Witness to the Light
The Evolution of Church Sanctuary Design & Standards of Comfort in the Last Century in Harrison County, Iowa

by

Sharon J. Gochenour

Submitted to the Department of Architecture in Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science in
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Signature of Author..
Department of Architecture
May 21, 2010

Certified by ....
Marilyne Andersen
Associate Professor, Building Technology
Thesis Supervisor

Accepted by ....
Leslie K. Norford
Professor, Building Technology
Chairman, Undergraduate Curriculum Committee

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ABSTRACT

This thesis investigates the factors that have caused changes in church sanctuary design in Harrison County, Iowa in the last century, focusing on daylight and thermal qualities. Most of the churches in the county today were built in the Gothic and Romanesque Revival styles between 1880 and 1930, before the era of active climate control. Cultural, historic, and aesthetic factors, as well as the available heating technology, shaped the original design of each church. As the ability to heat and cool interior spaces became more advanced, expectations of comfort changed and design priorities shifted. To understand the effects of changes in design and their likely motivation, case studies of the Missouri Valley Church of Christ and the Logan Christian Church were done, two churches built in the early 20th century and remodeled extensively in the middle of the century. These case studies included daylight simulations and thermal calculations. In general, in the post-renovation condition these churches had less illuminance throughout the year, somewhat less glare, and much less energy lost to conduction and ventilation. In the context of other area churches, it seems likely that new churches built in this county will have less glazing, overhangs to control overheating in the summer, and greater care taken when siting the church.

Thesis Supervisor: Marilyne Andersen
Title: Associate Professor, Building Technology

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1.0 Introduction

Given the most recent developments in church buildings in Harrison County (figure 1), the future of the local church as both an elevating visual experience and a hallmark of small-town architecture seems somewhat grim. Clearly the priorities of some congregations have changed. What is driving these changes? The rising costs of maintaining a climate-controlled building are likely implicated, but how specifically do they affect the way congregations go about designing and updating their churches?

How have changing standards of comfort and energy usage affected the renovation of historic churches and the design of new churches in Harrison County, Iowa?

1.1 Research context

What forces determine the shape of vernacular architecture? Certain aspects of form are dictated by climate, some by personal taste, others by economic necessity, and some by prevailing styles. When forces seem to be opposing and competing with one another – tradition and maintenance, aesthetics and comfort – which prevail? What does this show about the community that built this architecture, and what does it predict about the future of vernacular design?

Figure 1. Sunrise Community Church of the Nazarene, Missouri Valley, Iowa; former church building outside of Woodbine, Iowa (Google Maps 2010).

The buildings shown in figure 1 were both built as churches in the last decade in Harrison County. The structure on the left still houses a congregation in Missouri Valley, while the building on the right later became Norm's Tires and then a daycare center. Apart from the small "steeples" and small arched windows, these buildings' characteristics – a long, rectangular building with vertical metal siding and pitched roof – are more typical of another common structure of this agricultural area, large sheds used to house tractors and other machinery. These buildings stand in somewhat startling contrast to earlier church structures in the same area, which often contain elaborate stained glass windows, high ceilings, and true steeples with one or more bells. This contrast frames the comfort- and energy-related changes in design that have taken place over the last century.

1.1.1 Harrison County, Iowa

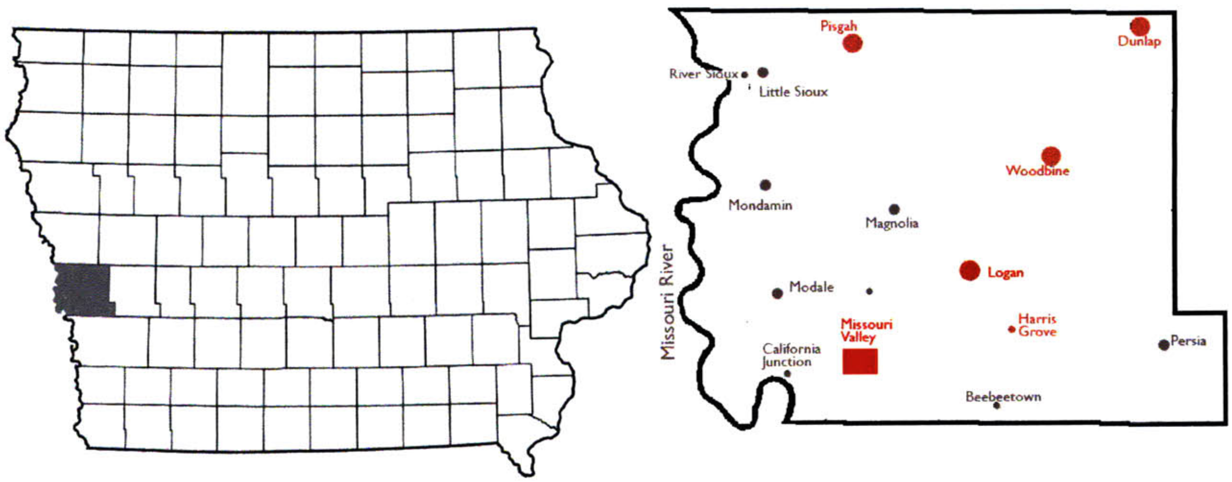


Figure 2. Map of the state of Iowa showing the location of Harrison County and the location of towns within Harrison County. Observations were made in towns highlighted in red (*Harrison County* 2009).

Harrison County (shown in figure 2) consists of 697 square miles and about 15,200 residents in a fertile portion of southwestern Iowa *(Harrison County* 2009*)*. It is an ethnically homogeneous area currently containing 40 active churches, of which five are Catholic, and the remainder of which span many of the major Christian denominations of the United States – Methodist, Presbyterian, Lutheran, Baptist, and a few others, most notably the Community of Christ Church, formerly the Reformed Church of Latter-Day Saints. About half of the churches in this county were established before the 1930s, though many currently occupy church buildings were constructed after that time (Darling 2009).

The study of church buildings is particularly interesting because of the interactions present between considerations of history, visual experience, and culture as well as more mundane construction and maintenance costs. This small area allows for an examination of the development of an important component of American vernacular religious architecture in a specific and limited context. The first white settlers did not arrive in this area until 1846, in the form of a family who parted ways from the initial Mormon journey to Utah (Hunt 1915). These settlers were primarily of English and German origin, though later some families of Irish and Czech descent would begin to enter the area (Hunt 1915). Until recently, the primary industries of the area have been agriculture and the railroad. Only three cities of any size are close enough to be influential – Des Moines, 130 miles away, Sioux City, 75 miles away, and Omaha, Nebraska, 30 miles away. This scarce population means that deliberate architectural planning largely passed over this area, leaving a great deal of room for local congregations and craftsmen to improvise. The number of influences on church architecture in this area, then, is quite small, when compared to similar areas in states like Illinois or Wisconsin, which have been inhabited for as much as a century longer and played host to the explorations of influential architects, and certainly when compared to a large urban area, such as New York or Boston.

Having lived in this county for eighteen years, I have moved in and out of many of its church buildings for various religious services and social functions – funerals, weddings, memorial services, and fish fries. I have encountered numerous incarnations of church daylighting, as well as oral histories of why these design decisions were made. This early exposure developed an interest in acquiring a more concrete grasp on how and why congregations had decided to construct and remodel their sanctuaries in a given way.

1.1.2 Typical church daylight evolution

Early Harrison County churches can be characterized by typical periodic changes in the church building, including the installation of electricity, expansion of the church building, and refinishing the interior. These changes also, sometimes unintentionally, affect the daylighting in the sanctuary. Many of the churches in this county were built before the advent of readily available electricity in the county – for instance, the Little Sioux Methodist Church, built originally in the 1870s, was not wired for electricity until 1922 (Darling 2009). The original church buildings likely had to rely largely on natural light for their services, while today's congregations have usually added electric light fixtures in their sanctuaries.

These windows also have an enormous thermal impact. When many of these churches were constructed, it seems likely that only limited (if any) heating or ventilation system was in place. The windows would be extremely important in maintaining the interior environment, as they allow for both thermal gains and losses. Advances made in HVAC systems became increasingly able to mitigate this gains and losses in the last century. Forced air heating systems began to be installed in British and American public buildings in the mid-19th century (Bruegmann 1978). However, rural construction trends often lagged their urban counterparts by several decades.

Large expanses of glass that released a great deal of heat in the winter and allowed in an excessive amount of heat in the summer may have been tolerated more readily before total climate control was readily available. Some churches have chosen to simply apply another layer of glass on top on their extant large sanctuary windows, stained glass or otherwise, while others may have eliminated such windows entirely while remodeling or rebuilding. Certainly increased interior environmental control became possible upon the advent of forced-air HVAC systems, but the expenditures required by these systems also made new economic demands that may have forced public buildings such as churches to realign their design priorities.

Other common changes include the addition of educational and administrative spaces, other buildings, or trees around the church that now block or filter the light available to its sanctuary. When Iowa was settled, it was almost entirely open grass prairie, with virtually no trees in existence. Over the past century and half, lived-in and the edges of agricultural areas have become increasingly wooded (Iowa Prairie Network). It is likely that the exterior finishes on several churches have also changed. Many were built at least nominally in the "Prairie Gothic" or Romanesque Revival style. Churches in these styles in other areas of the U.S. were sometimes painted gray or tan to look like stone before being whitewashed in more recent years (Steege 1987). This pair of images of the Dunlap Congregational Church, below in figure 3, suggests a similar change of finishes.

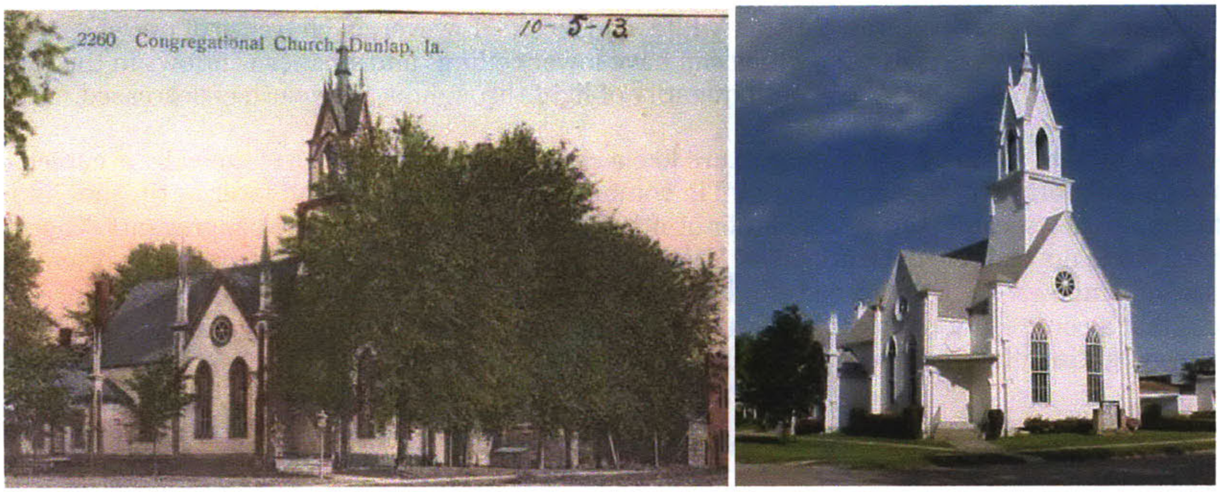


Figure 3. Dunlap Congregational Church from a 1913 postcard; Dunlap Congregational Church in 2001 (Walsh 2009).

Many older sanctuaries have entirely remodeled interiors – pews oriented in new ways, ceilings dropped, and original finishes replaced, all of which strongly affect the daylight of the interior (Missouri Valley Christian Church). In more recently built churches, changes to the approach to the design of space and light of the sanctuary are even more evident.

Figure 4. Grace Community Fellowship Church, built in 1954 (Google Maps).

In figure 4 above, a more typically modern approaches to sanctuary construction can be seen. The windows are made of uncolored glass and take up a relatively small percentage of the overall wall space. There is no steeple; the most noticeable signs that this is a religious, semi-public building are the double doors and the single, undifferentiated volume of the building.

How have these changes in typical treatment of the sanctuary and its lighting affected the light inside? They have profound effects upon the quantity and timing of light, the presence of glare, and the thermal comfort due to solar gains. The specific effects of changes in turn reflects upon the changing priorities of the congregation in terms of visual and thermal comfort.

The quantity of light is determined by the amount of direct light and reflected light the sanctuary receives throughout the year. The amount of reflected light is determined by exterior and interior finishes, external barriers, and the geometry of the building, while direct light is primarily affected by the geometry of the building and the placement and size of the windows. In some remodeling cases, the quantity of light available in the sanctuary may have increased after removal of old stained glass windows, repainting dark interior finishes white, and so on. However, in churches of newer construction (as shown in figure 4), which can have lower ceilings and smaller windows in the sanctuary, it seems likely that the overall quantity of light throughout the year has decreased.

The timing of light is important in a structure like a church sanctuary, which is typically occupied only during a small portion of the weak. Timing, in combination with exterior and interior finishes and the orientation of pews, can determine whether or not glare is bothersome for the congregants. Thermal comfort, while now largely determined by HVAC systems, is also highly dependent on the orientation and size of windows – a badly placed window can result in overheated congregants, for instance. The choices that a congregation makes in preserving, updating, or replacing the sanctuary architecture that affects daylighting illuminate something about their priorities as a church.

1.2 Design Movements leading up to Prairie Gothic

All you who seek to honor these doors,
Marvel not at the gold and expense but at the
craftsmanship of the work.
The noble work is bright, but, being nobly bright, the work
Should brighten the minds, allowing them to travel through the lights
To the true light, where Christ is the true door.

These words were inscribed on the doors of the cathedral of St. Denis, built 1140-1144, at the instruction Abbot Suger (Halsall 1996, Trachtenberg & Hyman 2003). This early Gothic building pioneered many of the key components that later became characteristic of the type – the pointed arch, the rose window, and the attention to light as a spiritual aspect of the church that would influence virtually all later Western Christian houses of worship (Suger 2009).

This idea about light in the church – as a way to not only glorify God through fine craftsmanship but also to bridge the enormous chasm between heaven and earth – to "travel through the lights/To the true light" – persisted for many centuries in European church building, evidenced by great care given to the windows of Gothic-style churches and cathedrals (Trachtenberg & Hyman 2003). Colored glass in these windows could both be worked to represent important figures and stories from the Bible and add interest and sparkle to an often overcast, monochromatic northern European sky (Lam 1986). Stained glass containing figures and religious scenes was found throughout Europe from the 1100s to the 1500s, but from 1600 on stained glass was only a minor decorative element in otherwise clear windows (Raguin 1990). As the sculptural extravagance of the Baroque period blossomed, the tradition of colored glass waned dramatically, to such an extant that in the late 1700s, a craftsman was hired to replace the windows of "ancient style" in Notre-Dame of Paris with clear windows, their only color a thin border around the edges (Raguin 1990).

1.2.1. Overview of Church Design in America

These Gothic works of careful daylighting, however, are separated by several centuries and an ocean from the Harrison County churches that they strongly influenced, as shown by the presence of pointed arches, round windows, and steep spires in many area churches. The first of the still-extant 35 churches in this county was built in the 1870s (Darling 2009). How did important elements of this style come so far and become so widely interpreted?

For several centuries preceding the building of the Harrison County churches Protestant and Catholic church building practices diverged widely. In general, Catholic church spaces are focused on the mystery of the mass, the liturgical procession, and the holy relic present in the altar, while most Protestant churches were developed as simpler barns in which to hear the Word of God (Trachtenberg & Hyman 2003). Anglican and Episcopalian churches, which retained elements of the mass and liturgy, tended to use forms that more closely mirrored those of Catholic worship spaces (Williams 1997).

One of the first types of church established in America was the Puritan meetinghouse of the Northeast, a form that would later influence much pioneer architecture in its simplicity and functionalism (Williams 1997). The earliest of these structures, such as the Hingham Meetinghouse in Massachusetts, were relatively basic, with little ornament, high ceilings for good visibility of the pulpit, and some exposed construction, such as the rafters (Williams 1997, Trachtenberg & Hyman 2003). A style of construction later typical of less well-to-do congregations, the clapboard church of wooden construction and wooden siding, was also established in the Northeast. One last holdout remained from the Gothic period through all this time – the spire, a symbol of church visible from miles away. While initially Puritan churches scorned the stylistic architecture seen in Southern Episcopalian structures, by the 1700s New England churches were also being built in the Neoclassical Style (Williams 1997). This style was believed to indicate some of the order and discipline necessary to a holy church (Trachtenberg & Hyman 2003).

By the time white settlers had come to Iowa, however, architectural favor had fallen upon another historical style: The Gothic. Gothic revival in the United States, initiated by such buildings as Richard Upjohn's 1846 Trinity Church in New York, affected church building in the center of the country perhaps more than any other style (Heathcote & Moffatt 2007, Williams 1997). Architects such as Augustus Pugin attached not only stylistic but religious significance to the rise of this new building type. As the Gothic had been the only style entirely developed by Christian builders, he reasoned, it could be the only morally correct style in which to build a church. Neoclassical styles were based on the inventions of pagans and were therefore inferior (Heathcote & Moffatt 2007). The idea of the medieval Christian as a virtuous workman who created art in a state of mystic faith supported the Gothic revival style as not just the fashionable choice but the morally correct choice for the 19th century urban (and rural) context (Raguin 1990.) Perhaps the immigrants and migrants who came to find farmland in the Midwest embraced the Gothic and Romanesque Revivals styles because they saw attractive parallels between themselves and the faithful laborer archetypes associated with these periods. Many congregations chose to build structures which adhered with some strictness to Gothic forms and proportions, such as cruciform plans and colonnaded flanking aisles. Even in these hallchurch-like structures, however, care was taken to not isolate the back pews from the pulpit (Hampton 1997.) Other churches, even Catholic ones, chose to discard the aisles altogether in favor of better preaching space, instead incorporating extensive neo-Gothic ornamentation and windows to increase the visual complexity and interest of the sanctuary (Hampton 1997.)

A great influx of knowledge about a variety of historical styles in the late 1800s led to the development of an eclectic style in the United States, that not only utilized Gothic elements prominently but also Romanesque and Classical ones (Trachtenberg & Hyman 2003). The 1870s and the 1880s were periods of great experimentation in American architecture. During this time even wealthy congregations with the ability to hire an architect built churches with occasionally bizarre combinations of stylistic elements (Hampton 1997). The "Prairie Gothic" of the Iowa plains owes more to this impulse than pure Neo-Gothicism; pioneer church builders borrowed elements freely from all these styles (Williams 1997). Whatever impulse there was to improvise was somewhat reigned in by church-building pattern books that made their way westward with pastors and other settlers, such as Upjohn's *Rural Architecture* and the Congregational Church's 1853 publication, *A Book of Plans for Churches and Parsonages*. These books predominately contained plans for churches in the Gothic and

Romanesque styles, respectively (Steeges 1986). These styles would be maintained for many decades in the Midwest.

1.2.2. Window design trends

It had become fashionable in Europe in the late 18th and early 19th centuries to collect medieval stained glass, and these collections provided source material for neo-Gothic glass artists in the later 1800s. The composition of these collections also helped define what was considered desirable and "authentically" Gothic. For instance, one important collection, gathered by Lord Jerningham of Norfolk around 1800, was primarily late medieval German glass, a glazing tradition very distinct from the English (Raguin 1990). By 1839, enough research had been compiled about these windows of "ancient style" that artists felt themselves capable of producing new works in artistic continuity with those of several centuries earlier. These artists expressed great interest in artistic unity in church design as a superior value to historical authenticity (Raguin 1990).

The glazing tradition which perhaps that greatest influence on the churches of this area was the Munich Gothic. In the early 1800s, Ludwig I of Bavaria had encouraged a revival of crafts associated with Germanic heritage, such as the spectacular glazing tradition that had produced such works as Cologne Cathedral (Raguin 1990). Many German Catholic architects came to reside in the U.S. in the 1860s, and many distinctively German churches were built between 1865 and 1910, based both on Romanesque and Gothic traditions (Hampton 1997). The expanding railway allowed church plans and specifications to be shipped quickly across the United States, and notable German neo-Gothic churches were built in St. Paul, Minnesota and St. Louis, Missouri. While the Gothic revival movement in Episcopalian churches on the east coast focused on English Gothic had its beginnings in the 1840s, German scholars did not begin teaching principles of Gothic design until the mid 1850s (Hampton 1997). The timing of this influx of German design probably brought about its deep roots in the Midwest, as the land rush for cheap farm ground began almost at the same time (Tamisiea 1971).

The English tradition of stained glass, often embraced by American congregations who were ethnically Irish, English, or Scottish, typically contained figures that appeared more two-dimensional, scenes that lacked perspective, and sudden changes from colored to white glass (Raguin 1990.) These windows often occurred with Perpendicular Gothic framing, as very large areas of stained glass focused on vertical lines and delicate tracery (Ross 1996). This style was more formal, and less organic, than older Gothic styles (Ross 1996). In contrast, the German or Munich Gothic style of glazing was inspired by the Nazarene school of painting, which emphasized jewel colors of red, green, blue, and gold and three-dimensional figures (Raguin 1990).

Pioneer community churches usually started out with simple windows. While *Upjohn's Rural Architecture* proscribed the pointed Gothic style that was spreading across nearby frontier in Minnesota as early as the 1860s, often even simple pointed windows were squared off due to the inexperience of frontier builders (Gundersen 1987). It would take another twenty to thirty years before many of the innovations and fashions of the coast appeared in the Midwest. Although glass technology had been steadily improving since the Middle Ages, allowing the production of larger sheets of glass for window glazing, dramatic change in how glass was produced did not occur until the earlier 20th century. In 1905 the Fourcault process was invented in Belgium, such that glass could be produced in large sheets of more even thickness for a more economical price (*Glass History* 2010.) This, combined with innovations by glass artists such as Louis Comfort Tiffany, who experimented with textured glasses with great depth of color such as ripple glass and favrile glass, doubtless helped open a period of extravagant stained glass for even relatively small churches (*Tiffany Glass* 2010).

