takes him or her through the front door above the boiler in the basement beneath – the warmth underfoot is matched by the relative darkness in offering a marked sense of enclosure and protection from the famously variable Glasgow elements. The visitor is then drawn up the main stairs by light filtering down from above, into the Museum which is broadly lit by glazed strip lights in the pitched roof: it is as if one has been transported outside again, only into an idealised environment for viewing art (Fig. 15). The relationship between the studios to the north of the spine wall, and corridor, loggia and hen run to the south is similar: the north light provided by the famous studio windows creates *the* ideal environment for painting and composition, but also heightens the pleasures afforded by the warmth of the horizontal sun when it punctures the façade in the south-facing spaces. The spine wall carrying the ducts plays a crucial role in the design: it is in effect the hearth of the building, a solid expanse of thermal mass to retreat to in the cool of winter or heat of summer. This can be seen in the thermal properties of the adjacent spaces – the larger volumes, such as the studios and museums space, have a greater temperature range than the smaller volumes (where the thermal dampening effect of the mass of the warmed spine wall will have more impact) such as the corridors or the library (the only exception to this rule is in the 'hen run', where the heat transfer through the all-glass construction largely counteracts the effect of the thermal mass).[67] Instead of fireplaces the spine wall is equipped with hinged drawers that would flood the spaces with tempered air from the fan room (Figs. 16, 17). The key to the sophistication of this environmental design therefore lies in the combination of Mackintosh's understanding of the peculiar local character of the Glasgow climate, and the opportunities afforded for occupants to take control of their own comfort and surroundings.

Conclusion

Compared with other building types, the combination of the quantity and complexity of the quality of light required for an art school was unique in late Victorian Britain. Factories and train sheds often followed the example of the Crystal Palace in the use of steel and glass roofs as a structural strategy to span large spaces that more than adequately illuminated the spaces beneath for the use of complex machinery, and art galleries tempered this simple device with the thermal properties of masonry and the horizontal moderation of direct light necessary to protect art displayed to the public for the first time. Town halls and law courts, on the other hand, more concerned with the political display of civic propriety, often took the form of expansive mat plans punctuated by light wells with little thought given to the orientation or quantity of light admitted through uniformly respectable moulded facades. While more overt in their expression of the requirement for plentiful light, the new board schools that sprung up in various cities around the country often had to make do with less than ideal inner city sites, and so classrooms were lit from whichever orientations offered the easiest access to open space. As has been demonstrated, however, the architects of the art schools in Manchester, Birmingham and Glasgow went out of their way to secure what they considered the best light for studio spaces: directional north light encompassing a segment of the sky from the horizon to as close to the apex as was practicable without admitting glare. This led to quantifiably more glass being employed in carefully selected areas of the facades, quantifiably more light being admitted into the interior, and the deployment of architecturally radical servicing strategies to moderate the unusually thermally sensitive interior environments that resulted.

The contemporary testing and discussion of the warm air system at the school in Glasgow represents an early case of the now widely documented phenomenon whereby the resolution of environmental problems with improved technology leads to more demanding expectations of comfort on the part of building users. However it is striking that the accepted range of comfort conditions in the school, between approximately 15°C and 18°C (59 - 64°F) in the regular studios in February/March 1910 (the temperature was raised in the life studios by means of radiators), is around 4°C (7°F) lower than that which would be accepted today. This can be explained partly by changing socio-cultural factors (e.g. as regards clothing), but must also represent evidence of a rapid evolution of physiological expectations, as technological servicing regimes have become the norm rather than the exception.