1.3 Harrison County Churches: History, Evolution, and Climate Control

Harrison County, since its founding in the mid-1800s, has undergone a steady and distinct church evolution – from the simple boxes of the first pioneers, to churches with elaborate stained glass paid for by the railroad boom, to modern churches with plainer glass and more angular forms. Cultural forces, prevailing architectural styles, and developing climate control technology have fueled these changes.

1.3.1 The history of denominations and church-building

The first white settlers in Harrison County were splinters from the Mormon migration across the United States, closely followed by migrants from Tennessee, Indiana, and Ohio (Hunt 1915, Tamisiea 1971). Perhaps the first church in the county was the Reorganized Church of Latter-Day Saints, who held services in a log tabernacle near present-day Missouri Valley in 1850 (Hunt 1915). Because the first settlers in the area were Mormon, a religious movement initiated in New York and the Northeast, many were probably familiar with the building styles in vogue there and possibly brought these architectural ideas with them (Williams 1997). Tenessee is today a state largely of English descent, while German is the most common ancestry in Indiana and Ohio (American Factfinder.) Presumably these groups brought some of these church-building traditions and senses of aesthetics with them.

Harrison County was organized by the Fourth General Assembly of the state of Iowa in 1853, seven years after Iowa became a state (Tamisiea 1971, *Iowa* 2010.) The sale of good farmland at $1.25 an acre encouraged a land rush, and by 1867 there were seven villages on the map: Magnolia, Calhoun (no longer existing), Little Sioux, St. John's (later to become Missouri Valley in 1865), Dunlap, Woodbine, and Logan (Tamisiea 1971.) After the Mormons, the first minister to preach in Harrison County was a Methodist Episcopal who arrived in 1851 (Hunt 1915.) Methodism soon overwhelmed the area; by 1905 half of all the forty-two churches in the county were Methodist. Baptist churches were built in the major towns in the 1860s and 1870s; Presbyterian churches formed in Missouri Valley and Woodbine at about the same time. A denomination originally known as the Campbellites, now referred to as the Christian Church of the Church of Christ, organized in the county 1860 and built its first churches in the 1880s. Many of these congregations met in private homes or in school buildings before building their own structures (Hunt 1915). These first churches were invariably quite modest – the first Campbellite church in Mondamin was twenty-four feet by thirty-eight feet, the size of a large college classroom (Hunt 1915).

Based on the ethnic makeup of the area today – 37.7% of Harrison County residents claim German ancestry, 17.5% percent claim Irish, and 14.3% claim English, as well as a scattering of Scandinavian nationalities – many of these hopeful farmers were probably new immigrants from Europe (American Factfinder.) The German population came with two closely associated churches, Lutheranism and Catholicism (Raguin 1990, Darling 2009). The Irish population was largely Catholic, and based on the names of the parishes of this county – two St. Patrick's, St. Anne's, and St. Bridget's of Erin – it seems likely that this population, rather than German immigrants, first built the churches of this denomination (Darling 2009). However, in 1905 the second largest church population was Catholic, so presumably the large German population made up part of these congregations. Given the heavily German makeup of the surrounding area, including cities where architects, materials, and craftsmen might have been procured, like Omaha, Nebraska, and Sioux City, it seem likely that German Catholic church-building traditions were an important influence in this area (American Factfinder).

The county's economic growth was greatly increased by the introduction of the railroad in the 1860s and the first railroad shops in 1868. The railroad ran along the west edge of the Loess Hills, going through Missouri Valley in the southwest corner of the county. The railroad shops, including the round house, machine shops, repair blacksmith, and paint shop, employed 500 men in 1900, bringing a great deal of wealth to this community. The population of Missouri Valley grew quickly from 2300 in 1885 to over 4000 in 1900, compared to the current population of 2750 people (*Missouri Valley* 2010, Tamisiea 1971). Logan became the county seat in 1891 and so likely saw more of this wealth than some of the more distant towns in northern Harrison County (Tamisiea 1971). In 1915 the Lincoln Highway passed through Missouri Valley on its way to the larger city of Council Bluffs, another route for commerce to enter the town (Tamisiea 1971). A number of beautiful and expensive churches were built during this period, and a number of smaller frame structures were replaced with brick ones, perhaps due to the brickyard that briefly operated in Missouri Valley in the 1880s and 1890s (Tamisiea 1971, Darling 2009). St Patrick's Catholic Church in Missouri Valley, a large brick building with a tower, was built in 1892 for $15,000. The Woodbine Christian Church, built in 1905, cost $20,000. A new brick church for Missouri Valley Church of Christ, built in 1913, cost $10,000. The Logan Christian Church, a smaller frame structure with extensive stained glass and three bells, was built in 1901 for $8000 (Darling 2009, Hunt 1915, Logan Centennial 1987).

Economic prosperity decayed rapidly in Missouri Valley and the surrounding communities after the railroad strike of 1922. In 1921 the railroad shops only employed 50 men (Tamisiea 1971). Coincidentally or not, no new churches were built between 1921 and 1928, perhaps while the county recovered from this economic blow (Darling 2009). In 1929, Missouri Valley became the crossroads of highway 75 and 30, the latter of which also ran through Logan and Dunlap, perhaps sparking a brief economic upturn that produced another set of large and attractive churches – Dunlap's large St. Patrick's parish church, built in 1929, the Missouri Valley Presbyterian Church, built in 1930, and the Missouri Valley St. Paul Lutheran Church, built in 1935 (Darling 2009). The Great Depression and World War II followed, greatly decreasing the number of churches built. Only six churches in the county were built between 1950 and the 1990s (Darling 2009).

The number of congregations has held steady since 1905; at that time there were reported to be 42 congregations, and in 2009 there were approximately 40 (Hunt 1915, Darling 2009).

1.3.2 Typical sanctuary and window characteristics

The earliest churches in Harrison County were often built in an extremely simple Prairie Gothic style like that in figure 5, displaying pointed arch windows in otherwise undistinguished white frame structures. The sanctuary was almost indistinguishable from a schoolhouse and perhaps only a little taller than a normal single-story house. Although these windows did not typically have stained glass, the glass for the windows was still expensive and it took some skill in carpentry to create the pointed-arch shape shown in figure 6 (*Glass History* 2010, Gundersen 1987). Congregations in smaller towns continued to build and use churches of this form into the 20th century (Darling 2009.)

Figure 5. Mondamin Catholic Church in a photo from 1909 showing the most basic form of Prairie Gothic (Walsh 2009)

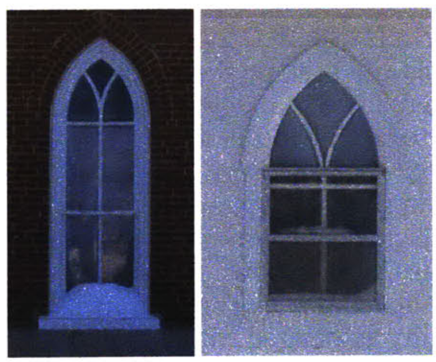


Figure 6. Windows from a former Baptist church in Dunlap, Iowa, built 1879, and the United Pentecostal Church in Pisgah, built in the early part of the 20th century (*Historical Attractions in Dunlap.)*

Later churches, like those in figure 7, took on a shape more similar to buildings influenced from Upjohn's *Rural Architecture,* though there were no Episcopalian churches in the county to have received these plans directly (Gundersen 2009). In the 1880s and 1890s churches began appending taller steeples to front of sanctuaries that were still simple and boxy and purchasing a bell or bells for these towers.

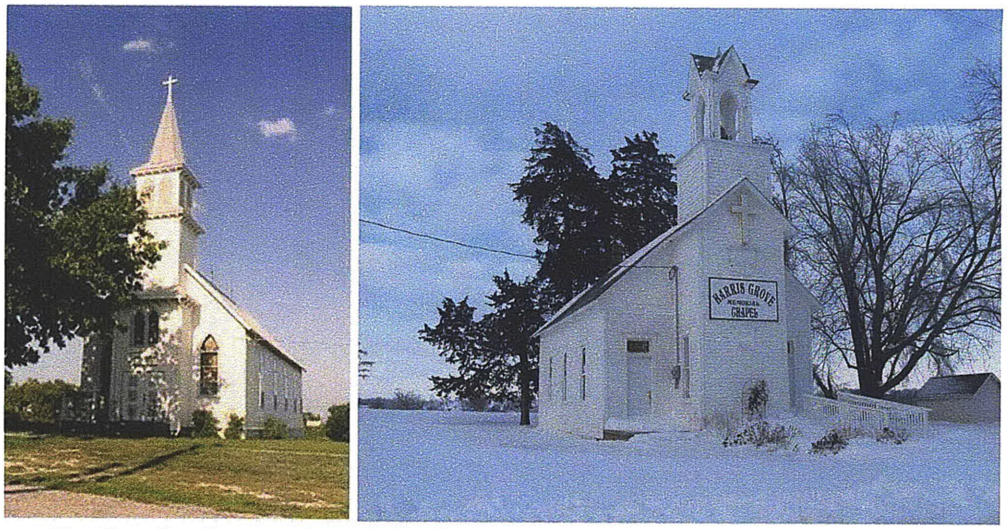


Figure 7. Magnolia Zion Lutheran Church, built 1884; Harris Grove Church, built 1890 (Walsh 2009).

From 1900 to 1930, many churches in Harrison County installed elaborate stained glass windows, typically with bright, jewel-tone glass and organic shapes that no doubt owe some of their creativity to Art Nouveau styles and experimenters like Tiffany (*Tiffany Glass* 2010). Given the ethnic makeup of Harrison County, it is also possible to see the influence of some German Gothic glazing traditions in these windows. Gothic Revival churches in Germany were most heavily influenced by the Nazarene school of painting, which used glowing colors, three-dimensional Renaissance-styled figures, and organic motifs (Raguin 1990). These glowing colors show up in many windows throughout the county, like those of the St. Patrick's Catholic Church shown in figure 8. Also in figure 8 is an example of glass-painting from the county, a portrait of Jesus from the Missouri Valley Church of Christ which has some of this three-dimensional quality associated with German stained glass.

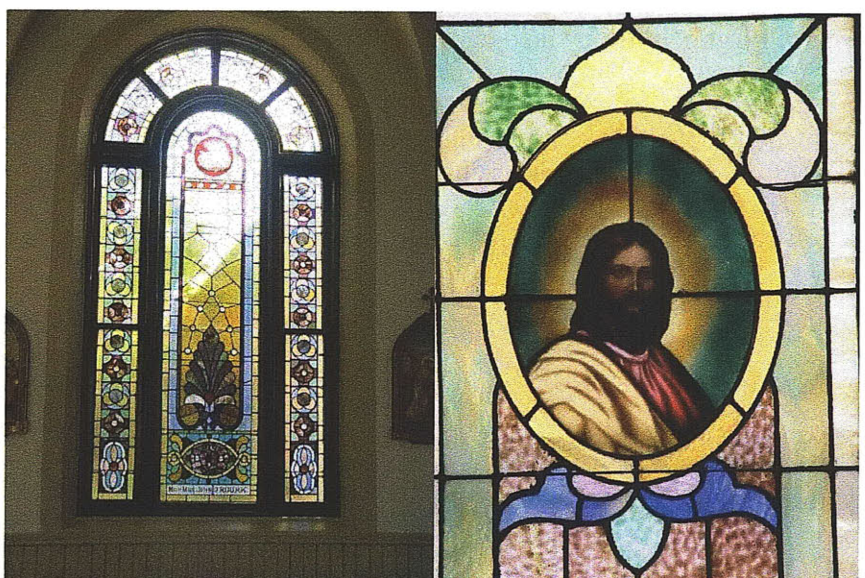


Figure 8. Window with organic shapes and deep colors from St. Patrick's Catholic Church in Missouri Valley; three-dimensional figure painting with ripple glass from the Missouri Valley Church of Christ (Cates 2010).

In terms of sanctuary design, essentially all churches in Harrison County repeated the "preaching barn" model of a single large room without aisles; variation happened primarily in the ceilings, which were sometimes vaulted with a single large barrel vault. These round vaults were often covered in later years with planar dropped ceilings to allow for air ducts and extra insulation. St. Patrick's, an interior view of which is shown in figure 9 below, uses the ceiling vaults to give the impression of an aisled, Gothic-type church without actually dropping columns which would take up valuable seating space. This could again be seen as a sign of an influence of the German community; at this time large urban churches were also being built that used Gothic styling but chose the form of German hallchurches over narrower and longer English forms to avoid isolating the back pews (Hampton 1997). By this time churches had begun to more freely blend elements of Romanesque revival, such as rounded arches, with the Prairie Gothic style in which the first churches had been constructed.

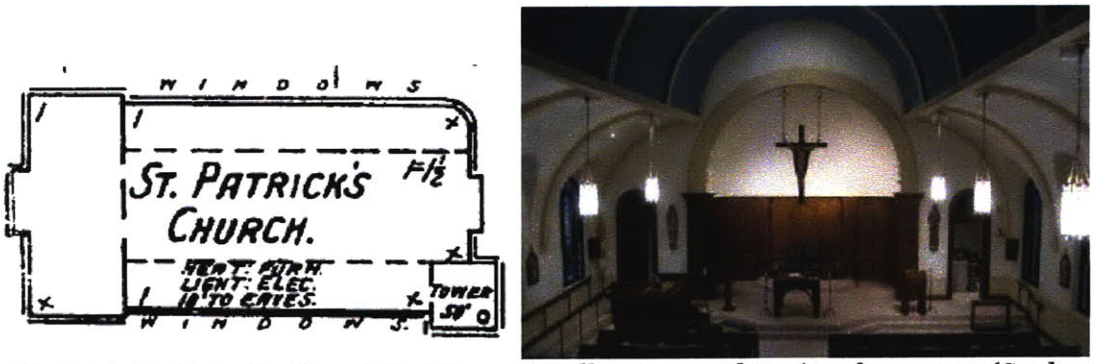


Figure 9. St. Patrick's Catholic Church in Missouri Valley, Iowa. Plan view from 1901 (Sanborn Maps 1901, *Pictures of Our Church*)

In other parts of the U.S., the choice between Munich Gothic Revival style windows and English Gothic Revival style windows often coincided with the ethnic makeup of a congregation (Raguin 1990). Although the majority of church windows in Harrison County seem to align more closely with stylistic characteristics of German windows, the Missouri Valley First Presbyterian Church, shown in figure 10, has windows more typical of the English style, with its combination of white and colored glass and more formalized style (Raguin 1990). At that time, it was likely that the Presbyterian congregation in this town was still made up primarily of families of English or Scottish descent, implying that the decision to install these particular windows aligned with a certain cultural heritage.

Figure 10. A window from the Missouri Valley first Presbyterian Church, built in 1930 (Cates 2010).

As the 1930s progressed, it became more common to construct windows with simplified, rectangular panes of glass and insert small painted roundels as the focus the window, as in figure 11. These modern designs were perhaps cheaper to create than the complex organic shapes of church windows of earlier decades, and they also foreshadowed the more angular, simpler stained glass that would become popular in the 1950s.

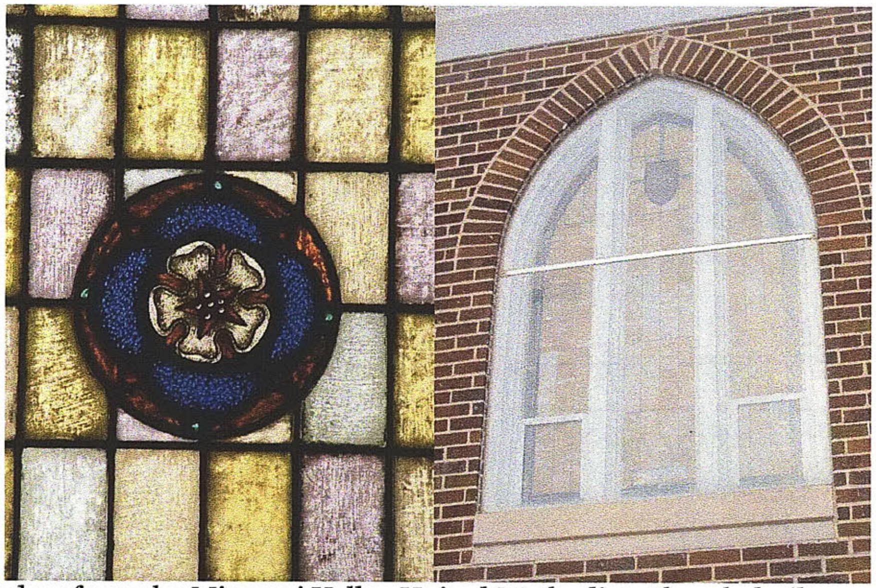


Figure 11. A window from the Missouri Valley United Methodist Church, built 1937; window from Missouri Valley St. Paul Lutheran Church, built 1927 (Darling 2009, Cates 2010).

Figure 12. Churches of the 1950s in Harrison County; at left, St. John Evangelical Lutheran Church, built 1958; at right, Missouri Valley First Lutheran, built 1959 (Darling 2009).

Churches built in the 1950s through the 1970s, such as those in figures 12 and 13, in Harrison County typically used more angular shapes in their windows, smaller areas of glazing, and larger individual panes of glass. Often the sanctuaries lowered their ceilings from previous heights. Of course there are exceptions to these general trends; the First Lutheran church sanctuary shown in figure 12 has a twenty foot ceiling and ceiling-to-floor windows spanning fifteen feet of its north wall. However, the desire for a more "modern," angular shape is still clear from its form.

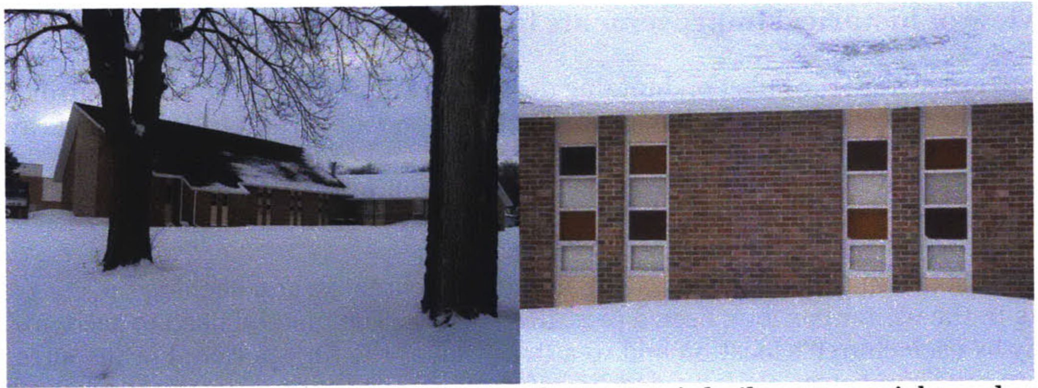


Figure 13. Woodbine Community of Christ (formerly R.L.D.S.), built 1973; at right, a closeup of the window.

Figure 14. St. Anne's Catholic Church in Logan, Iowa, built in 1920; windows from 1980s (Darling 2009).

There is also the issue of how the sanctuaries in older churches are restored or renovated. This will be discussed further in sections 1.3.5 and 1.3.6, but it is important to note that how a church maintains and restores its windows illustrates some idea of how the congregation views itself. The window in figure 14, although it is crafted in a more traditional style with a roundel and organic elements at the top, is actually a fairly new window, installed when the congregation of St. Anne's renovated their church in the 1980s. That they chose windows of a more traditional design suggests that they see themselves as caretakers of a building of historical significance or that their heritage is somehow tied to the upkeep of their place of worship.

The most recently built churches in Harrison County were discussed in section 1.1; these churches are constructed almost entirely of prefabricated materials, have very little glazing and no colored glass, and have comparatively low ceilings in their worship space.

1.3.3 Overview of historical improvements in climate control

It is difficult to exaggerate the effect on building design of comprehensive climate control systems such as air conditioning, forced-air ventilation, central heating, and air filtration. The options available to congregations to keep their sanctuaries warm in the winter and cool in the summer have increased greatly, but in some ways their affordable aesthetic design options have lessened as energy management becomes more important.

The Midwestern states in general have heating-dominated climates, and keeping the congregation from freezing in the winter has long been a pressing concern. The method used to accomplish this varied greatly by each church's location and wealth as well as the time period. For instance, although northern Harrison County was settled a decade before southern county, it was not as closely associated with various economically important railroad lines which brought wealth and technological innovation to Missouri Valley in particular (Tamisiea 1971). The Pisgah United Methodist Church, built in 1890, used kerosene lamps along the back wall for illumination and two wood stoves at the front and back of the church for heat; it was not wired for electric lighting until 1924 (Darling 2009). In contrast, the Missouri Valley city government had moved to provide electric lighting in 1888, and by 1898 the Iowa Power and Light Company (located on Erie Street in Missouri Valley) had pioneered a heating system for homes and businesses that included a central steam plant (Tamisiea 1971, Sanborn 1901).

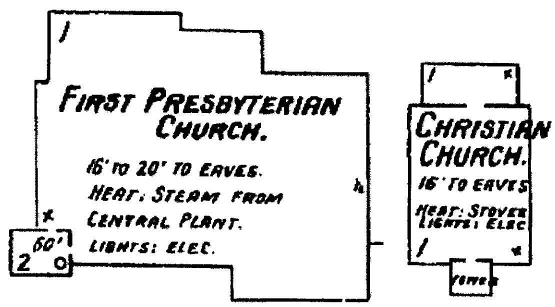


Figure 15. Two methods of heating in 1901 Missouri Valley, Iowa; the First Presbyterian Church was already connected to the central plant for steam heat, but the Christian Church was still using wood stoves. (Sanborn Maps 1901).

Some types of heating available to the citizens of Missouri Valley in 1901 are shown in figure 15. The large and presumably wealthy Presbyterian Church had already been connected to the three-year-old central steam plant, while the much smaller Christian Church, though it had electric lighting, was still using wood stoves for heat. Other churches at this time in Missouri Valley used furnaces, presumably gas-burning, as gas facilities had been installed shortly after telephones in 1880 (Tamisiea 1 971).

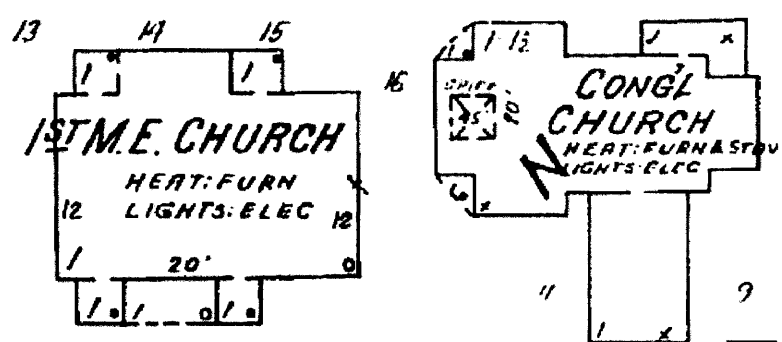


Figure 16. Two methods of heating in Dunlap, Iowa in 1930 – furnaces and wood stoves (Sanborn Maps 1930).

Dunlap, a larger and more prosperous town in northern Harrison County, was still using some wood stoves to heat even its relatively large Congregational Church in 1930 (shown in 1913 and 2001 in figure 16.) Otherwise furnaces, burning oil or gas, were the primary method of heating churches at this time (Sanborn 1930).

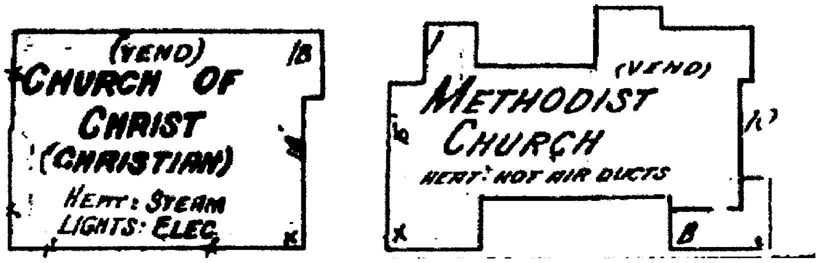


Figure 17. Heating in 1944 Missouri Valley, Iowa. The 31-year-old Church of Christ building had been connected to the central steam plant, but the Methodist Church had installed hot air ducts – some version of central heating (Sanborn Maps 1944).

By 1944, the Church of Christ in Missouri Valley had hooked into the central steam plant, as shown in figure 17. The Missouri Valley Methodist Church was one step ahead of that – they had already started heating their church with hot air ducts.

Although the first “room cooling unit” was marketed in 1929, most churches in Harrison County did not install air conditioning until the 1960s or later (*Air Conditioning Timeline* 2010). The Logan Methodist Church, for instance, installed air conditioning in 1964, but the Logan Christian Church did not add air conditioning to their building until 1974 (Darling 2009, Centennial Book 1987).

How does these technological changes affect changes in church design? The churches associated with wood stoves were typically the smallest, box-like structures. The energy usage concerns associated with these churches were essentially the cost of wood; the congregation was, in some sense, entirely in control of how much energy was used to heat the building. The furnace thermostat was invented in 1883, beginning an era of heating control (Zwaniecki 2008). Churches with these first thermostats still had relatively little control over their precise environment, but the more efficient method of heating allowed their buildings to become bigger. The ability to heat a large space was more important than the cost of heating a large space. Thermostats that lowered the indoor temperature when rooms were not invented until 1924, and thermostats that responded to outdoor temperatures were not invented until 1934 (*Comfort Catches On* 2010). The fact that furnaces were used for over half a century before these energy-saving measures were invented suggests that energy costs were cheap enough until this point that large windows and high ceilings, features that often sap energy from a heating system, were not considered liabilities. The Great Depression forced a reassessment of energy expenditures (*Comfort Catches On* 2010.)

1.3.4 Missouri Valley Church of Christ

The two case studies in this thesis will examine the Missouri Valley Church of Christ and the Logan Christian Church, two congregations with buildings from the first part of the 20th century that have since undergone extensive renovations, particularly upon their sanctuary spaces.

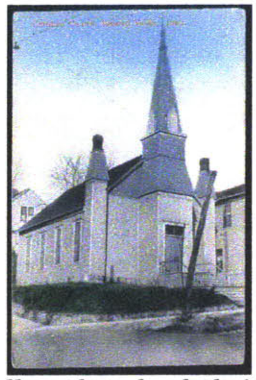


Figure 18. First Missouri Valley Church of Christ, built 1887 (Walsh 2009).

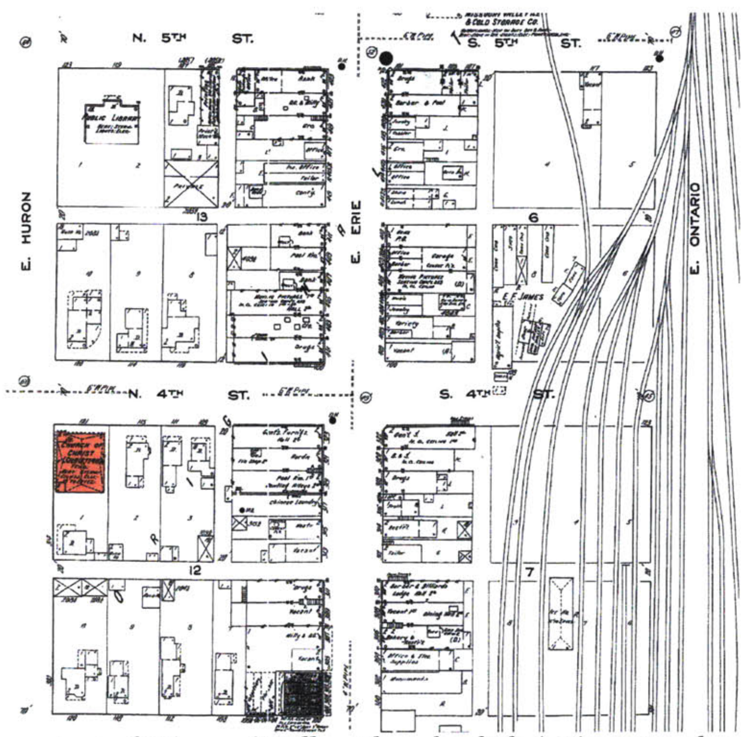


Figure 19. Immediate context of Missouri Valley Church of Christ in 1913; church highlighted in red. The numbered streets run on a north-south axis. (Sanborn Maps 1913.)

The Missouri Valley Christian church was organized in 1883. The first building, shown in figure 18 above, was built in 1887; it was a 40' by 45' frame structure a block away from the location of its modern building. In 1913, membership was over 200, and a new brick building was built for $10,000 and dedicated (Hunt 1905, Darling 2009). This is the modern structure, mapped shortly after its construction in figure 19, which still contains all of the original stained glass windows. The north, east, and south walls each contained two large rectangular panels of windows and a half-circle of windows that lit the sanctuary. Each panel or bank of windows contains form individual windows, the two outermost of which were at one time operable. Until the 1940s fans and screens were installed in these windows to aid in sanctuary cooling (*Missouri Valley Christian Church.*)

Originally the ceiling was a large barrel vault, but it was dropped to a much lower flat ceiling in a series of renovations that occurred during between 1946 and 1950 (*Missouri Valley Christian Church*). The north balcony (shown in the photo on the right in figure 19) was blocked in to form a nursery, cutting those windows off from the sanctuary, and the entire upper bank of windows on the south wall and the top half-circle window on the east wall were also walled in from the inside, although they are still visible on the exterior of the church. Oral tradition and the church's written history suggest that these changes were made to cope with the economic blow of the Great Depression when many members of the congregation lost railroad jobs and the sanctuary became too expensive to heat (*Missouri Valley Christian Church*). Such changes could be expected not only to change the amount of light the sanctuary gets, as closing off the loft blocked a number of windows, but also the quality of the light, as a flat, lower ceiling does not reflect light in the same way as a higher, vaulted ceiling (*Missouri Valley Christian Church*). In addition to these changes, the seats were reoriented; they had formerly faced the southwest corner, but they were replaced with pews which faced the west wall directly, as shown in figure 21. From 1961 to 1964, a new educational unit with twelve new classrooms was added to the west side of the building (Darling 2009). From a visual inspection of the exterior, it is clear that at some point protective plastic was added on top of the windows, making them in a sense double-paned.

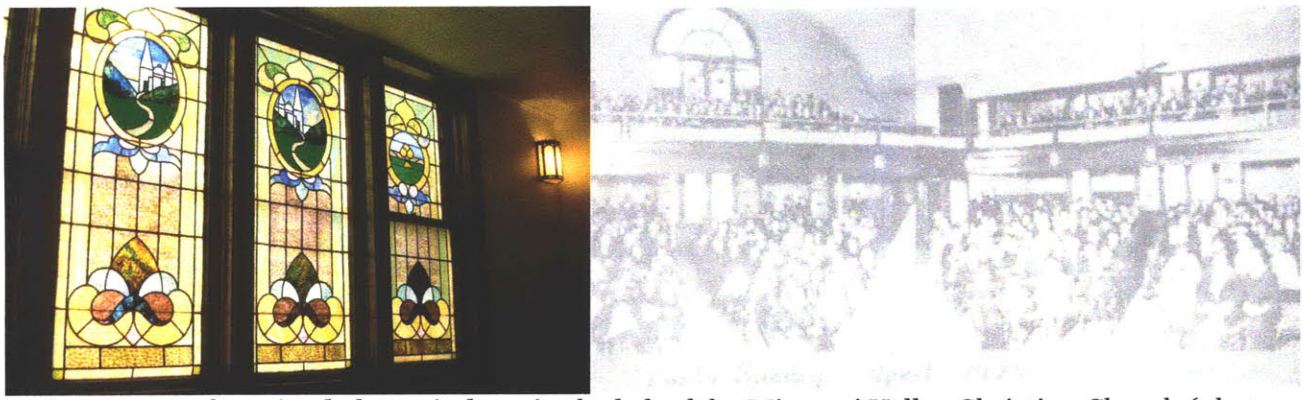


Figure 20. Left, stained glass windows in the loft of the Missouri Valley Christian Church (photo 2007). Right, a 1929 photo of the original vaulted space (*Missouri Valley Christian Church*).

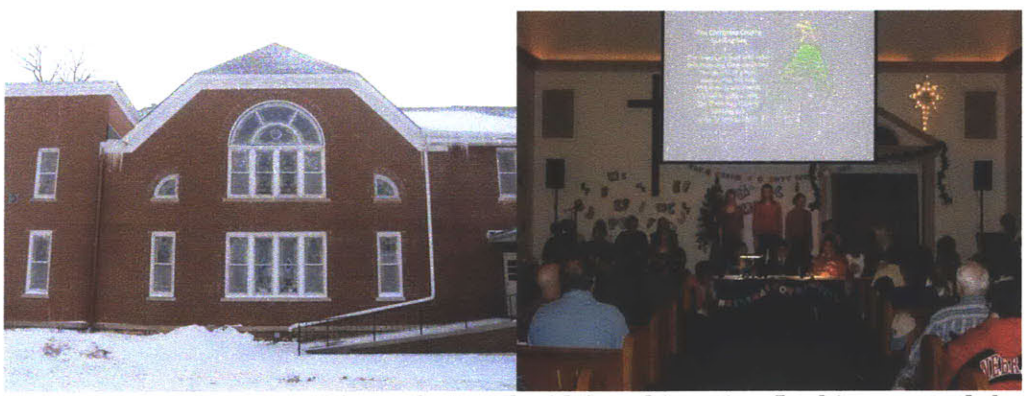


Figure 21. Modern-day church (seen from the north side) and interior (looking toward the west wall.)

1.3.5 Logan Christian Church

The Logan Christian Church was organized in 1887 and built its first building in 1888, a single-room frame structure heated by a wood stove and lighted by kerosene lamps. In 1901 a new, larger church building was erected for $8000, with large stained glass windows facing the east, south, and north, as shown in figure 22 (Darling 2009, Logan Centennial 1987). The site of the building in 1913 in shown in figure 13. The June 6, 1901 *Logan Herald-Observer* described the interior woodwork as being finished with white enamel and gilt designs, the interior walls being painted shades of green and yellow, and the three bells weighing 2000 pounds in total. Unfortunately this original building burned in 1904 (shown in figure 22), although the lower bank of stained glass windows (one is shown in figure 26) were salvaged and it was rebuilt on the same plan. The three bells were crushed and re-cast into a single larger bell (Logan Centennial Book 1987).

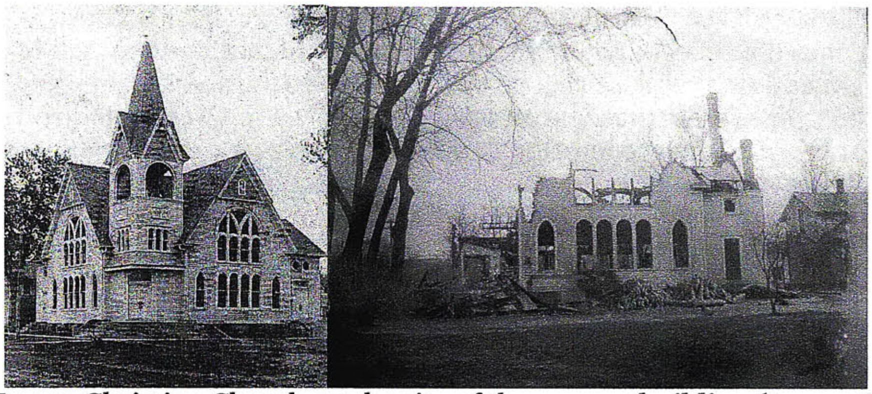


Figure 22. 1901 Logan Christian Church on the site of the current building (Logan Centennial 1987).

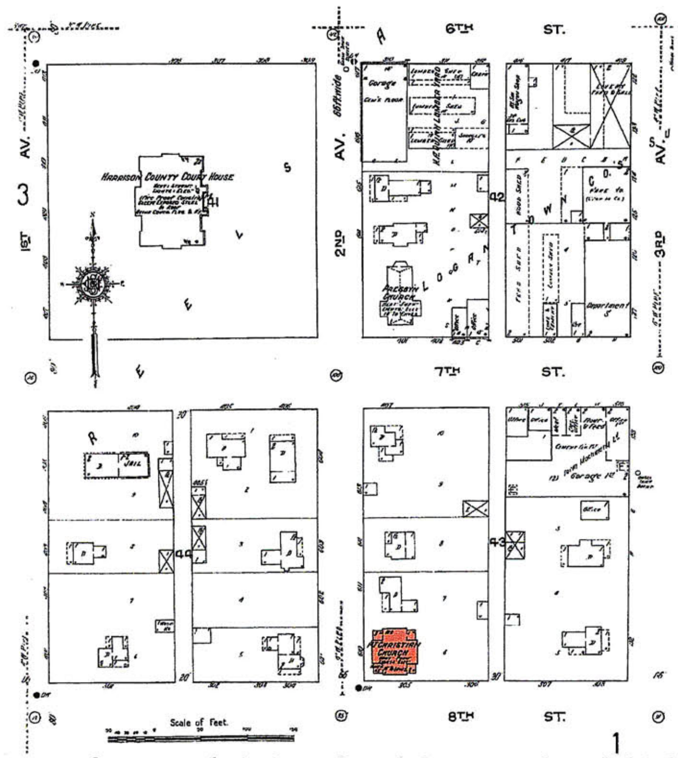


Figure 23 Immediate context of Logan Christian Church in 1913; church highlighted in red (Sanborn Maps 1913).

The church was quickly rebuilt and re-opened nine months after the fire. The building as it was from 1904 to 1960 is shown in figure 24 below. In 1960 extensive renovations began, starting with lowering the sanctuary ceiling. The towers at the corners of the church also had to rebuilt after 1958. In 1963 drywall and insulation were added to the entrance, wings, and balconies, and new pews and carpet were installed (Darling 2009, Logan Centennial 1987). The educational complex at the rear of the church was added in 1966. In 1970, the outside of the church was entirely remodeled. The cost of fixing the stained glass was deemed too high, so these were removed and replaced with a single large window on each facade of the church (Logan Centennial 1987). The old stained glass windows were donated to a church in Moorhead, Iowa which had been built on the same plan, but returned in 2010 when the Logan Christian Church built a new gym to the east of the church building (Ron Riley 2010). In 1973, the columns underneath the balconies, shown in the right picture in figure 24, were taken out; in 1975 the north and south balconies were removed, leaving the east and west balconies. A year later, air conditioning was installed. A hailstorm which caused massive damage to other church windows made re-roofing necessary in 1980 (Logan Centennial 1987, Darling 2009.)

The modern church is shown below in figure 25.

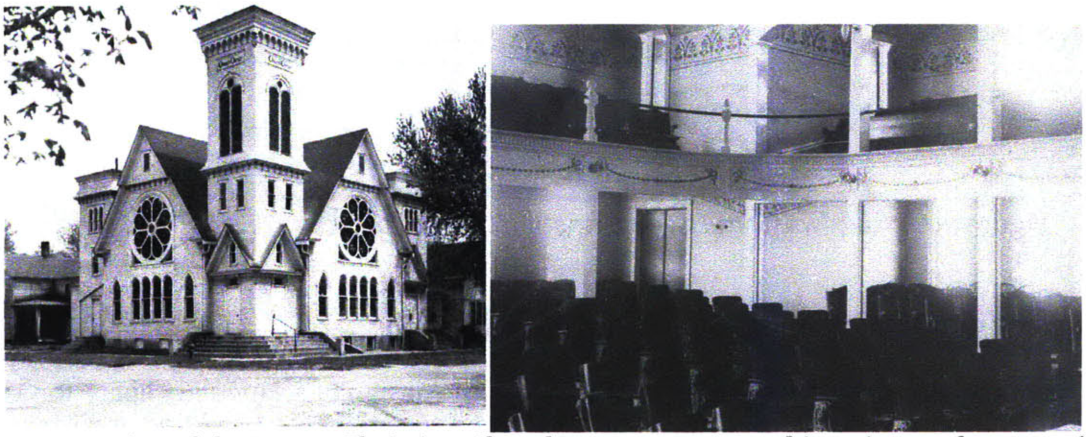


Figure 24. Exterior of the Logan Christian Church, 1904 – 1960 and interior, early 1900s (Logan Centennial 1987).

Figure 25. Exterior of the Logan Christian Church and interior in 2010.

Perhaps the most interesting transition made in the Logan Christian Church is from their original stained windows to the large, puzzle-like "art glass" windows added in the 1970s, shown below in figure 26. The original windows used organic shapes and Romanesque Revival forms, whereas the new windows are simpler and more angular. From visual inspection of the exterior of the church it is apparent that these new windows are double-paned or have a protective hard plastic sheet covering them.

Figure 26. Windows from Logan Christian Church before and after renovation.

1.3.6 Inherent challenges in typical church design

There are certain climate control challenges inherent in the design of a sanctuary space for a church. Sanctuaries much be spacious in plan such that 200 or more people may be seated at a time, given the typical congregation size in this area. Traditionally these buildings have quite lofty ceilings for the visually uplifting experience often found in cathedrals, but high ceilings also allow for balconies and increased visibility of the pulpit, which is a necessity in a preaching-based church.

If a church wishes to stay within church traditions, particularly Gothic Revival ones, it typically has a large amount of glazing on three walls of the sanctuary. This glazing is far more thermally conductive than the wall surrounding it, such that a great deal of thermal exchange will invariably happen through the windows. In general, this works against heating systems in the winter and cooling systems in the summer – heat flows out of the church and into the church, respectively, putting an extra energy burden on the climate control system, and therefore an extra cost burden on the congregation. These types of windows are also typically made up of many small pieces leaded together, which can increase the thermal conductivity of the window further – the lead acts as a thermal bridge. These windows can also be difficult to maintain for this reason; if one piece of the window is cracked or chipped by an accident or hail, for instance, it may be difficult or expensive to replace.

Added to this is the additional complexity there is a single most important time of use for most churches, Sunday morning from about 8:00 AM to about 11:00 AM, a time of day when the sun comes in at a fairly low angle. This means great potential for direct sunlight inside the church, which can be excellent for the visual experience and for solar heating in the winter, but also cause painful glare for churchgoers and cause uncomfortable overheating in the summer months.

These concerns, often demanding opposite courses of action from an aesthetic or historical approach, make coordinating church design a unique challenge.

1.4 Thesis structure

The central portion of this thesis will revolve around two case studies quantitatively examining the interior conditions, particularly daylight and thermal qualities, of the Missouri Valley Church of Christ and the Logan Christian Church before and after their remodeling projects. In the case of the Missouri Valley Christian Church, the impact on daylight of individual renovations, such as dropping the ceiling and covering windows, will be assessed with further simulations. This information can then be used to understand later developments in church design.

To assess the daylighting and visual comfort, digital models will be created in AutoCAD to represent the before and after conditions of each church. These models can then be assessed using the Ecotect-Radiance-Daysim package of software to determine the typical daylight autonomy and timing of light. Radiance pictures will be used to predict the probability of glare at key points throughout the year in various places in each sanctuary. Each renovation will also be examined independently of the others to assess which has the greatest effect on the interior visual characteristics and, therefore, the interior comfort of occupants.