While the influence of Mackintosh on the story of the development of the tectonics of modern architecture is much disputed (both in terms of whether modernism represented a radical break or a continuation and evolution of the groundwork of the late nineteenth century Arts and Crafts movement), the research presented here demonstrates at least that the environmental design of the Glasgow School of Art represents an essential part of the story of a paradigm shift in the conception of the internal environment of large institutional and commercial buildings, that arguably began in the mid-nineteenth century and was finally resolved with the development of modern air conditioning systems in the twentieth century. The essential catalyst for this change was an architectural desire to resolve the internal problems caused by the state of the atmosphere of the industrial city. This objective was sometimes (but not always) divorced from the anxiety about the state of the exterior climate, but it is ironic that when the seemingly insurmountable environmental problems that faced the atmosphere of the city were resolved, beginning with the Clean Air Act in London in 1952, the solution (air-conditioned interior environments divorced entirely from the outside and maintained by the application of large amounts of cheap energy) was so successful that it remains difficult for architects to make a case for a return to a less energy intensive, more passive method of regulating the interior environment of buildings. Within this narrative, the Glasgow School of Art stands out for three reasons: it arguably represents on one hand the culmination of Arts and Crafts environmental principles about the shaping of buildings to a particular local climate (as argued by Hawkes[73]), paradoxically at the same time the building integrates a universal technological system that allows an unprecedented level of control to be maintained over the environment of individual rooms and spaces (with consequences in the future for the tolerance users of the building would then have for internal conditions), but perhaps most significantly, these different environmental strategies and qualities are integrated architecturally with an unprecedented level of sophistication. In the quest for ever more light and cleaner air, supported by new technologies still in their infancy, in the face of the satanic darkness of the previous century, and in the evolution of the design of the varied and highly specialised spaces of the art school we can recognise the origins of the functional and environmental agenda of the modern movement.

Postscript: The Environment of the School Today

The building is now heated by a heat exchanger that extracts heat from a District Heating System located in the Bourdon building (currently the School of Architecture) to the west. A Building Management System monitors outside and internal air temperatures and humidities primarily in spaces considered key to the 'heritage' of the building (as the system was installed as part of a Lottery-funded preservation project).

The target room temperature during occupancy hours in all spaces is set at 20°C (68°F), and the minimum acceptable temperature on a 24-hour cycle is set at 11°C (52°F). When temperatures fall below 17°C (63°F) in the monitored spaces, the heating is switched on, and when temperatures reach 19°C (66°F) it is turned off again. Dampers installed in the original air plenums of the building open at 20°C (68°F) and close again at 18°C (64°F). In case of excessive heat gains in summer, two sets of auxiliary extract fans in the plenum system turn on at 25°C (77°F) and 28°C (82°F), and off at 22°C (72°F) and 25°C (77°F) respectively.[74]

While the new system of radiative heating panels was being installed in the building the author conducted a survey of occupant comfort, comparing the spaces where the new system had been installed with those spaces heated only by wall mounted radiators (the original plenum system no longer being operative). Occupants were asked for their 'Actual Mean Vote' on the ASHRAE Thermal Sensation Scale[76] and their 'Thermal Preference Vote' on the Nicol Scale, in order to differentiate between actual feeling and preferred feeling, as it should not be taken for granted that the preferred feeling is neutral (Fig. 18).[77] The surprising result was that the spaces which did not have the new system installed (which experienced a much wider range of temperatures), were found to be significantly more comfortable by the occupants. By way of explanation, occupants often commented that they expected the building to 'behave' in a certain way, as they were aware it was an old heavy stone building with little insulation, with large north facing windows. It seems that the discomfort associated with the new heating system was as much psychological as physiological.

The alterations have changed the atmospheric experience of the building as designed by Mackintosh – making the internal conditions more stable and uniform – an intervention which is paradoxically associated with greater discomfort by the occupants. As environmental quality is intrinsic to the architectural experience of a building – what UNESCO terms 'intangible heritage' – it should also be considered alongside the physical fabric when it comes to the conservation of significant buildings.[78]

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[2] T. Howarth, *Charles Rennie Mackintosh and the Modern Movement* (London: Routledge and Kegan Paul, 1952).
[3] Ibid., 74.
[4] Ibid., 75.
[6] K. Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture* (Cambridge, Mass., London: MIT Press, 1995), 2.
[7] D. Brett, *C.R. Mackintosh: The Poetics of Workmanship* (London: Reaktion Books, 1992), 99; Brett's argument is that "our relationship to structures is infused with bodily expectations - of weight, tension, impetus and rest." In the School of Art, "the more private the situation, the more likely a material is to be disguised; and the more public, the more likely it is to be displayed... The interactions between different materials and their working, and their relation to the several kinds of spaces, can be shown to reveal patterns that I will call a 'poetics'". Ibid., 75–76.
[12] Department of Science and Art, *Directory, with Regulations for Establishing and Conducting Schools of Art* (London: Department of Science and Art, 1888), 114.
[13] Ibid.
[14] J. F. Physick, *The Victoria and Albert Museum: The History of Its Building* (Oxford: Phaidon Christie's, 1982), 97–99.
[15] Department of Science and Art, *Tenth Report* (London: Department of Science and Art, 1862), 131.
[16] N. Pevsner, *Lancashire: The Industrial And Commercial South* (New Haven: Yale University Press, 1969), 313.
[17] For more on the history of the evolution of the art school building type, see R. Lawrence, "The Evolution of the Victorian Art School," *The Journal of Architecture* (forthcoming).
[18] The Glasgow School of Art, "Report of Deputation Appointed to Visit Manchester, Birmingham and London," March 1893, 3.
[19] Glasgow School of Art Building Committee, "Minutes," n.d., 2–20.
[20] R. G. Hatton, *Guide to the Establishment and Equipment of Art Classes and Schools of Art: With Estimates of Probable Cost, Etc.* (London: Chapman & Hall, 1895), 37–38.
[21] These descriptions are taken from the annotations on Mackintosh's sections of the completed building.
[22] These daylight factor calculations were conducted by the author in February 2009, between 1230 and 1300 hours, with external lux readings falling from 10,030 to 7,600 lux. As such, they are based on minor obstruction from the now demolished Foulis building and Newbery Tower on the north side of Renfrew Street (however this would have minimal affect on the figures as they obstruct light from the horizon rather than the brighter azimuth. Nevertheless, it is probably safe to assume that Mackintosh would have expected buildings of a comparable scale to be constructed opposite the art school.

[25] O. Prizeman, "Philanthropy and Light: The Formulation of Transatlantic Environmental Standards for Public Interiors through Andrew Carnegie's Library Building Programme, 1889-1910" (PhD, University of Cambridge, 2010), 185.
[26] W. Nicholson, *Smoke Abatement: a Manual for the Use of Manufacturers, Inspectors, Medical Officers of Health, Engineers, and Others* (London: Griffin, 1905).
[27] D. Hawkes, *Architecture and Climate: An Environmental History of British Architecture, 1600-2000* (Taylor & Francis, 2012), 129–130.
[28] H. H. Kimball, "The Meteorological Aspect of the Smoke Problem," *Monthly Weather Review* 42 (1914): 29–34.
[29] Glasgow School of Art Building Committee, "Minutes," 79–84.
[30] R. Banham, *Architecture of the Well-tempered Environment* (London: Architectural Press, 1969), 84.
[31] G. M. Cairns, "The Glasgow School of Art: An Architectural Totality" (PhD, University of Glasgow, 1992).
[32] B. Nagengast, "Early Twentieth Century Air-Conditioning Engineering," *ASHRAE Journal* (March 1999): 55.
[33] It is probable that Key's interest in developing this technology was initially as a tool to defend the market share of gas from the availability of cheap oil to the working classes and the new technology of electricity (which was installed at the School of Art) to wealthier clients. It was widely hoped that a method of taking away the bad odours and soot associated with gas, and the reliability of its supply, would ensure its survival as the dominant lighting system long into the twentieth century.
[34] J. S. Billings, *Ventilation and Heating* (New York: The Engineering Record, 1893).
[35] The term "ventilator" itself, as has been widely documented, refers to Dr Desaguliers's installation of a seven-foot diameter fan in the House of Commons in 1736, where, until 1817, the "ventilator" was the man responsible for cranking the fan by hand. See, for example, N. S. Billington, *Building Services Engineering: A Review of Its Development*, International Series on Building Environmental Engineering v. 1 (Oxford: Pergamon, 1982).
[36] B. M. Roberts and CIBSE Heritage Group, "Wilson Weatherley Phipson: Victorian Engineer Extraordinary, 1838-1891," 60, accessed November 16, 2010, http://www.hevac-heritage.org/electronic_books/WWP/WWP.htm. Phipson presented a paper on the installation to the Institution of Civil Engineers in 1878, where it was criticised by Professor James Thomson, brother of Lord Kelvin, who had heard "great complaints as to the ventilation of some of the crowded classrooms", and by a Mr Imray, who worked with Dr Reid on St. George's Hall in Liverpool, who described the system as "worse than useless", though to what extent this simply represented loyalty to a famous competitor is another question.
[37] See for instance J. Cook and T. Hinchcliffe, "Designing the Well-Tempered Institution of 1873," *Arq: Architectural Research Quarterly* 1, no. 02 (1995): 70–78.
[38] One report by the Schools Enquiry Commission of 1868 estimated that only a quarter of schools reached minimum acceptable environmental standards. See M. Vivian, J. Seaborne and R. Lowe, *The English School: Its Architecture and Organization: 1870-1970*, vol. 2 (London: Routledge & Kegan Paul, 1977), 5.
[39] Billings, *Ventilation and Heating*.
[40] See R. S. Blackham, *Roots of Tolkien's Middle Earth* (Stroud: History Press Limited, 2006).
[41] S. Macdonald, *The History and Philosophy of Art Education* (London: University of London Press, 1970), 185; For more information on ventilation and the development of indoor air quality standards in schools in Scotland, see C. Porteous, "Sensing A Historic Low-CO2 Future," in *Chemistry, Emission Control, Radioactive Pollution and Indoor Air*