To assess the thermal comfort of the sanctuaries and develop an idea of the energy expenditure required to maintain it, a thermal balance will be calculated for the before and after condition of each church, taking into account construction methods and materials and the heating and cooling systems in place at each time. This information will help determine the effect of the sanctuary design, particularly of the windows, in each case to the thermal comfort of the occupants. The thermal balance can also help generate an idea of the economic impact of the renovations made.

Finally, these results will be discussed in the context of the historical evolution of other churches in the county.

2.0 Analysis and modeling of daylight performance

The daylight inside the churches was analyzed using a series of computer simulations based on the program Radiance. The illuminance levels and the glare were assessed using two different metrics and types of simulations.

2.1 Geometric and material characteristics of selected churches

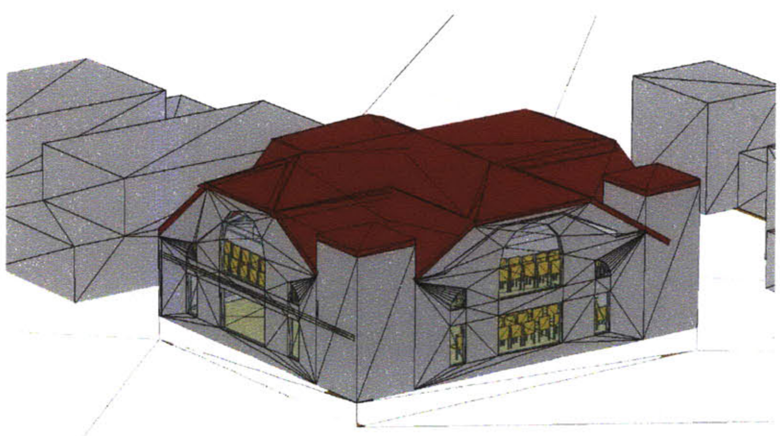
Simplified models were built in AutoCAD for the daylight simulations, and these simplified forms were also used when considering the thermal balance.

2.1.1 Missouri Valley Church of Christ

The Missouri Valley Church of Christ sanctuary was analyzed in its original condition (circa 1913) and its post-renovation condition (modern-day). In both case the effects of shading foliage and window leading (which would presumably block a small amount of light) were ignored.

2.1.1.1. Before 1940s Renovations

In the pre-renovation condition, the ceiling is vaulted, the north balcony opens into the sanctuary and contains seats, and all windows open into the sanctuary. The seats facing the southwest corner. The digital model is shown below in figure 27. The surrounding buildings were modeled based on the 1913 Sanborn map.



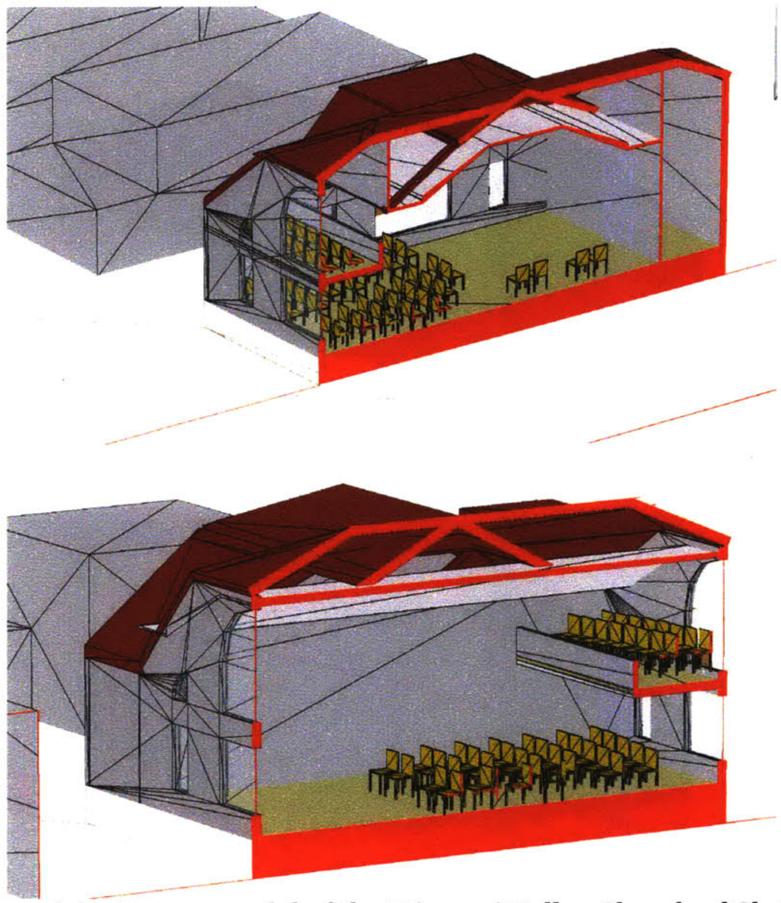


Figure 27. Screenshot of the Ecotect model of the Missouri Valley Church of Christ before; east-west section looking south; north-south section looking west renovations.

The following reflectances were used: 20% for the ground; 35% for the floor inside the sanctuary; 75% for the ceiling; 30% for the seats; 70% for the inside walls of the sanctuary; 65% for the other buildings; 35% for the exterior walls of the church; and 5% for the roof. The windows were assumed to have a transmittance of 35%.

2.1.1.2 Contemporary condition

In the post-renovation condition, the ceiling was modeled as dropped and flat, with the edge beveled inwards. The top bank of windows was blocked, and the north balcony was walled off. To mimic the protective plastic added on top of the windows, an extra plane was inserted into the remaining windows and given its own transmittance. The seats were replaced with pews that all faced toward the west wall. The church educational addition was modeled, and the surrounding building were modeled as shown by photos of the surrounding area and Google Maps (2010). The models are shown below in figure 28.

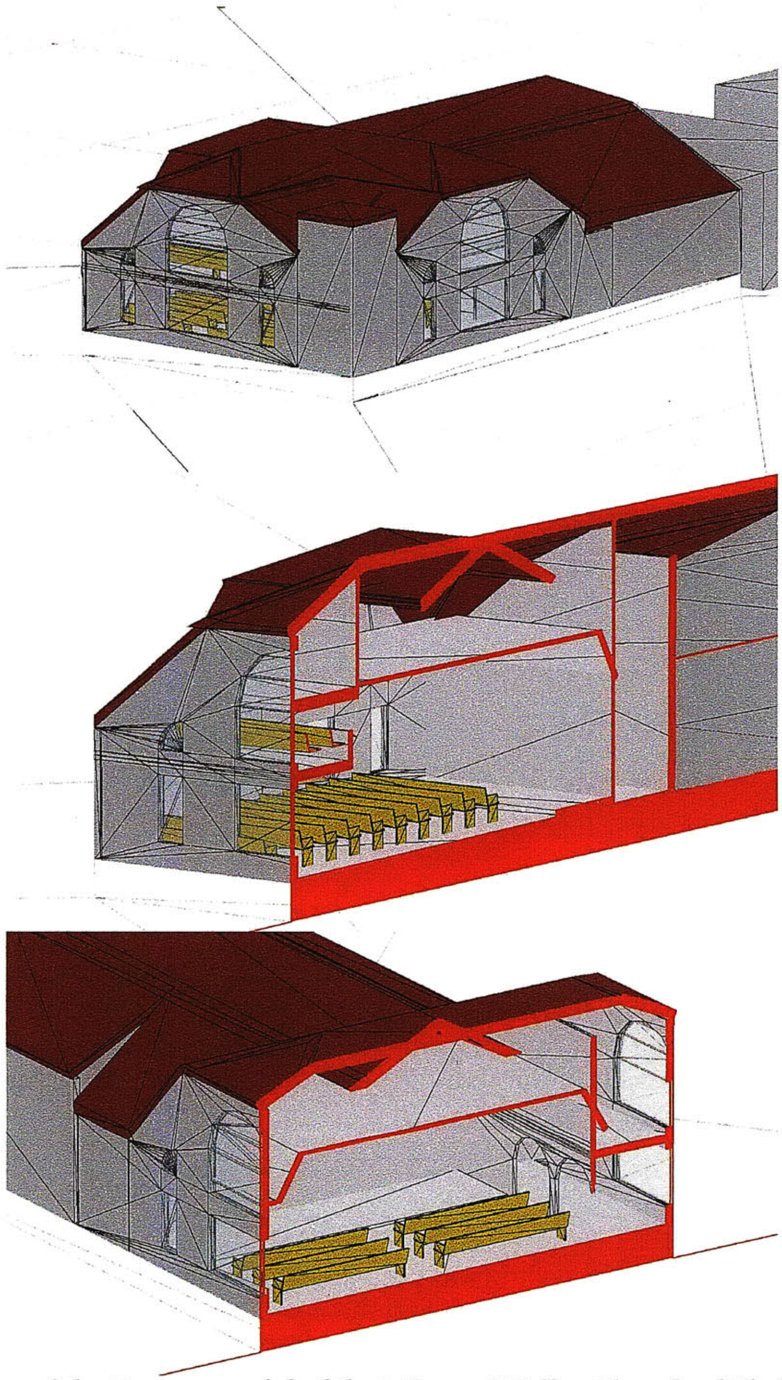


Figure 28. Screenshot of the Ecotect model of the Missouri Valley Church of Christ after renovations; east-west section looking south; north-south section looking west.

The same reflectances were used in this case, but the protective plastic layer was given a transmittance of 70%.

2.1.1.3 Single change conditions

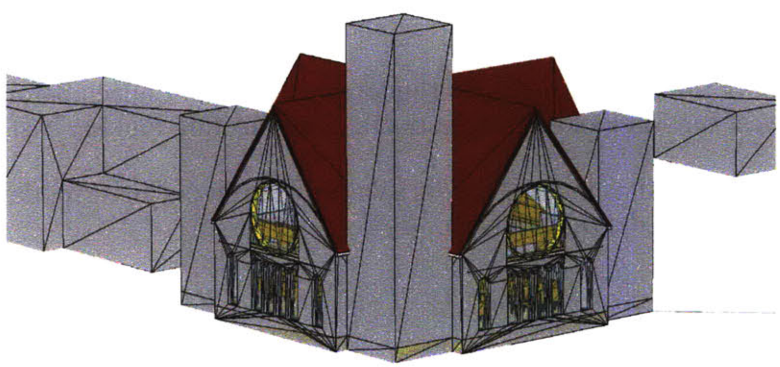
To isolate the effects of individual renovations, two additional daylight simulations were done for yearly illuminance. These were based on the pre-renovation model and made no other changes except those noted here. In the "windows changed only" model, the upper windows were blocked and an exterior layer was applied over the remaining windows, but the ceiling was not dropped. In the "ceiling changed only" model, the ceiling was dropped, but the windows punched through the beveled section of the ceiling and remained uncovered.

2.1.2 Logan Christian Church

The Logan Christian Church was analyzed in its condition after rebuilding in 1904 and in its present-day condition after renovations. Shading foliage, window leading, and window tracery were ignored in both cases.

2.1.2.1 Before 1960s-1970s Renovations

In the pre-renovation condition, the ceiling is vaulted. There are four balconies, each with pews: Three of equal size on the south, east, and west walls, and one smaller balcony set into the wall on the north wall (the choir loft.) The windows were modeled as in the before photos shown in section 1.3.6 – a large round window over six rectangular windows with rounded tops. The seating on the floor is modeled as individual seats. The tower at the southwest corner is modeled as 44' feet tall. The other buildings are modeled according to the 1913 Sanborn map of Logan. The model is shown below in figure 29.



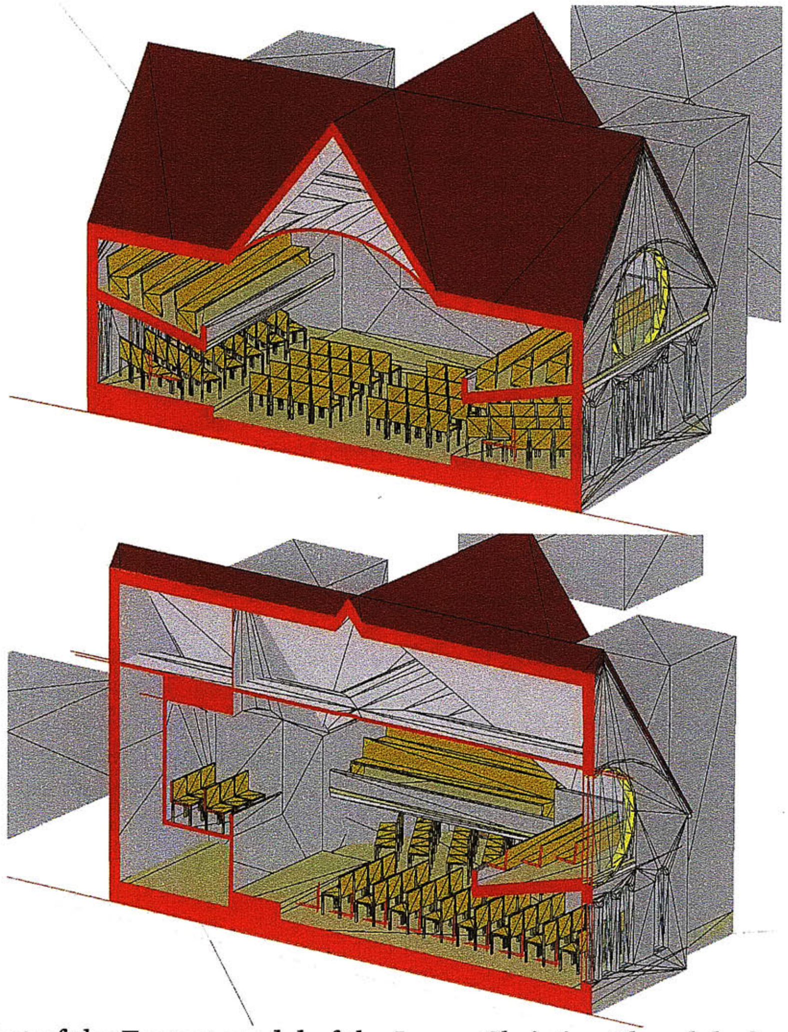


Figure 29. Screenshot of the Ecotect model of the Logan Christian Church before renovations; east-west section looking north; north-south section looking east.

The same reflectances were used as in the Missouri Valley Church of Christ model, except for the exterior wall, which was assigned a reflectance of 65%.

2.1.2.2 Contemporary Condition

In the post-renovation condition, the windows have been replaced with one large, angular window on each wall. An extra layer has been added on the exterior of all windows. The north and south balconies have been removed, and the pulpit and altar area has been pushed into the area that was formerly the choir loft and baptismal, farther away from the windows. The floor seating has all been modeled as pews, while the balcony seating is modeled as individual chairs. The ceiling is dropped substantially along the north-south axis of the church and made planar. Over the two balconies, it has only dropped a few feet but has also been made planar. The other buildings are modeled according to Google Maps (2010).

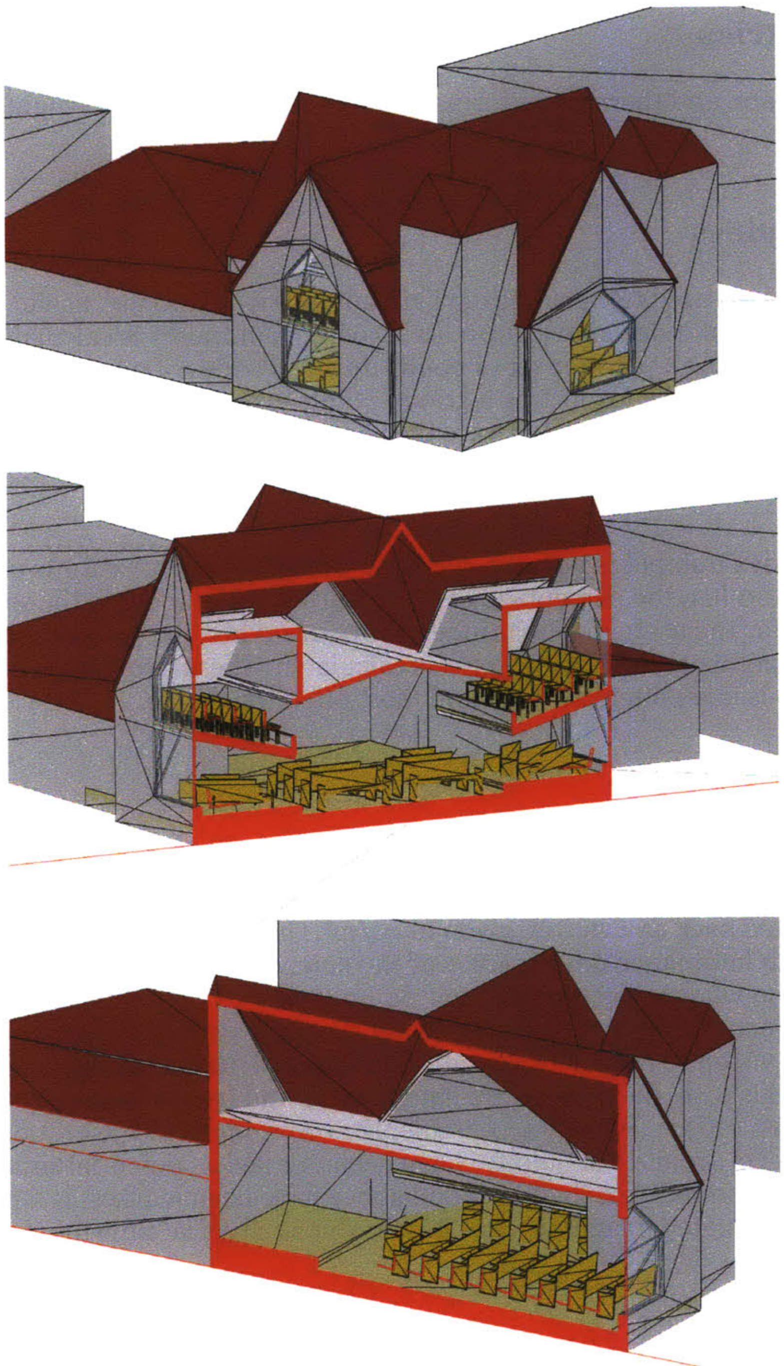


Figure 30. Screenshot of the Ecotect model of the Logan Christian Church after renovations; east-west section looking north; north-south section looking east.

The same reflectances were used. The extra layer on the outside of the windows was given a transmittance of 70%.

2.2 Analysis metrics

Yearly illuminance, glare, and thermal performance were analyzed using daylight simulations and heating calculations.

2.2.1 Daylight quantities

Daylight simulations were used to calculate daylight autonomy at 200 lux, useful daylight index below 100 lux, and useful daylight index above 2000 lux. Daylight autonomy is calculated by simulating the amount of light in lux hitting a point or set of points during a series of times during the year. In this case, the software calculated the lux hitting a grid of points every five minutes between 6:00 AM and 6:00 PM for every day of the year. The software then calculates the percentage of these values which are at 200 lux or above and reports this number, which is called the daylight autonomy (March 2006, Reinhart 2006).

The useful daylight index number is virtually identical except for the lux cutoffs used. For the useful daylight index below 100 lux, the percentage of times during the year when the sensor points are below 100 lux is calculated; for the useful daylight index above 2000 lux, the percentage of times during the year when the sensor points are above 2000 lux is calculated. These two numbers give an idea of where in the churches is most often too dark and most often too bright.

2.2.2 Glare

Glare is somewhat difficult to quantify, as what is defined as "glare" can be different for individuals and depend on the situation. Glare depends on the luminances of surface a viewer can see, or the amount of light reflected back at a viewer, given in cd/m^2. Glare is also dependent on contrast ratios – areas of extremely high luminance next to areas of extremely low luminance can be glary. Quantitatively, a person who cannot change their point of view usually considers contrast ratios higher than 1:3 (a surface reflecting cd/m^2 back at the viewer next to a surface reflecting 3 cd/m^2 back at the viewer) in their direct vision to be glary and contrast ratios of 1:10 in their peripheral vision to be glary (Andersen 2008). In this case, the viewers are churchgoers and free to look away from the source of glare, so higher contrast ratios are likely acceptable. However, high contrast ratios in places where the viewers usually look – i.e. around the pulpit – have been marked as potential sources of glare, and contrast ratios anywhere in the church of 1:20 and above have been marked as a potential source of glare. The time in all simulated images in 9:00 AM, as this is a typical time for church services to start.

2.2.3 Thermal analysis

A thermal balance was calculated for all conditions to account for energy exchange between the interior and the exterior of the churches. The total energy lost and gained in kilowatt-hours in the two churches through conduction, ventilation, and solar gains was calculated over the entire year, over the three months of summer (June, July August), and over the three months of winter (December, January, February.) These numbers were used as a basis to estimate the heating and air conditioning needs and energy costs to each church pre-renovation and post-renovation.

2.4 Digital modeling & software

Daysim was used to generate annual daylighting data, a process which utilizes both Radiance and Ecotect (March 2006, Reinhart 2006).

Ecotect and Daysim together work as a more convenient interface to Radiance, a well-validated daylight simulation software (Reinhart 2006). AutoCAD is used to create a simplified three-dimensional model. This is exported to Ecotect, where materials are assigned to each group of surfaces (such as the inner walls and ceiling) and a grid of sensor points is set up. This information is then exported to Daysim. Daysim uses Radiance's calculation engine to quickly generate daylight values over a set number of annual increments for the given sensor points. This information can then be used to generate a daylight autonomy number, or percentage of time when the daylight quantity at the sensor point meets the desired value.