Quality (InTech, 2011), http://www.intechopen.com/articles/show/title/sensing-a-historic-low-co2-future.
[42] Birmingham Society of Arts and School of Design Management Committee, "Minutes," n.d., 22–23.
[43] A typical installation described by the company's historian is as follows: "Fresh air came in through a duct from outside in the graveyard, and went down into a chamber in which the furnace was situated. The air got heated by coming into contact with the iron casing, the furnace, and then went out through a duct in the floor of the church, circling round and returning through another duct in the chamber, to be re-heated." G. N. Haden & Sons Ltd, "Transcript of a Tape-recorded Conversation Between Mr R. L. Cox, Haden's Historian, and a Visitor to the Exhibition of Documents, Drawings, Photographs and Models Held at Tavistock Square, London in 1966 to Commemorate Haden's 150th Anniversary," 1966, 10–11, http://www.hevac-heritage.org/electronic_books/haden_activities/haden_activities.htm.
[44] J. Swift (1996), *Changing Fortunes: The Birmingham School of Art Building 1880-1995* (Birmingham: ARTicle Press, 1996), 11.
[45] According to R. L. Cox, "other forms of heating began to supersede the warm air system, in many types of building anyway, and I suppose that most frequently used was the low temperature hot water system, or as it was called in those days, the warm water system. This term sounds a bit amusing today, but they had a fear that if air passed over a hot surface – by hot I am not sure what they meant – it would produce that burnt smell and perhaps make air injurious to health. This effect was no doubt quite common with certain makes of warm air stove, so they applied the same reasoning to radiating surface heated by hot water." G. N. Haden & Sons Ltd, "Transcript of a Tape-recorded Conversation Between Mr R. L. Cox, Haden's Historian, and a Visitor to the Exhibition of Documents, Drawings, Photographs and Models Held at Tavistock Square, London in 1966 to Commemorate Haden's 150th Anniversary," 13.
[46] Birmingham Museum and School of Art Committee, *Minutes*, I, pp. 10–15.
[47] Swift (1996), *Changing Fortunes*, 12; Birmingham Society of Arts and School of Design Management Committee, "Minutes," 257.
[48] P. Planat, *Course de Construction Civile, Part 1: Chauffage Et Ventilation Des Lieux Habites* (Paris, 1880).
[49] D. Stark, *Charles Rennie Mackintosh and Co., 1854 to 2004* (Glasgow: Stenlake Publishing, 2004), 199.
[50] B. M. Roberts and CIBSE Heritage Group, *Building Services Heritage* (CIBSE Heritage Group, 2003), 21.
[51] English Heritage, "Heating and Ventilation," Publication Cover, January 20, 2009, 37, http://www.english-heritage.org.uk/publications/heating-ventilation/.
[52] B. F. Co Sturtevant, *Ventilation and Heating, Principles and Application*, 1896, 105–107.
[53] Cairns, "The Glasgow School of Art: An Architectural Totality," 99–100.
[54] Glasgow School of Art Building Committee, "Minutes," 79–84.
[55] Ibid., 59–60.
[56] Glasgow School of Art Architect's Correspondence, n.d., 3/1/12e.
[57] Ibid., loose letter.
[58] Ibid., loose report.
[59] It is interesting to note how much lower these temperatures are then present day comfort standards – and yet they were deemed satisfactory. Victorian standards of dress might be held responsible, though it is tempting to speculate that the building's users might also have had expectations more in line with the natural properties of the building's construction and the changing seasons.