After the model was exported to Daysim, the location was set at Council Bluffs, Iowa, latitude 42.4 degrees north, longitude 71 degrees east. Council Bluffs is the nearest city for which Energy Plus weather data is available; it is about 22 miles south of Missouri Valley and about 31 miles south of Logan (Google Maps). The simulation time step was set at 5 minutes, so the program calculated the daylight value at the sensor point every 5 minutes through one year. The ground reflectance was left at the default of 20%. The optical qualities of the materials, reflectance and transmittance, were set in each simulation as described in section 2.4.2 below. As neither church uses shading devices such as blinds in its sanctuary, the "shading device mode" was left on "static shading device." This model assumes all shading is in the form of static building geometry. Simulation parameters were set at 5 ambient bounces, 1000 ambient divisions, 20 ambient super-samples, 300 ambient resolution, 0.1 ambient accuracy, and 6 limit reflections, as per the recommendation in the Daysim tutorial (Reinhardt 2006). The occupancy period for which the daylight autonomy was calculated was 6:00 AM to 6:00 PM. These Daysim parameters were used in all experiments in this paper.

One way to visualize how daylight acts inside these models is to create a color-coded spatial gradient that indicates where the areas of highest and lowest daylight autonomy are. In this case, the daylight autonomy spatial grid covers the floor area, and all sensors point up. The grid was set at two heights for two different simulations in each church – 5' for the floor seats and 16' for the balcony seats. This type of grid is useful to assess the daylight falling on a horizontal work plane (in this case on an open Bible or hymnal), and it can indicate what areas are more often well-lit during the year. The threshold for daylight autonomy was entered into the software as 200 lux. This number was chosen because it is sufficient to keep the congregation alert and to do light reading, such as a song from a hymnal (Pechacek 2008, *Illuminance – Recommended Light Levels* 2005). The "installed lighting power density" was set to zero.

For the glare analysis, the Radiance rendering program was used through the RadianceCP interface, where reflectance were set, the view angles were changed to 180 degrees vertically and 180 degrees horizontally, and the view type was set to fish eye. In the Radiance view program it is possible to click on different areas of the image and get cd/m^2 readings, which then can be compared to get an idea of contrast ratios and glare.

3.0 Analysis of changes on sanctuary conditions

In this section, the results of the daylight simulations and thermal calculations for Missouri Valley Church of Christ and the Logan Christian Church are presented.

3.1 Missouri Valley Church of Christ

The daylight simulations, glare analysis, and thermal calculations for pre- and post-renovation conditions follow, as well as daylight simulations for theoretical conditions in which only the windows are covered or only the ceiling is dropped.

3.1.1 Daylight simulation

Color-coded grids were created to represent the daylight autonomy and UDI of all conditions.

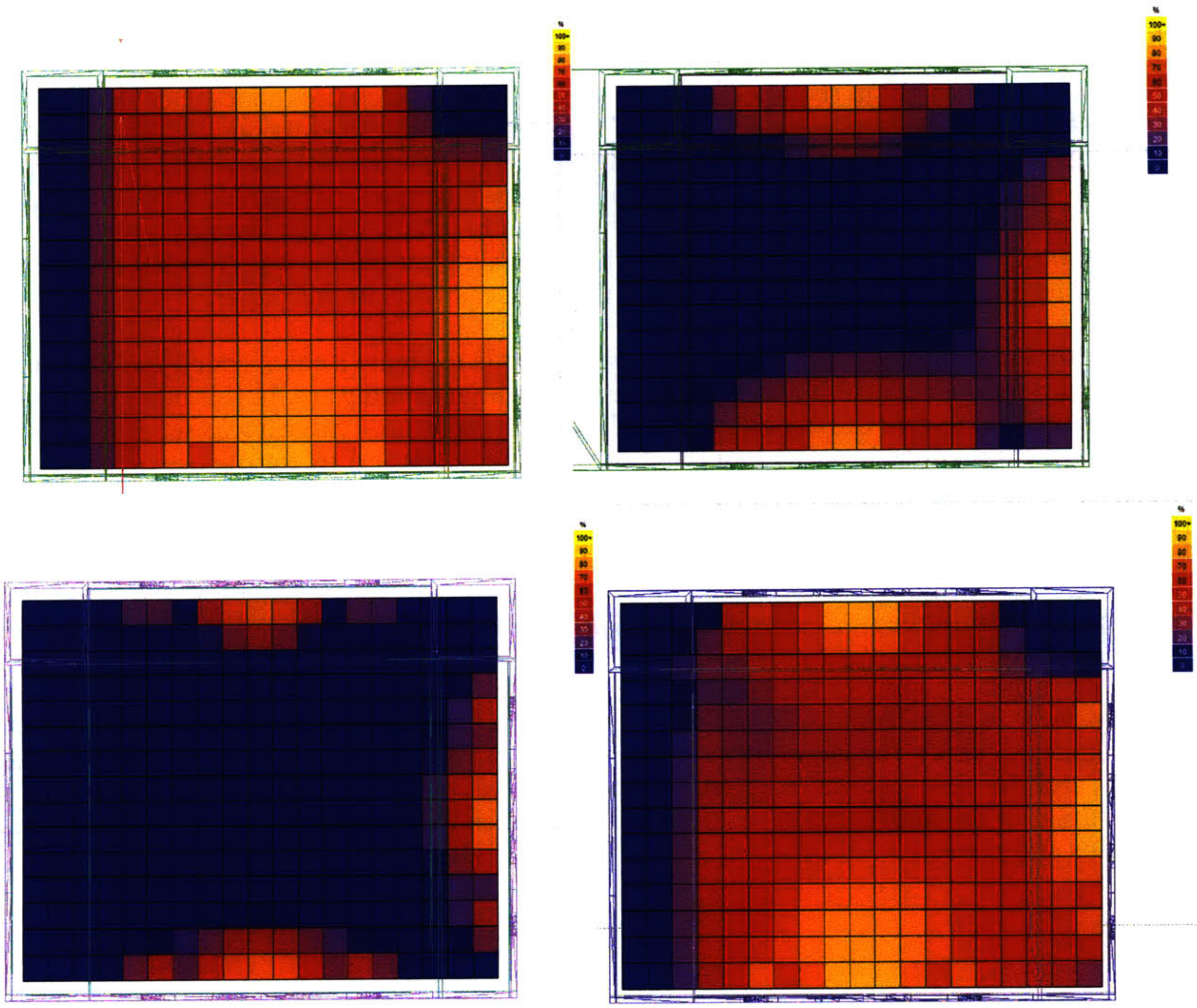


Figure 31. Missouri Valley daylight autonomy (at 200 lux) before and after changes, floor seats as compared to the windows-only changed configuration (bottom left) and the ceiling drop-only configuration (bottom right)

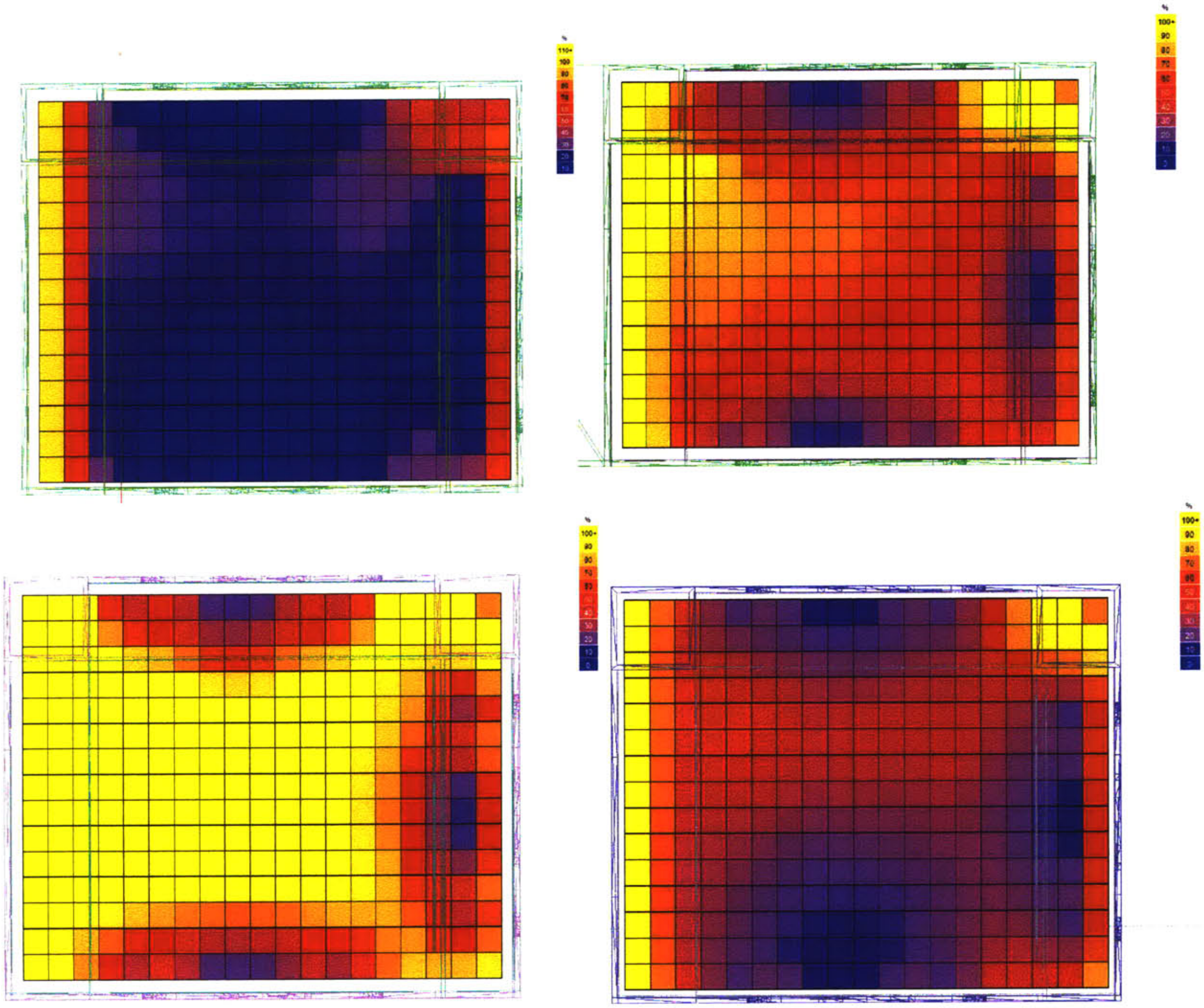


Figure 32. Missouri Valley UDI<100 before and after changes, floor seats, as compared to the windows-only changed configuration (bottom left) and the ceiling drop-only configuration (bottom right).

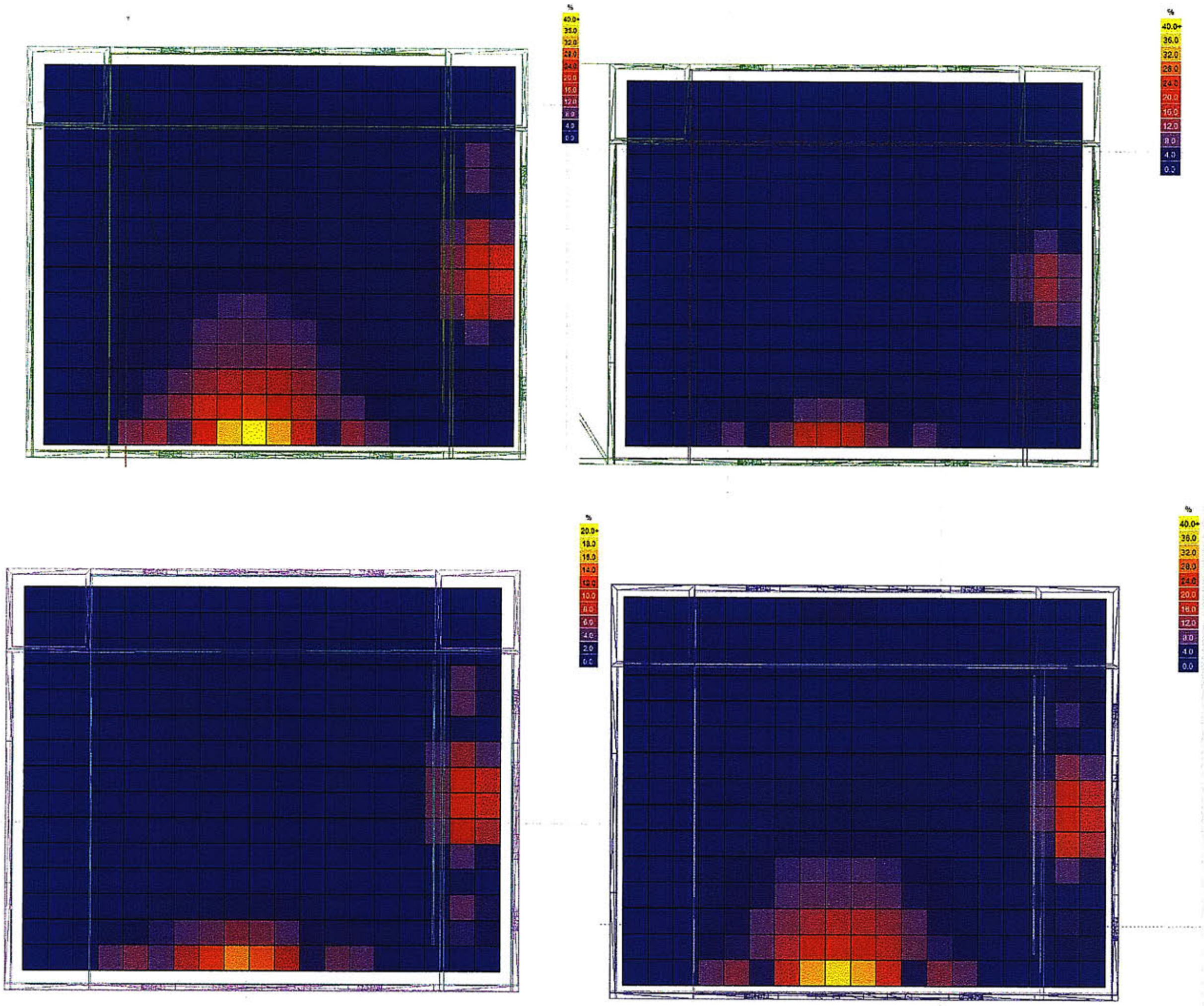


Figure 33. Missouri Valley UDI>2000 before and after changes, floor seats, as compared to the windows-only changed configuration (bottom left) and the ceiling drop-only configuration (bottom right).

In both conditions the sanctuary shows spots near the large window where 200 lux is reached 100% of the considered hours. In the remodeled condition, these spots of high daylight autonomy quickly diminish toward the center of the church. In contrast, even in the center of the sanctuary in the pre-renovation condition, at least 70% daylight autonomy was maintained. Compared to the pre- and post-renovation conditions, the condition in which only the windows are covered but the ceiling in not dropped has the overall lowest daylight autonomy, with the small spots at the windows peaking at 70%. In the condition in which the ceiling is dropped but the windows are not covered, however, areas of 100% daylight autonomy penetrate deep into the church from the windows, and even in the problematic northwest corner of the church the daylight autonomy remains at 50% (figure 31).

In the renovated condition, the northwest corner of the sanctuary is always below 100 lux, indicating that in these areas it would likely be difficult to read without the aid of artificial light. (This is notable because in the modern church, the piano is located in this area.) In the pre-renovated condition, this area is below 200 lux 40% of the testing period. The "windows covered only" condition does not just fail to meet 200 lux most of the year, it also remains below 100 lux for the entire year for most of the area of the sanctuary (figure 32).

The area where the UDI is above 2000 lux (figure 33) is small in all configurations. The pre-renovated condition reaches 2000 lux in a small patch near the south window 40% of the time and in another patch by the east window 24% of the time; the "ceiling dropped only" condition is extremely similar. In the renovated condition, above 2000 lux is only reached 24% of the time at most. The south window patches tend to coincide with the aisle, while the east window patches occur where there is seating. In the "windows covered only" condition, a very small spot next to the southern windows is above 2000 lux 16% of the time.

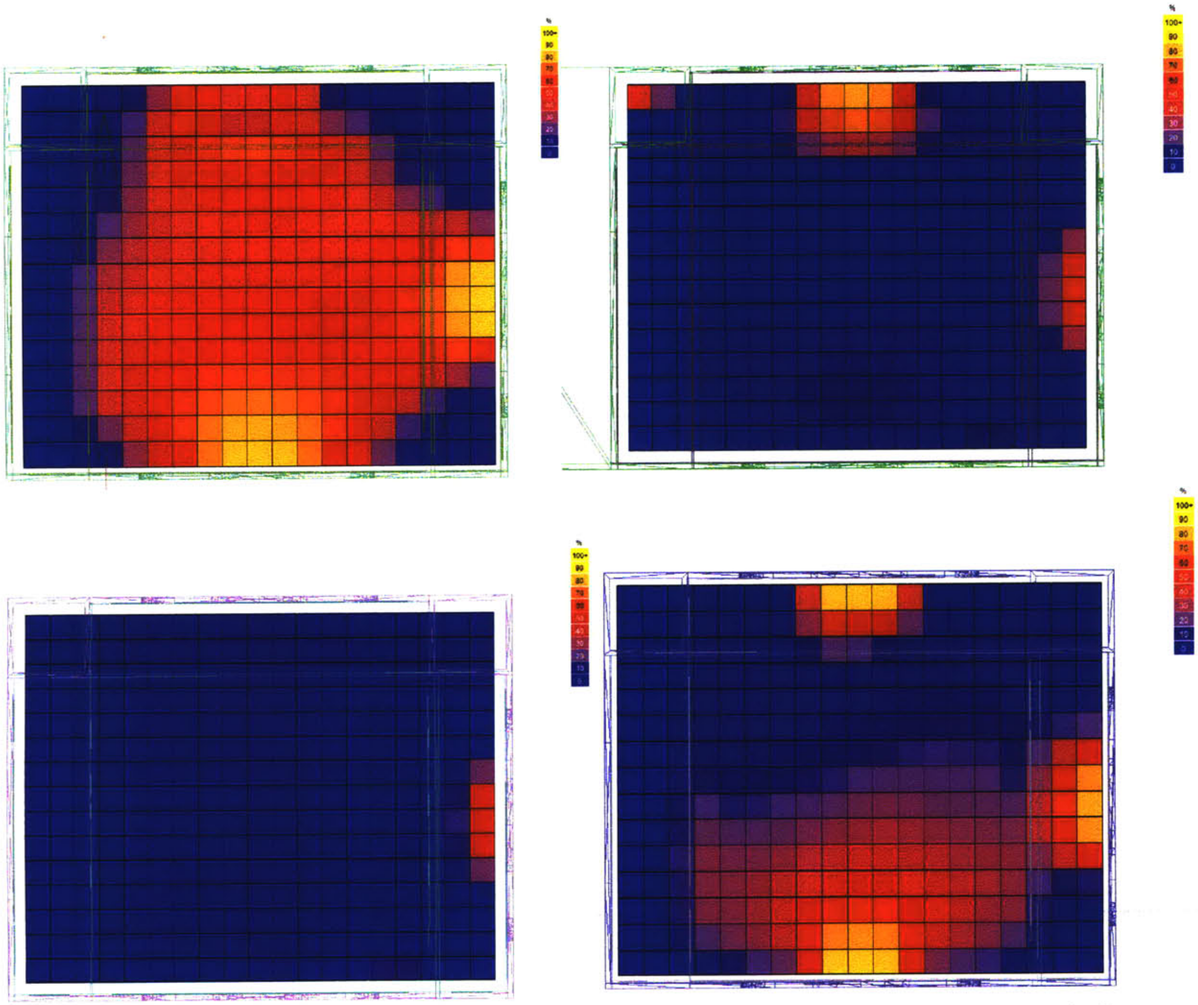


Figure 34. Missouri Valley daylight autonomy (at 200 lux) before and after changes, balcony, as compared to the windows-only changed configuration (bottom left) and the ceiling drop-only configuration (bottom right).

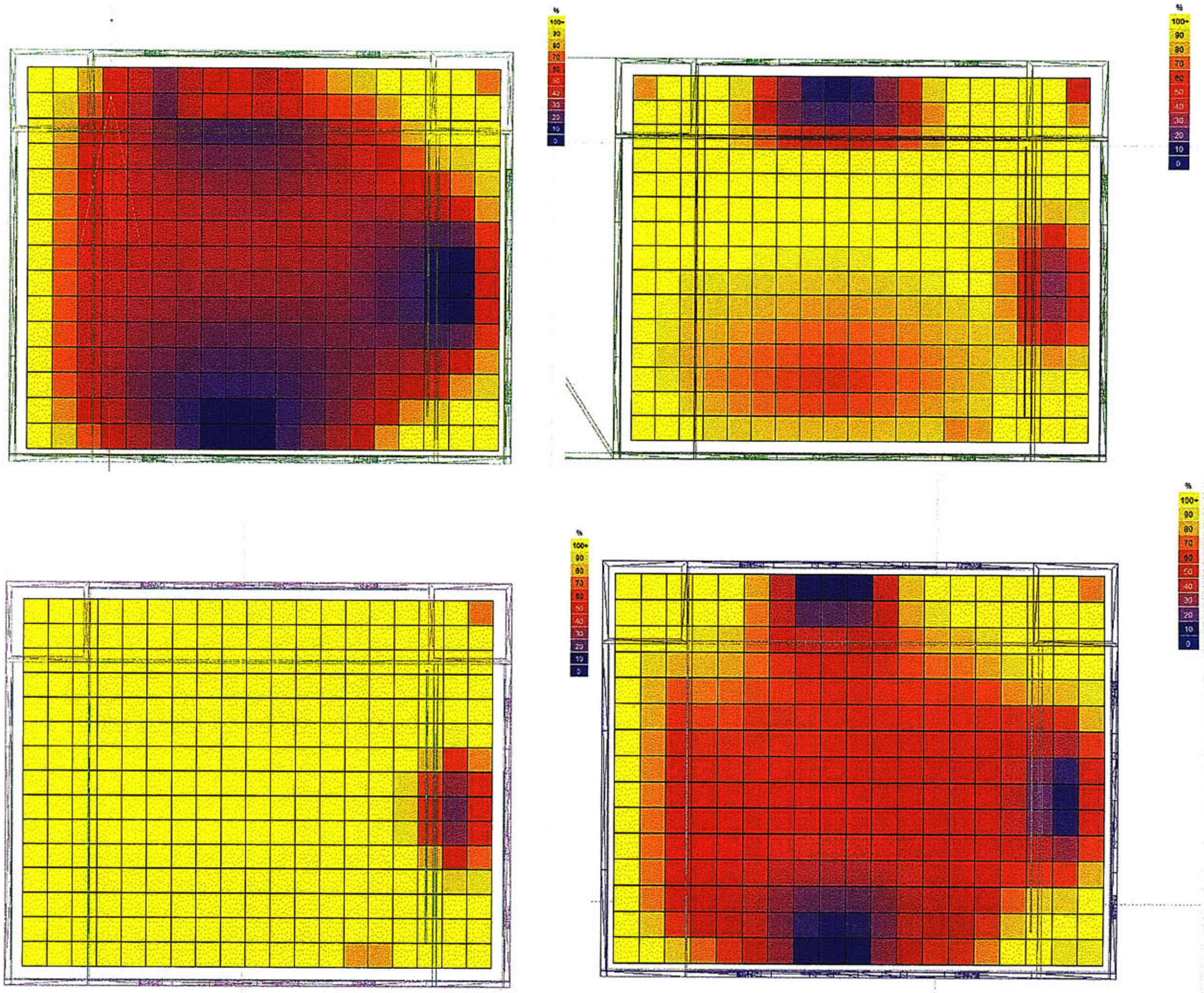


Figure 35. Missouri Valley UDI<100 before and after changes, balcony, as compared to the windows-only changed configuration (bottom left) and the ceiling drop-only configuration (bottom right).