[60] GSA Archives, Box A/12, "Description and Schedule of Contents", in James Macaulay, *Glasgow School of Art: Charles Rennie Mackintosh* (London: Phaidon, 1993), 7.
[61] See R. Bruegmann, "Central Heating and Forced Ventilation: Origins and Effects on Architectural Design," *Journal of the Society of Architectural Historians* 37, no. 3 (October 1, 1978): 154.
[62] A. Brown, R. McKenzie, and R. Proctor, eds., *The Flower and the Green Leaf: Glasgow School of Art in the Time of Charles Rennie Mackintosh* (Edinburgh: Luath Press Ltd, 2009).
[63] A. MacMillan, "A Modern Enigma: A Paradox of Reduction and Enrichment," in *Mackintosh's Masterwork: The Glasgow School of Art* (Glasgow: Chambers, 1989), 66.
[64] D. Mountjoy, *A Creel of Peat: Stray Papers* (London: Adelphi Press, 1910), 5.
[66] Conversation with author, 25/03/09.
[67] On an overcast day in March the diurnal temperature range of one of the studios and museum were measured to be around 3.5K, compared with around 2K in the corridor and library. These measurements were taken in March 2009 – however the modern computer-controlled heating regime is set up with the same control profile for the whole building, so we can assume any differences are a result of the physical properties of the various spaces.
[73] D. Hawkes, "Il Movimento Arts and Crafts e l'Architettura dell'Era Post-Industriale," in *Regionalismo dell'Architettura* (Padova: Franco Muzzio, 1990), 111.
[74] Taken From Commissioning Settings, DSK Controls, courtesy of Harley Haddow Consulting Engineers, Edinburgh.
[76] ASHRAE, "Standard 55: Thermal Environment Conditions for Human Occupancy" (ASHRAE, 2004).
[77] M. Humphreys and M. Hancock, "Do People Like to Feel 'neutral'?: Exploring the Variation of the Desired Thermal Sensation on the ASHRAE Scale," *Energy and Buildings* 39 (2007): 867–874.
[78] See R. Lawrence, "Assessing the Environmental Heritage Value of Atmospheric Experience," *Proceedings of the International Conference on Intervention Approaches for 20th Century Architectural Heritage* (June 2011).

Captions

Fig.1. The north façade of Glasgow School of Art to Renfrew Street, showing the main studio windows.
Fig.2. The studios at South Kensington.
Fig.3. The north façade of Manchester School of Art to Grosvenor Square.
Fig.4. The art laboratory, Birmingham School of Art.
Fig.5. The composition room, Glasgow School of Art.
Fig.6. Interior of studio, Glasgow School of Art.
Fig.7. Light fittings in photograph by Henry Bedford Lemere.
Fig.8. Plan of the extension basement, indicating location of duct system, Birmingham School of Art.
Fig.9. Chimney, Birmingham School of Art.
Fig.10. "Duplex Heating and Ventilating Apparatus", from B. F. Co Sturtevant, *Ventilation and Heating, Principles and Application*, 1896.
Fig.11. Section detailing fan installation and main plenum, Glasgow School of Art.
Fig.12. Tests of heating system of the Glasgow School of Art.
Fig.13. The south façade of Glasgow School of Art.
Fig.14. Corridor, Glasgow School of Art.

Fig.15. The museum, Glasgow School of Art.
Fig.16. Closed ventilation drawers on the spine wall, ground floor corridor.
Fig.17. Open ventilation drawers on the spine wall, first floor corridor.
Fig.18. Actual Mean Vote and Thermal Preference Vote.