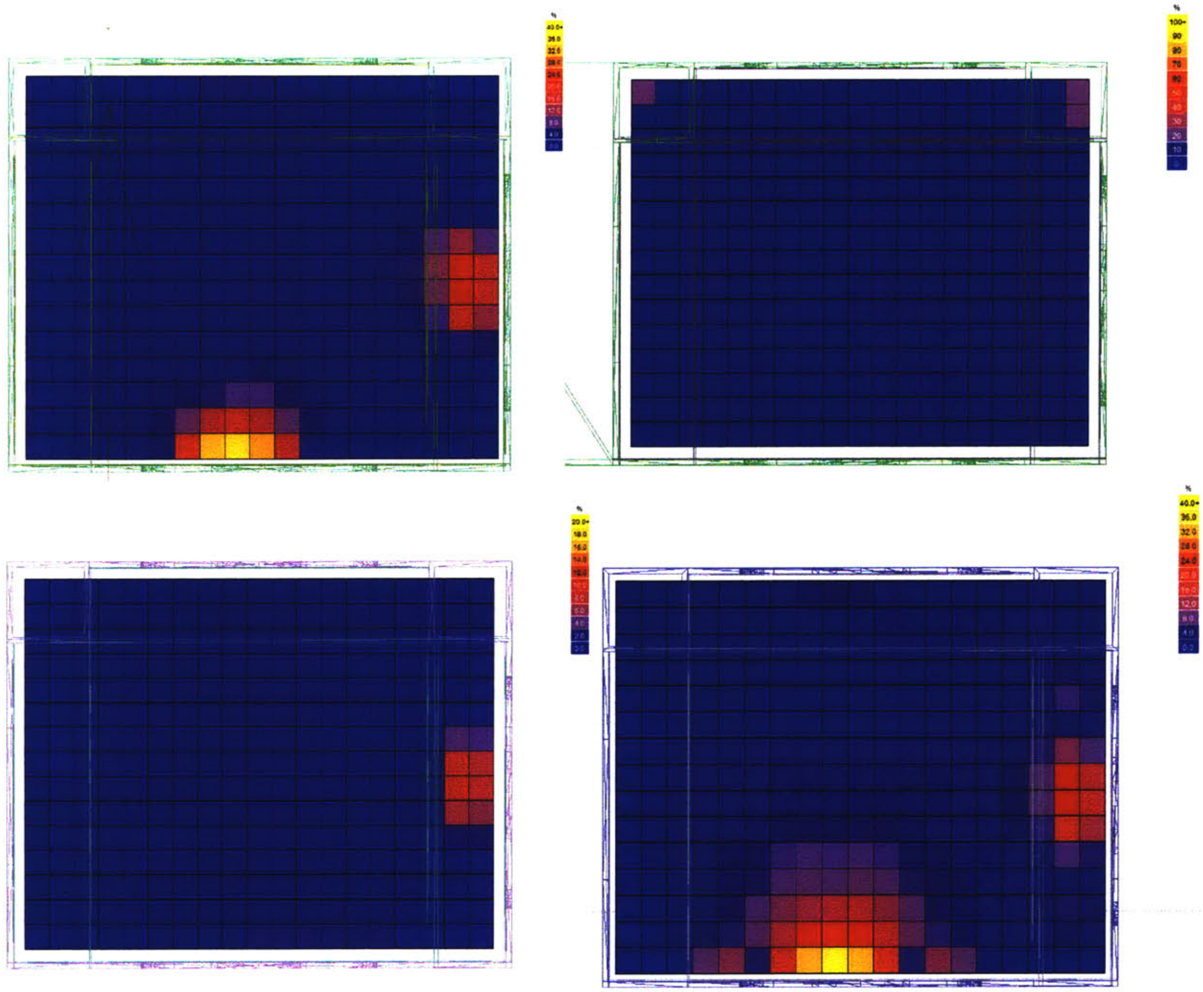


Figure 36. Missouri Valley UDI>2000 before and after changes, balcony, as compared to the windows-only changed configuration (bottom left) and the ceiling drop-only configuration (bottom right).

The differences in daylight autonomy are more exaggerated at the balcony level, as shown in figure 34. It should be noted that the patch by the north window in the renovated condition is no longer part of the sanctuary, as it has been walled off from the rest of the space. The balconies are narrower, so less of each actual seating area reaches a daylight autonomy of 50% or above. In the pre-renovated condition, approximately half the north balcony receives 200 lux at least half the year and about a third of the east balcony receives 200 lux 60% of the year or more. In the renovated condition, only 15-20% of the area of the balcony is lit with 200 lux 60% of the year or more. The "windows covered only" condition render essentially no useful daylight at the balcony level – there is only one small patch, probably less than a sixth of the east balcony, which receives more than 100 lux 40% of the year.

In the renovated condition, two-thirds of the balcony receives less than 100 lux for the whole year (figure 35), indicating that individuals probably cannot read music or do other tasks there by daylight alone.

On the balcony level daylight levels exceeding 2000 lux are essentially not an issue in any condition, as shown in figure 36.

3.1.2 Glare

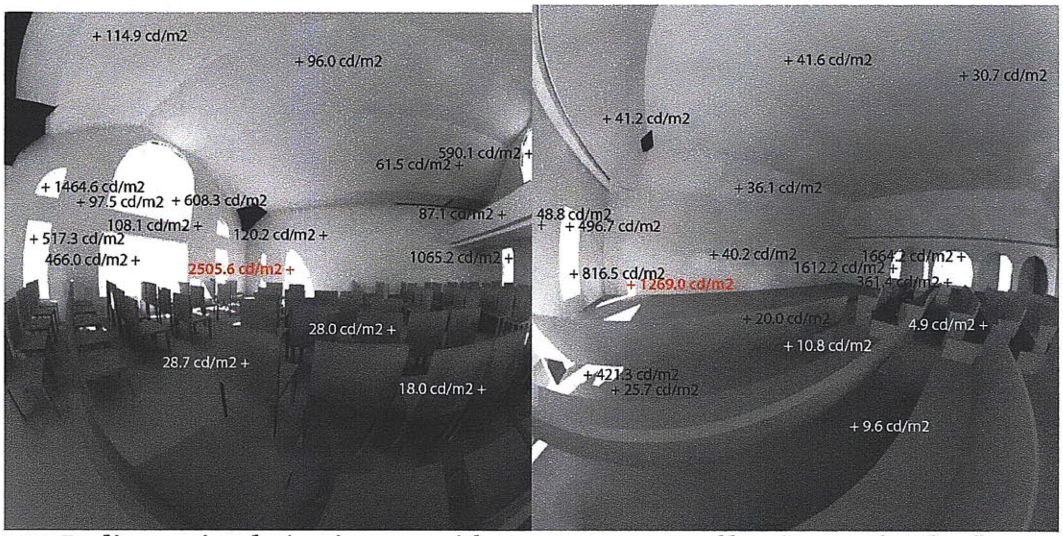


Figure 37. Radiance simulation images with measurements of luminance for the floor seats on September 21 at 9 AM pre-renovation (left) and post-renovation (right).

In figure 37, some of the glare issues in the pre-renovation and post-renovation conditions are illustrated. The high south windows in the pre-renovation condition tend to throw large bright spots on the wall behind the pulpit throughout the year, which is problematic because this is in the central vision for most of the congregation. Also, the congregation is turned toward the south bank of windows, which are very bright, even if they do not technically go over a 1:20 contrast ratio. These issues are largely mitigated into the renovated condition because the high windows are no longer present and the congregation is perpendicular to the south bank of windows, although the overall luminance of the sanctuary is about half that of the pre-renovation condition.

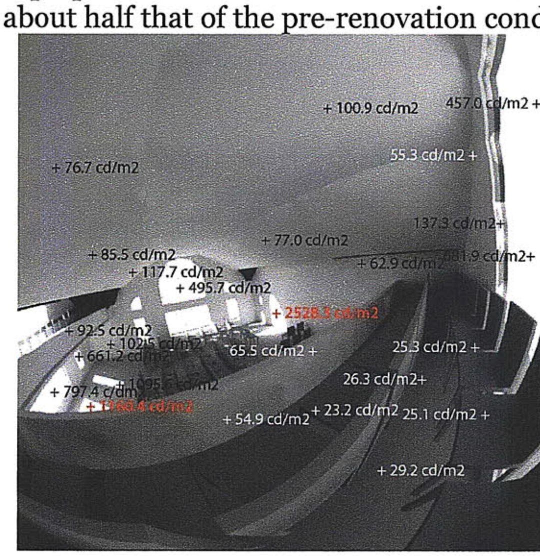


Figure 38. Radiance simulation image with measurements of luminance for a seat on the north balcony on September 21 (pre-renovation.)

Another way that the renovations mitigated the glare problem was by restricting seating in areas of the church that were previously very glary. The north balcony faced the south bank of windows directly and therefore had much potential for viewer discomfort. These seats are no longer part of the sanctuary, as this balcony was walled off for use as a nursery.

Refer to chapter 7.0 for an appendix of Radiance images used for glare analysis.

3.1.3 Thermal balance

A cursory overview of weather data for this area shows that this climate is a heating-dominated one. The average daily temperatures in March, June, September, and December are respectively 7.8°C (46°F), 21.6°C (71°F), 19.7°C (67°F), and 0.4°C (33°F), compared to standard interior temperature of 21.1°C (70°F) (Energy Plus Weather Data).

To develop an idea of the church's energy usage throughout the year before and after remodeling, a thermal balance was calculated for both conditions: $\Delta S = Q_i + Q_c + Q_v + Q_e + Q_s$, where Q_i is the internal heat gain, Q_c is the conductive heat gain/loss, Q_v is the ventilation heat gain/loss, Q_e is evaporative heat gain/loss and Q_s is the solar gain. Q_e was considered negligible and not calculated, as evaporative cooling is of fairly minimal importance in Iowa's climate. It was assumed that this church sanctuary is used for approximately three full days a week – all day on Sunday, all day on Thursday for youth services, and a cumulative day for other gatherings and services – or about 13 days a month.

The component of Q_i contributed by the heating system is unknown; it was assumed that enough energy would be put into the system to keep the church at a comfortable temperature of 21.1°C (70°F).

Q_c was calculated with the equation $Q_c = \Sigma(A \times U) \times \Delta T$, where A is area, U is U-value, and ΔT is $T_O - T_I$. Typical U-values were assumed for windows and walls – 2.14 W/m^{2}K for the walls, 2.59 W/m^{2}K for the roof before remodeling, and 5.0 W/ m^{2}K for the windows before remodeling. After remodeling, 0.59 W/m^{2}K was used for the roof (taking into consideration the large air space introduced by dropping the ceiling) and 2.8 W/m^{2}K was used for the windows (taking into consideration the clear panel added to the exteriors of all windows) (Szokolay 2004). When the air layers on the surfaces of the skin of the building are taken into account, this gives U-values of 1.6 W/m^{2}K for the walls, 1.8 W/ m^{2}K for the roof before remodeling, 2.7 W/m^{2}K for the windows before remodeling, 0.54 W/m^{2}K for the roof after remodeling, and 1.9 W/m^{2}K for the windows after remodeling. ΔT was 13.3 K, -0.5 K, 1.4 K, and 20.7 K for March, June, September, and December; each of these months was assumed to represent three months of the year. The roof was approximated as 422 m^2. Before remodeling, the area of walls was 168 m^2 and the area of the windows was 92 m^2; after remodeling, the area of the walls had increased to 212 m^2 and the area of the windows had decreased to 48 m^2. The west wall of the sanctuary was not included in this calculation because it adjoins the church offices and Sunday school rooms, which are presumably the same internal temperature as the sanctuary. Before remodeling, the heat lost because of conduction was estimated to be 4.17×10^4 kW-h a year; after, it was about half that, 2.15×10^4 kW-h a year.

Q_v was calculated with $Q_v = qv \times \Delta T$, where qv = 0.33 x number of air changes x volume of church and ΔT is defined as above (Szokolay 2004). An air exchange rate of 8 changes/hour was assumed, within the recommended range for church buildings (*Air Change Rates* 2005.) The volume of the sanctuary was approximated as 1544 m^3. Given these values, it can be approximated that 1.33×10^5 kW-h worth of energy is lost from the church each year due to ventilation before renovations. After the renovations, the dropped ceiling and closed-off north balcony decreased the sanctuary volume to 1300 m^3. This gives 1.12×10^5 kW-h, a decrease of 2.1×10^4 kW-h per year.

Q_s was calculated with $Q_s = G \times sgf$, where is G is the irradiance on a vertical facade and sgf is the solar gain factor of the window. A solar gain factor of 0.42 was used for the stained glass (Szokolay 2004).

Ecotect was used to create stereographic shading charts for each facade of the building. From these graphs it was determined that none of the surrounding buildings (either before or after remodeling) provided significant shading. The east facade self-shades after noon throughout the year. With this pattern of shading, 430 kW-h/m^2 hit the east facade on the occupied days during the year, 650 kW-h/m^2 hit the south facade, and 32 kW-h/m^2 hit the north facade (ASHRAE 1997). Before the remodeling, the church would have gained 1.5×10^4 kW-h through its windows each year; after the remodeling, it gained 7.56×10^3 kW-h through the windows.

In total, the Q_c, Q_v and Q_s terms give an energy usage of 1.4×10^5 kWh for the modern-day church, a decrease 4.9×10^4 kWh from the 1.9×10^5 kWh used in the original condition. Typical energy usage in this climate zone for a building of religious worship is about a quarter of that, 3.1×10^4 kW-h (*Average Retail Price* 2010). Possibly the very large windows with minimal insulation make the energy use for this building higher than the average.

During just the three months of winter, when ΔT is estimated to be 20.7 degrees K, the heat losses were 3.5×10^4 kWh in the pre-renovation condition. After the renovations, 2.5×10^4 kWh were used in the three months of winter, decreasing the energy use during this period 9.6×10^3 kWh.

Previously the heat gain during the summer months was considerably greater – before the renovations, 2.8×10^4 kW-h were gained through conduction and solar contributions during these months, whereas after, the gains are only about half that amount, 1.38×10^4 kW-h.

These numbers are summarized in figure 39 below.

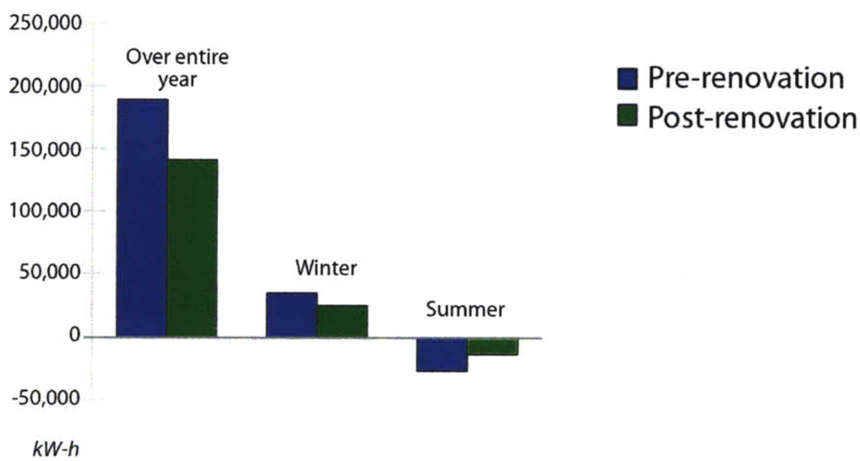


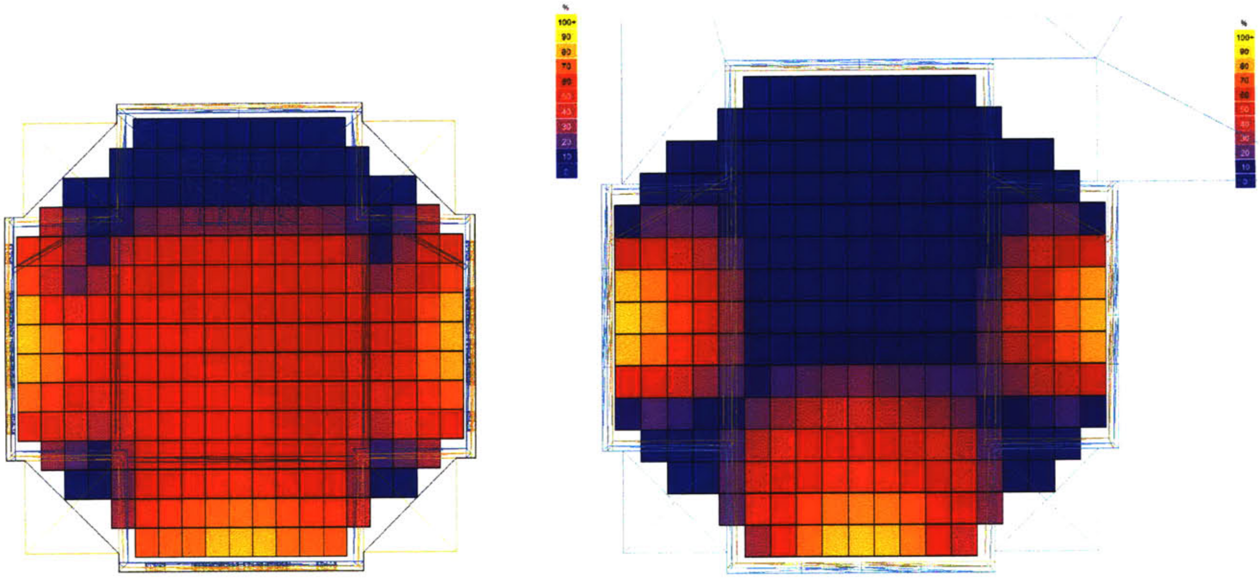
Figure 39. Comparison between energy use in the Missouri Valley Church of Christ pre- and post-renovation over the entire year, in just the winter months, and in just the summer months.

3.2 Logan Christian Church

In this section the daylight simulations, glare analysis, and thermal calculations for pre- and post-renovation conditions are presented.

3.2.1 Daylight simulation

Color-coded grids were created to represent the daylight autonomy and UDI of all conditions.



Figur40. Logan daylight autonomy (at 200 lux) before and after changes, floor seats

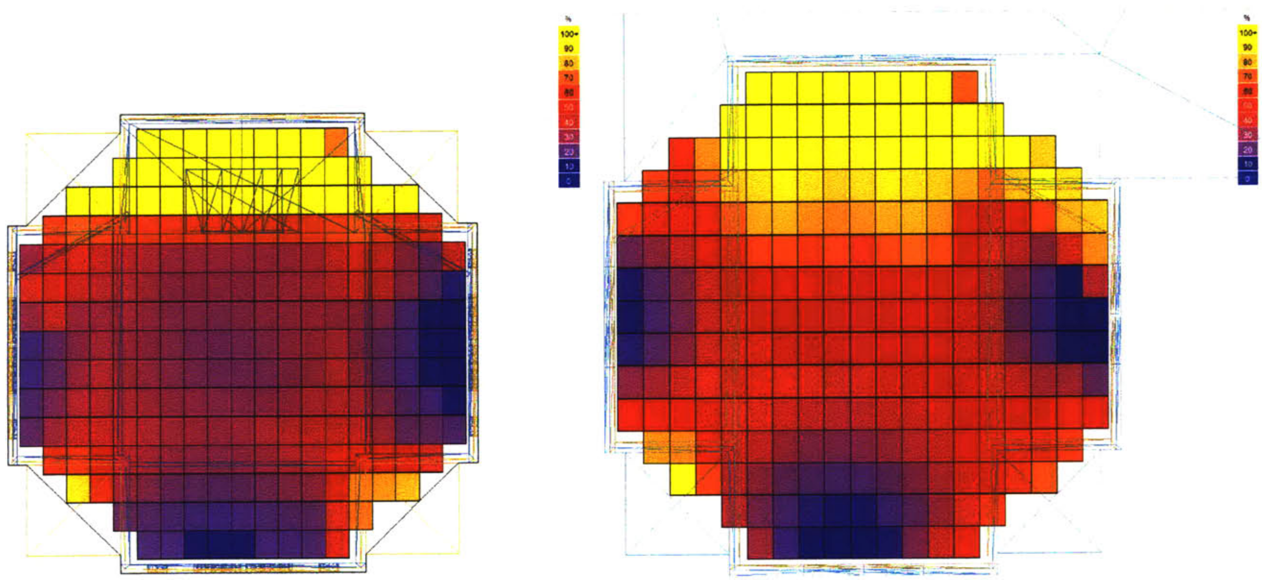


Figure 41. Logan UDI<100 before and after changes, floor seats

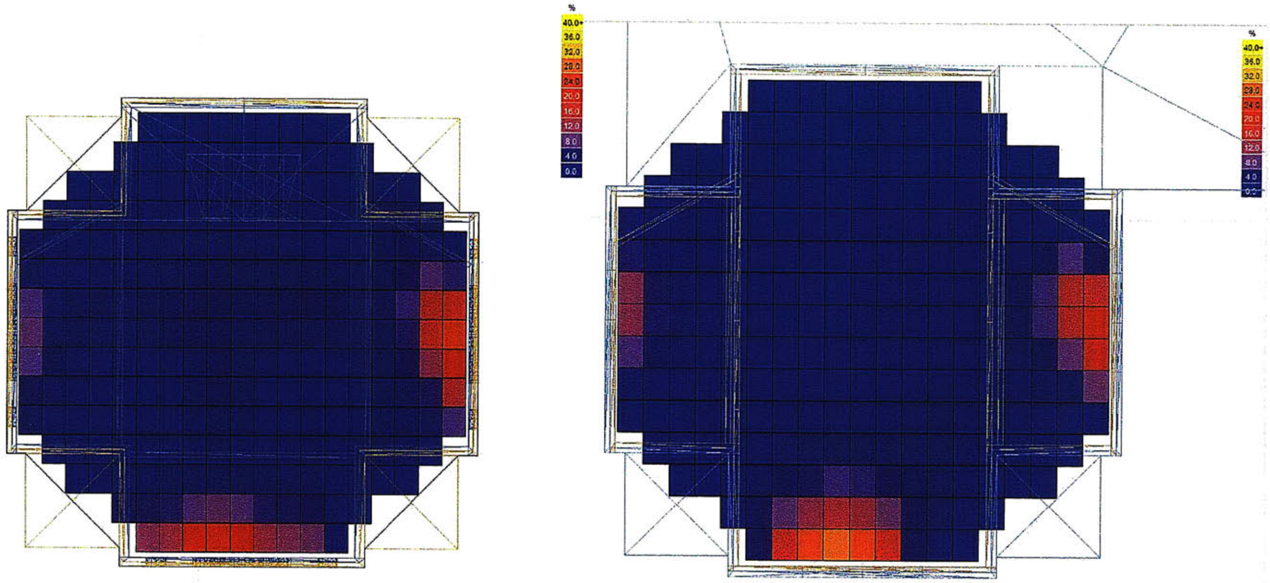


Figure 42. Logan UDI>2000 before and after changes, floor seats

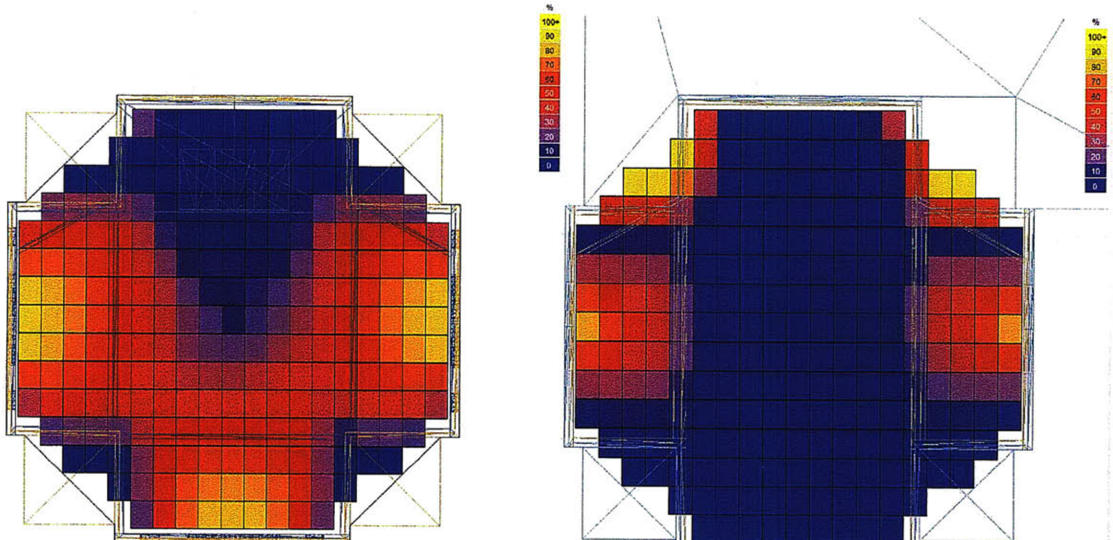


Figure 43. Logan daylight autonomy (at 200 lux) before and after changes, balcony

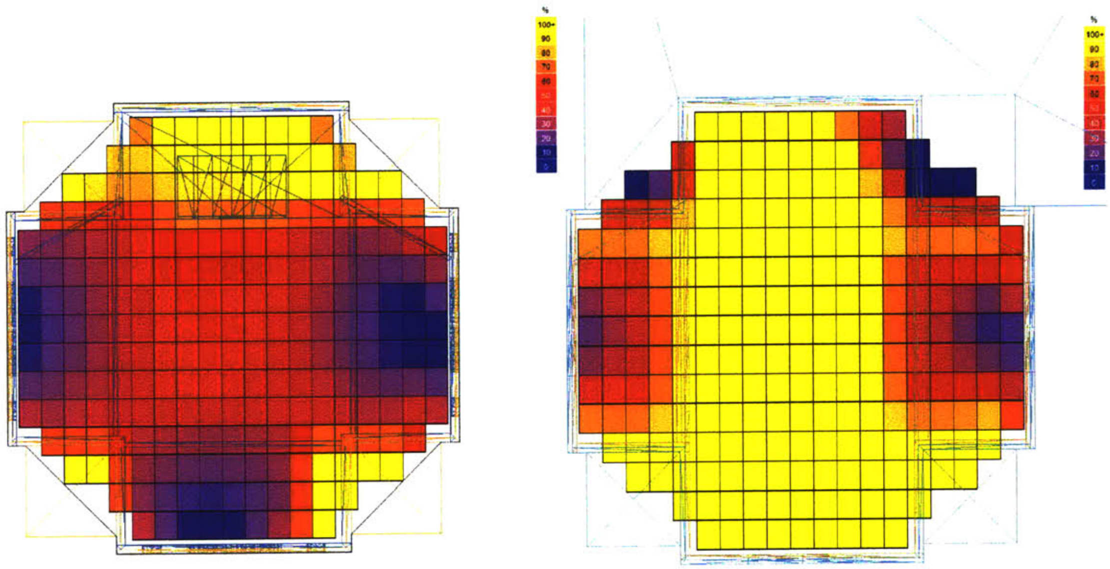


Figure 44. Logan UDI<100 before and after changes, balcony

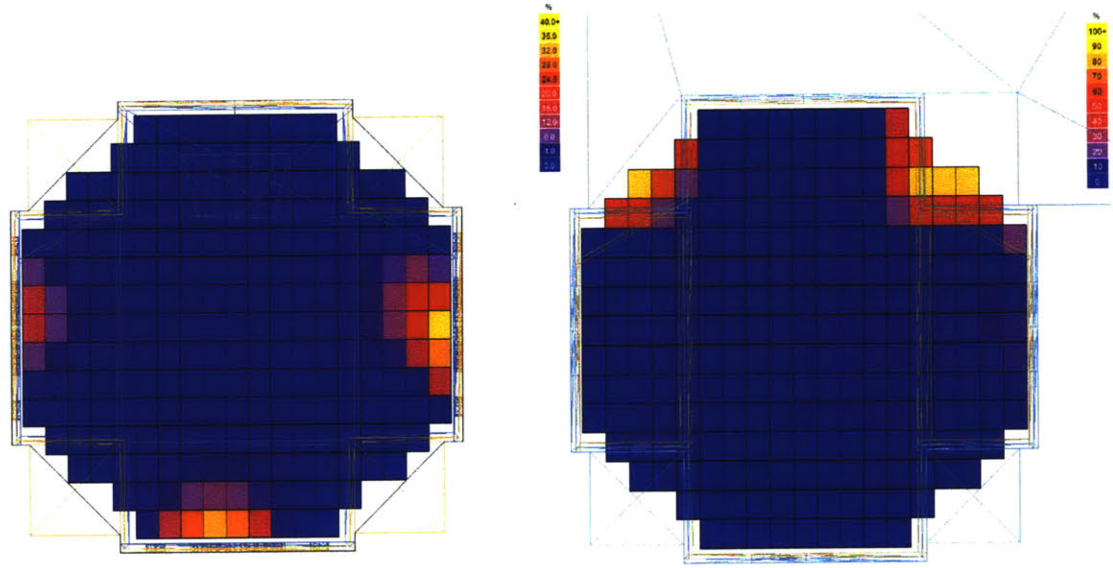


Figure 45. Logan UDI>2000 before and after changes, balcony

Daylight autonomy in the Logan Christian Church (figure 40) shows a similar pattern to the Missouri Valley Church of Christ – while the daylight autonomy levels for 200 lux near the windows are similar for the pre-renovated and renovated conditions, the center of the pre-renovated sanctuary reaches 200 lux 50% of the year, whereas the center of the renovated sanctuary never reaches 200 lux. (Note: The blue patch in the north arm of the pre-renovated sanctuary results from this part of the church not being part of the sanctuary at that time.)

However, the renovated church does reach between 100-200 lux at least 50% of the year, as indicated by the fact that it only dips below 100 lux 50% of the year, as shown in figure 41. This is probably enough to read a hymnal or bible.

The spots of above 2000 lux are virtually unchanged between the two conditions, as indicated as figure 42.

The most notable change is the decrease from fairly high daylight autonomy (70-100%) on the south wall at balcony level to no daylight autonomy, as shown in figure 43; however, the balcony at this level was also removed in the renovated condition.

In both conditions, the occupied portions of the balcony level are above 100 lux for most of the year (figure 44).

As in the Missouri Valley Christian Church, receiving above 2000 lux is not an issue at the balcony level for either condition (figure 45).

3.2.2 Glare

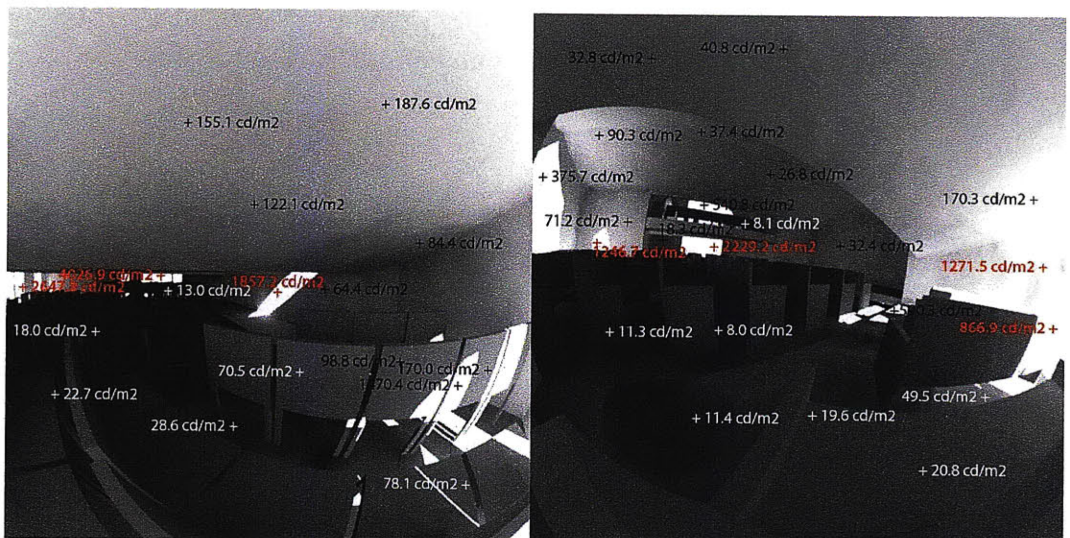


Figure 46. Radiance simulation images with measurements of luminance for the floor seats under the balcony on September 21 at 9 AM pre-renovation (left) and post-renovation (right).

One of the most problematic daylight issues in the church before renovation was the large spot of daylight thrown on the pulpit and altar area by the high windows in the morning for at least half the year (shown in figures 46, 47, and 48). While other glare sources in the church, such as the east and west windows, can be avoided by the viewer by glancing repeatedly away, these spots occur in the congregation's focal points, as visual contact with the pastor is important in a preaching-based service. This problem was basically resolved by shifting the glazing position downward. A bright spot still appears on the wall behind the altar in the renovated condition during December, but it covers a much smaller area, appears for a shorter period of time during the year, and presumably would cause less discomfort. As can be seen in figure 47, while the east and west windows are still somewhat glary from the floor seats, the contrast ratios have decrease from about 1:30 to 1:20.

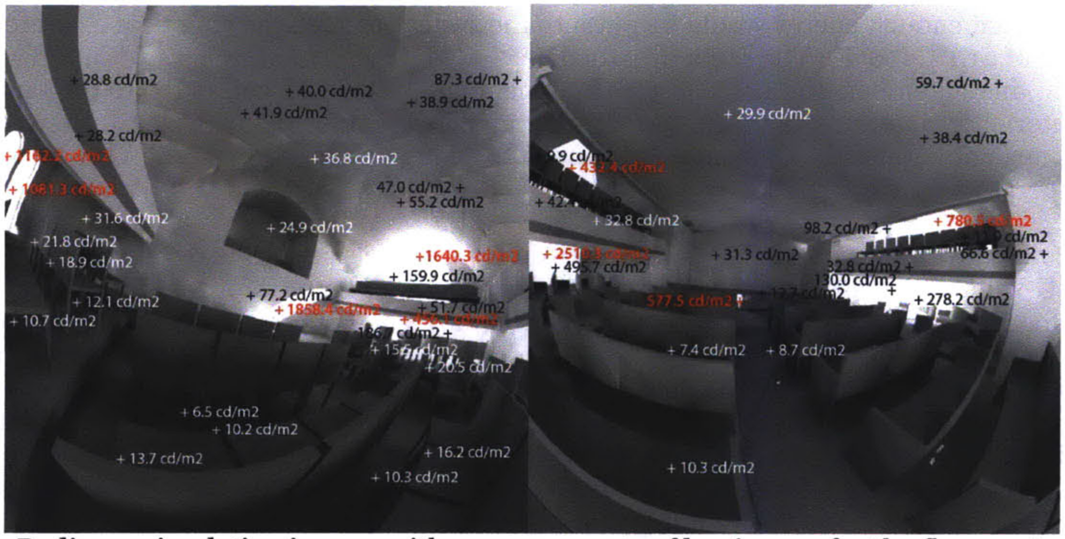


Figure 47. Radiance simulation images with measurements of luminance for the floor seats under the balcony on September 21 at 9 AM pre-renovation (left) and post-renovation (right).

Like the Missouri Valley Church of Christ, one way the Logan Christian Church mitigated glare problems was by removing sanctuary seating for which glare was an issue. The south balcony, because it commanded such a complete view of the church, had glare issues all year long (figure 48). This balcony was removed, and the somewhat limited visibility of the remaining east and west balconies effectively reduces glare.

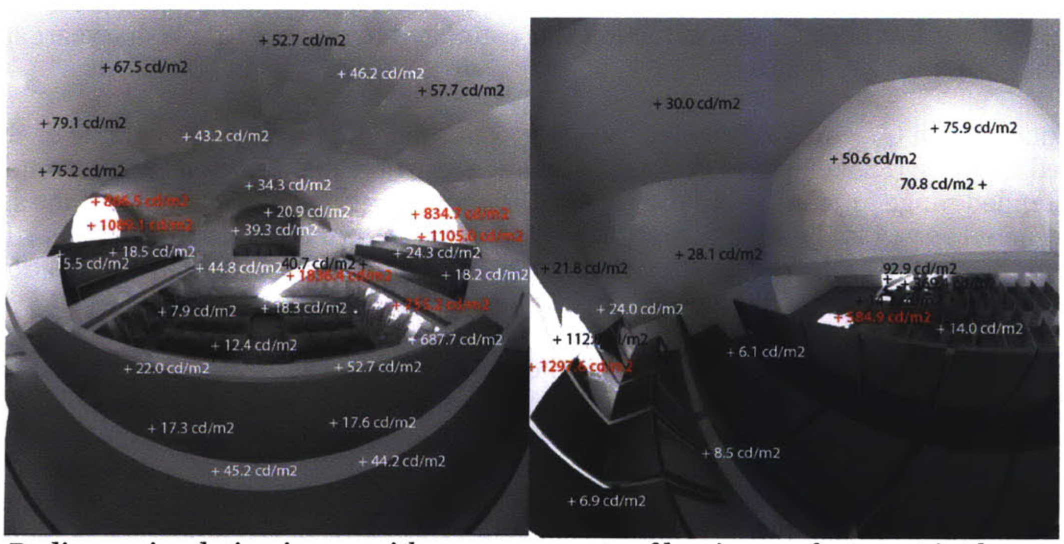


Figure 48. Radiance simulation image with measurements of luminance for a seat in the south balcony (pre-renovation) and the west balcony (post renovation) on September 21 at 9 AM.

Refer to chapter 7.0 for an appendix of Radiance images used for glare analysis.

3.2.3 Thermal Balance

Largely the same assumptions were made to calculate the thermal balance, $\Delta S = Q_i + Q_c + Q_v + Q_e + Q_s$, for the Logan Christian Church as in the Missouri Valley Church of Christ. Q_e was considered negligible; the church was considered to be in use for 13 days a month. Q_i was not calculated, but it was assumed that enough energy would be put into the system to keep the church at a comfortable temperature of 21.1°C (70°F). The same climate data – 7.8°C (46°F) in March, 21.6°C (71°F) in June, 19.7°C (67°F) in September, and 0.4°C (33°F) in December – was used, compared to the same standard interior temperature of 21.1°C (70°F) (Energy Plus Weather Data). The Q_e term was considered negligible, and the Q_i term was assumed to be high enough to maintain the interior at a steady temperature 21.1°C (70°F).

Q_c was calculated with the equation $Q_c = \Sigma(A \times U) \times \Delta T$, where A is area, U is U-value, and ΔT is $T_O - T_I$. Typical U-values were assumed for windows and walls – 2.20 W/m²K for the walls, 2.59 W/m²K for the roof before remodeling, and 5.0 W/ m²K for the windows before remodeling. After remodeling, 0.59 W/m²K was used for the roof (taking into consideration the large air space and insulation introduced by dropping the ceiling), 0.86 W/m²K was used for walls (taking into account the insulation that was added), and 2.8 W/m²K was used for the windows (taking into consideration the clear panel added to the exteriors of all windows) (Szokolay 2004). When the air layers on the surfaces of the skin of the building are taken into account, this gives U-values of 1.6 W/m²K for the walls, 1.8 W/m²K for the roof, and 2.7 W/m²K for the windows before remodeling, and U-values of 0.75 W/m²K for the walls, 0.54 W/m²K for the roof, and 1.9 W/m²K for the windows after remodeling. ΔT was, again, 13.3 K, -0.5 K, 1.4 K, and 20.7 K for March, June, September, and December; each of these months was taken to represent three months of the year.

The roof was approximated as 151 m² before remodeling and 165.3 m² after. Before remodeling, the area of walls was 88.8 m² and the area of the windows was 41.4 m²; after remodeling, the area of the walls had decreased to 86.7 m² and the area of the windows had also decreased to 37.5 m². The north wall of the sanctuary was not included in this calculation because it adjoins the church offices and Sunday school rooms, which are presumably the same internal temperature as the sanctuary. Before remodeling, the heat lost because of conduction was estimated to be 1.6×10^4 kW-h a year; after, it was about half that, 7.4×10^3 kW-h a year.

Q_v was calculated with $Q_v = qv \times \Delta T$, where qv = 0.33 x number of air changes x volume of church and ΔT is defined as above (Szokolay 2004). An air exchange rate of 8 changes/hour was assumed, within the recommended range for church buildings (*Air Change Rates* 2005.) The volume of the sanctuary was approximated as 743 m³ before renovations and 741 m³ after. About 6.4×10^5 kW-h worth of energy was lost from the church each year due to ventilation before renovations. After the renovation, the slightly smaller volume decreased the energy lost to ventilation to 6.1×10^5 kW-h.

Q_s was calculated with $Q_s = G \times sgf$, where is G is the irradiance on a vertical facade and sgf is the solar gain factor of the window. A solar gain factor of 0.42 was used for the stained glass (Szokolay 2004). Ecotect was used to create stereographic shading charts for each facade of the building. From these graphs it was determined that none of the surrounding buildings (either before or after remodeling) provided significant shading. The east facade self-shades after noon throughout the year; the west facade self-shades before noon throughout the year. With this pattern of shading, 429 kWh/m² hit the east and west facades each on the occupied days during the year and 719 kWh/m² hit the south facade (ASHRAE 1997). Before the remodeling, the church would have gained 1.6×10^4 kWh through its windows each year; after the remodeling, it gained 7.37×10^3 kW-h through the windows.

In total, the Q_c, Q_v and Q_s terms give an energy usage of 7.6×10^4 kWh for the modern-day church, a decrease of 1.3×10^4 kWh from the 8.9×10^4 kWh used in the original condition. Typical energy usage in this climate zone for a building of religious worship is about half of that, 3.1×10^4 kW-h (*Average Retail Price of Electricity* 2010, *Climodat Reports* 2010). In this case, it is possible that the insulation used may have been underestimated.

During just the three months of winter, when ΔT is estimated to be 20.7 degrees K, the heat losses were 1.1×10^4 kWh in the pre-renovation condition. After the renovations, about 9.3×10^3 kWh were used in the three months of winter, a decrease of 1.7×10^3 kWh. For comparison, the winter energy expenditures were formerly only about 12% of the energy used each year, and this energy savings is only about 2% of the energy previously required for the whole year.

The summer energy expenditures form a very small portion of the total energy used. Before renovations, about 3.2×10^3 kWh of energy were absorbed through the windows and had to be removed by cooling systems. About 2.8×10^3 kWh are absorbed through the windows in the contemporary church, a decrease of only 440 kWh, or less than a percentage point of the total energy use before renovations.

These numbers are summarized in figure 49 below.

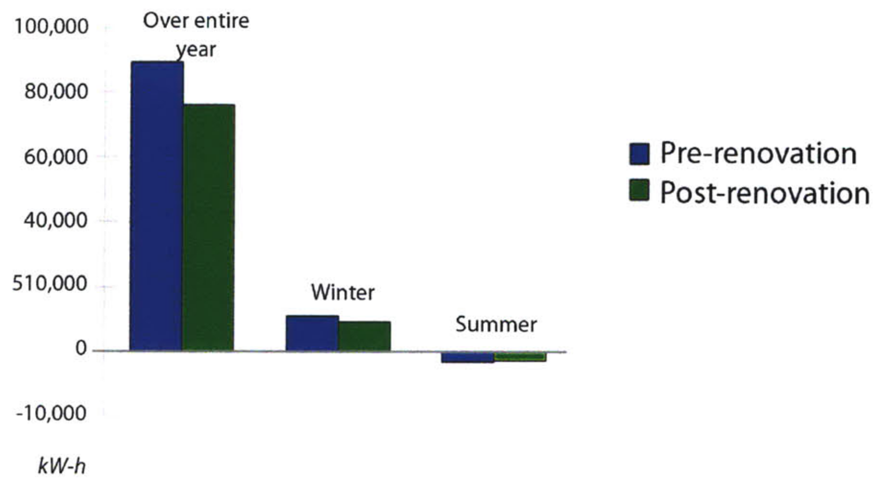


Figure 49. Comparison between energy use in the Logan Christian Church pre- and post-renovation over the entire year, in just the winter months, and in just the summer months.

4.0 Discussion of changes and their motivation

In this chapter, the effects of the renovations on daylight and energy expenditures will be discussed, and likely rationales for the renovation choices made will be proposed.

4.1 Missouri Valley Church of Christ

The primary motivations for the Missouri Valley Church of Christ's renovations will be inferred in this section from the effects these changes had on daylight autonomy, useful daylight index, glare, and energy usage. The effects of individual renovations on daylight autonomy, specifically dropping the ceiling and covering windows, will also be discussed.

4.1.1 Effectiveness of renovations and side effects

The renovations in the Missouri Valley Church of Christ had a primarily negative effect on the daylight autonomy and useful daylight index. Before these changes, electric lighting was largely unneeded during daylight hours throughout the year; afterwards, all but the outermost edges of the sanctuary require it. The glare in the sanctuary has been somewhat decreased by removing the most glary seats facing the south window and covering the high windows, but the renovated sanctuary still has glare issues, so this does not seem like a compelling rationale for the renovations made.

Why then were these changes made?

The thermal balance indicated that the new sanctuary configuration loses about 4.9×10^4 kWh less energy to its surroundings each year, meaning that the church previously had to pay for that much more energy to heat this room. With a conservative estimate of 6.8 cents per kWh, this is a savings of about \$3310 a year in energy *(Average Retail Price of Electricity* 2010*)*.

Timing is also important. Solar gains during the summer cannot make up for heat lost through conduction in the winter. During just the three months of winter, when ΔT is estimated to be 20.7 degrees K, the difference in conductive heat losses is 9.6×10^3 kW-h between the before and after conditions, or about \$820 a year worth of energy, assuming 80% efficiency in the church's heating system (). Keeping in mind that this calculation is only for the sanctuary, and that at the same time the sanctuary was being remodeled the church was being expanded, such that there is at least an equal volume of offices, kitchens, and classrooms that also must be heated during this time, this seems significant.

Examining the summer months also proves interesting. From June to August, there is a conductive gain of heat through the windows and walls as well as solar gains through the windows. Previously the heat gain during the summer months was considerably greater – before the renovations, 2.77×10^4 kWh were gained through conduction and solar contributions during these months, whereas after, the gains are only about half that amount, 1.38×10^4 kWh. With the same energy estimate and assuming a COP of 3 for the church air conditioners, this space costs \$320 to air-condition every summer. Before the renovations this church did not have air conditioning and thus did not have this extra energy burden. However, if the congregation had decided to leave the sanctuary as it was and install air conditioning, it would have cost about \$320 a year more than the current sanctuary to keep cool. Compared to the previous estimated costs of energy to heat and cool the sanctuary, the current costs are about 26% less. These values are summarized in figure 50.

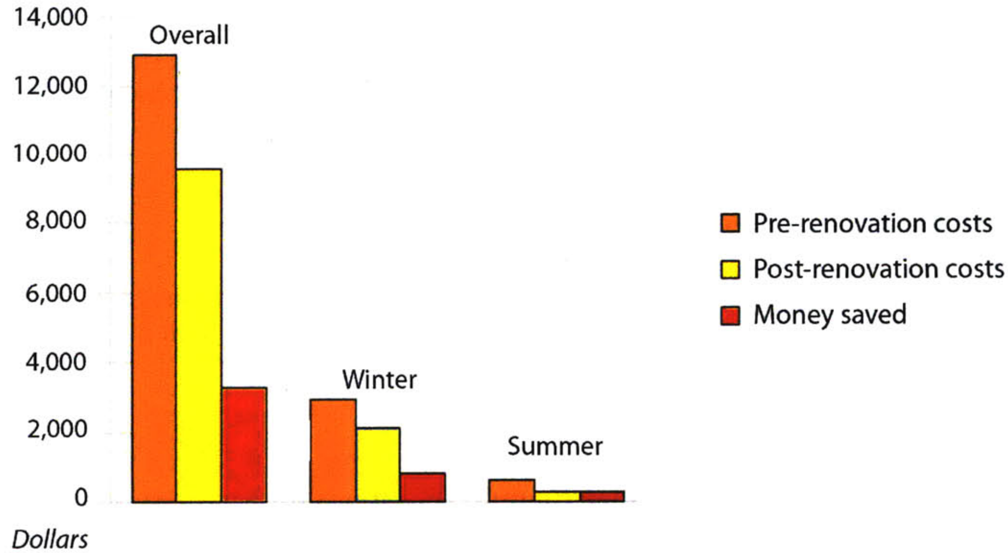


Figure 50. Comparison of costs in the Missouri Valley Church of Christ pre-renovation and post-renovation, and the money saved. For the heating costs, an 80% efficiency for the heating system was assumed; for the cooling costs, a COP of 3 was assumed.

4.1.2 Noted problems in the contemporary church

The most readily apparent problem introduced into the church was the very low daylight autonomy throughout. To determine which renovation had the greatest negative effect on the yearly illuminance, particularly toward the center of the church, two extra simulations were performed, one in which the windows were covered but the ceiling was not dropped and one in which the ceiling was dropped but the upper bank of windows still let light into the sanctuary. The "windows covered only" condition had even lower yearly illuminance than the actual renovated church, whereas the "ceiling dropped only" condition was only slightly darker than the original building. This suggests that a more moderate approach to improving the thermal performance would have been to drop the ceiling, block the top half-circles of windows only, and leave the upper rectangular bank of windows intact. This approach would have decreased the volume of the church, therefore decreasing the heat lost through ventilation, as well as reducing the glazing area somewhat. The fact that blocking the windows without dropping the ceiling results in a darker condition suggests that for the sake of yearly illuminance churches should attempt to preserve windows near the ceiling, as lower windows cannot bounce light as deep into the sanctuary. Leaving high windows to provide illuminance thus must be coordinated with positioning these high windows carefully to avoid glare at the front of the church.

4.1.3 Ideas about motivation for change

The renovations in the Missouri Valley Church of Christ were almost certainly motivated by the cost of energy to heat and cool the church. Although glare was something of a problem in the original church, the building was actually so bright that the overall contrast ratios were not extremely high. Particularly because the north balcony and not the east balcony was walled in, it seems clear that the amount of conductive losses through these windows that were not regained through solar heat was unacceptable. While the ceiling could have been dropped just to install air ducts for central heat and air conditioning, it was lowered enough to significantly decrease the volume of the church and the heat lost through ventilation, suggesting it was for thermal purposes and not just mechanical convenience that this choice was made.

The change of seating orientation from facing the southwest corner to facing the west wall was likely motivated by glare concerns, as it puts the south windows firmly in the peripheral vision rather than in the central vision, where they are more likely to cause glare.

4.2 Logan Christian Church

The rationale for Logan Christian Church's change of windows and ceiling drop will be determined in this section through examination of the effects of renovations on the daylight autonomy, glare, and heat exchange.

4.2.1 Effectiveness of renovations and side effects

In terms of illuminance, the Logan Christian Church renovations were more successful than those of the Missouri Valley Church of Christ. A much higher daylight autonomy was maintained throughout the church, and even the center of the church only dipped below 100 lux for 50% of the year, suggesting that most of the time the congregation would be able to read without the aid of electric lighting. On the balcony level, most of the daylight autonomy was lost at the south end of the church, but it made sense to sacrifice illuminance there after the south balcony was removed. This renovation may have been more successful because the initial siting of the church was more "energy-conscious;" there were no large amounts of glazing facing the north that could not recoup their conductive losses through solar gains.

The glare was partially reduced by removing seating with notable glare issues, such as the south balcony, and by dropping the position of the glazing in the walls such that fewer bright spots were thrown directly on the wall behind the pulpit and altar in the central vision of churchgoers.

Some money was saved by the renovations, mostly due to an increase in insulation and the corresponding decrease in energy lost through conduction. These savings are summarized below in figure 51.

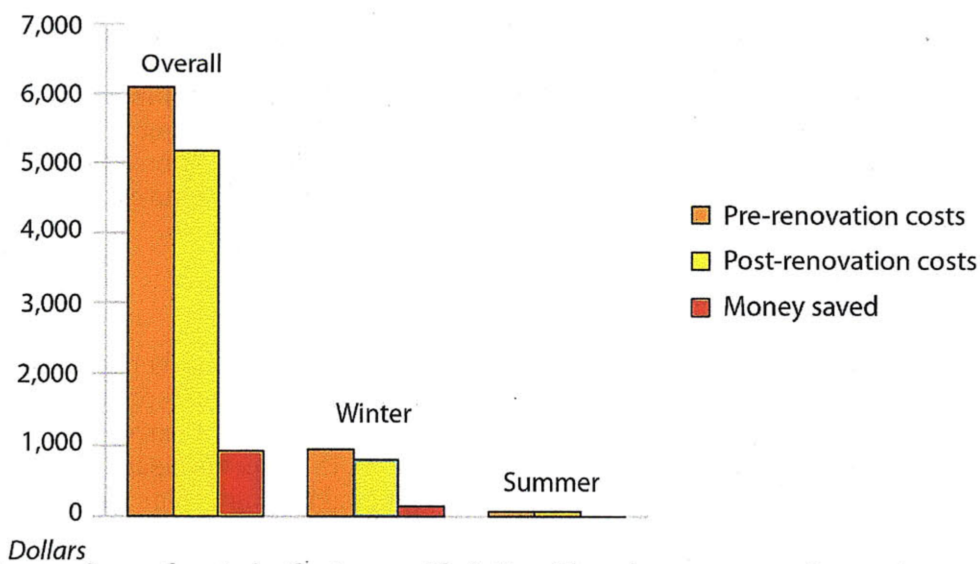


Figure 51. Comparison of costs in the Logan Christian Church pre-renovation and post-renovation, and the money saved.

4.2.2 Noted problems in the contemporary church

The luminance was reduced very evenly in the modern church, such that even though many of the former glare spots were reduced in brightness, nearly the same contrast ratios were preserved. However, in many ways – overall illuminance and energy used to heat and cool the church – the church was quantitatively successful both before and after the renovation, suggesting that factors other than comfort were the driving forces in the renovations.

4.2.3 Ideas about motivation for change

The motivation for the renovations in the Logan Christian Church is less obviously linked to thermal comfort and energy usage than the renovations in the Missouri Valley Church of Christ. The amount of money saved per year is relatively small – about $1000 – and mostly due to material changes, such as the addition of insulation in the roof and walls, rather than configuration changes. This is a smaller church, but the overall saving were a lower percentage of the original energy costs.

However, there were significant glare issues in the pre-renovation church. While these are entirely resolved in the contemporary building, retaining a similar amount of glazing but shifting it downward decreased the glare in the central vision of most congregants by decreasing the bright spots thrown on the stage and pulpit area.

The deciding factor in the renovation might not have been the cost of energy lost through the windows but the cost of repairs. The old windows, one of which is shown in figure 53 and discussed in the the introduction, were quite intricate, with almost no two pieces of glass the same size or shape. These windows had apparently suffered some damage during their six decades of use, because during the 1970s renovations they were deemed too expensive to repair and instead entirely replaced with "art glass" (Logan Centennial 1987). The new windows were composed of rectangular pieces of glass, which are presumably easier to replace if necessary.

Figure 53. One of the original windows from the 1904 Logan Christian Church, removed in 1970.

5.0 Limitations of this research

Due to necessary simplifications in both the types of research done and the specific simulations, this research has certain limitations.

There are wide variety of reasons for renovating a sanctuary or changing how it is designed, many of them not discussed in this paper. Weather damage likely played a role in the change of windows at the Logan Christian Church and the Woodbine Christian Church; congregation-specific historic events were not taken into account (Darling 2009). The initial cost of windows and the availability of stained glass artisans or companies was not researched, both of which are doubtless a deciding factor in the decision of whether or not to install them. The question of theological evolution was essentially left untouched. An underlying assumption of this paper is that the visual experience of a church is part of its value to its congregation and the community, but this is not necessarily held to be true by all church bodies. Some congregations may object to the money spent on designing and constructing a building when they believe that money could be better used in service to others. Perhaps these questions could have been answered with interviews or surveys in a future study. Certainly this document does not address all the reasons for which churches change, and further investigation into the social and theological contexts of each individual church would prove fascinating.

On a smaller scale, certain simplifications were necessary were made in each simulation that may make the results less accurate. Certain components, such as shading foliage, that could significantly affect the daylight autonomy, were neglected entirely. The glare assessment is perhaps not accurate because the Radiance images were produced without color or great detail in the windows. People often do not consider interesting objects, even very bright ones such as stained glass windows, as glary as boring ones (Lam 1986).

In terms of the thermal calculations, these numbers are primarily for comparative purposes. Simplifications were made regarding the geometry of the building to make calculations easier. The ventilation term was also broadly estimated because of the lack of information about which windows were operable in the pre-renovation conditions, as well as uncertainty about how airtight the churches are in their contemporary states. The lack of information about the heating systems before and after the renovation makes the energy and costs calculations tentative at best. Simulation with software like Energy Plus may have produced a more accurate representation of the energy use and savings.

This research could be extended in any number of ways – interviewing congregations, doing daylight autonomy and glare simulations on other churches in the area, creating precise representations of how much energy is being by each church and when – that could help further understand this portion of American culture, and, perhaps, more about the forces at work on religious buildings in general.

6.0 Conclusions

In this thesis, I examined the historical evolution of churches in Harrison County, Iowa from a period before prevalent active climate control into a period utilizing active climate control. Focusing on daylighting, I assessed which aspects of church design were sacrificed and which were prioritized as design values changed. I became interested in the question of comfort and energy in the context of churches initially because I wonder if (and worried that) the cost of carefully maintaining a specific environment within a church would eventually totally preclude the visual experience of a beautiful church. Most congregations in this area are no more than 400 people and thus often lack funds to both build a architecturally exciting building and maintain it. In some ways, this makes each church and its defining design choices a more accurate representation of what each congregation values.

6.1 General trends in church evolution

The case studies have shown that renovated churches and newer churches tend to have overall lower illuminance throughout the year, and therefore lower daylight autonomies and greater need for electric lighting. There is somewhat less glare in newer churches, but the overall lower levels of luminance mean that even relatively dim "bright spots" can cause discomfort. There is a tendency to block high windows and retain glazing at a lower level, likely because these high windows tend to throw bright spots on the altar and pulpit, causing discomfort.

They also typically take less energy to heat and air-condition, by reducing glazing area and adding insulation in walls and roofs. Some changes, such as blocking in north windows, are clearly driven by energy costs and thermal comfort, but the motivation for others is less clear. Lowering the ceiling substantially can decrease the amount of energy used to heat the air in the sanctuary, but just making a rounded ceiling planar has less noticeable effect.

6.2 Results in context of county

Certain changes seen in the two case studies seem fairly typical for churches in this county. For instance, both of these churches dropped their ceilings about mid-century, a decision shortly preceding the introduction of air conditioning and the accompanying air ducts. Dropping the ceiling also provides a place to add in more insulation. As shown in figure 53, this tpe of ceiling is invariably made planar and angular, or simply flat, when dropped, although the original ceilngs were frequently vaulted in a smooth curve. Neither of these types of renovations reflects light in the same way a barrel vault.

Figure 53. Dropped ceiling in St. Anne's Catholic Church in Logan, Iowa.

For those churches who have installed new windows, such as the Logan Christian Church, or those new churches built since about the 1950s, there is tendency to use windows that are made up of larger individual pieces of glass cut in rectangular or triangular shapes – perhaps because these pieces are easier to replace, or perhaps because windows broken less often by leading have better thermal properties. Also, many later stained glass windows are installed as double-pane windows. This is in contrast to earlier churches which were installed as single-pane windows and later covered over in protective plastic. Being installed as double-pane windows from the start is preferable on two levels – one, the second pane tends to be of higher quality and have a higher transmittance, and two, the windows doubtless are more airtight and have better thermal performance.

There is an obvious trend toward using less glazing in newer churches and building with lower ceilings. In some ways, this could be considered a return to the earliest sanctuary forms that appeared in Harrison County, the simple Prairie Gothic boxes with small pointed windows. However, at that point in time the cost of glass rather than the cost of energy was the limiting factor (*Glass History* 2010.) The far extreme of this approach is perhaps displayed in figure 54 below, which show the relatively new Community of Christ (formerly R.L.D.S.) church in Missouri Valley. This building has virtually no glazing at all, a ceiling no higher than a single-story house, and at first, second, and even third glance is indistinguishable from a private home.

Figure 54. Recently build Missouri Valley Community of Christ Church (formerly R.L.D.S.); a minimum of glazing.

6.3 Predictions

What this thesis has illuminated are realistic ways that church sanctuaries can incorporate stained glass, high ceilings, and other traditional hallmarks of religious architecture and still be energy-conscious. In both of the case studies, the costs of traditional buildings were explored in terms of comfort and energy usage, and by determining what was too demanding for these congregations to maintain it is possible to sketch out some ideas of what would be affordable given the expectations for a modern church.

The value of discussing effective ways to preserve old churches and build new churches of great beauty is not merely aesthetic. Stained glass and daylight-rich designs, such as high ceilings, contribute heavily to the value of church buildings and, in some sense, to the self-attributed value of a congregation. Churches without these investments tend to change hands quickly, as has been the case for the machine-shed type church in Woodbine, Iowa that was discussed in the introduction. Even when churches cease to be used as religious structures, they are often re-used in ways that are valuable to their communities – as senior centers, museums, or attractive apartments. Churches, perhaps more than any other type of building in this area of Iowa, contribute to the visual texture and attractiveness of each community. By being the least basic and perhaps the least practical buildings present in a county of barns, farmhouses, utilitarian schools, and boxy storefronts, churches form visible anchors of local heritage.

Even when stained glass is no longer installed as an architectural feature, preserved windows can become heirlooms for their congregations. The Logan Church of Christ, after having windows returned that had been donated to the Moorhead Christian Church after their renovations, decided to install them indoors in their new gym next door (Riley 2010). The Missouri Valley Community of Christ Church (formerly the R.L.D.S. church, shown in figure 53) took a similar approach with the windows from their old building when they constructed a new sanctuary earlier this decade (Struble 2010.) This practice stands in somewhat surprising contrast to the attitudes of many of the original neo-Gothicists. In an 1864 catalog of their own work, the stained glass manufacturers Heaton and Butler criticized Renaissance windows for not blending in as architectural decoration in a unified design. These windows were considered works of art in their own right, and therefore could not be subservient to an overall program of uplifting and virtuous design in their respective churches (Raguin 1990). Such a contrast points out that stained glass has taken on a host of meanings, secular and historical, since Abbot Suger first commanded the congregants of Saint-Denis to allow the lights of his church to "brighten their minds" (Halsall 1996).

Issues that arose in the case studies were the need for careful siting of churches, wise choice of materials, and the placement of windows. Admittedly the orientation of windows depends to a certain extent upon the lot that the congregation is able to secure, but a huge amount of north glazing is certainly an energy liability, though it may control somewhat for glare. The importance of good materials – good insulation in the walls and roof, as well as double-paned windows – is of paramount importance. High windows in the south and east of a sanctuary, while they provide a great deal of illumination, also tend to throw painfully bright spots of glare on the pulpit and altar areas, which can cause discomfort for the congregation. These windows should be placed with care to avoid this if possible.

What of newly constructed churches in Harrison County? How do they deal with the issues of heat loss through windows and overheating while still providing an exciting visual experience?

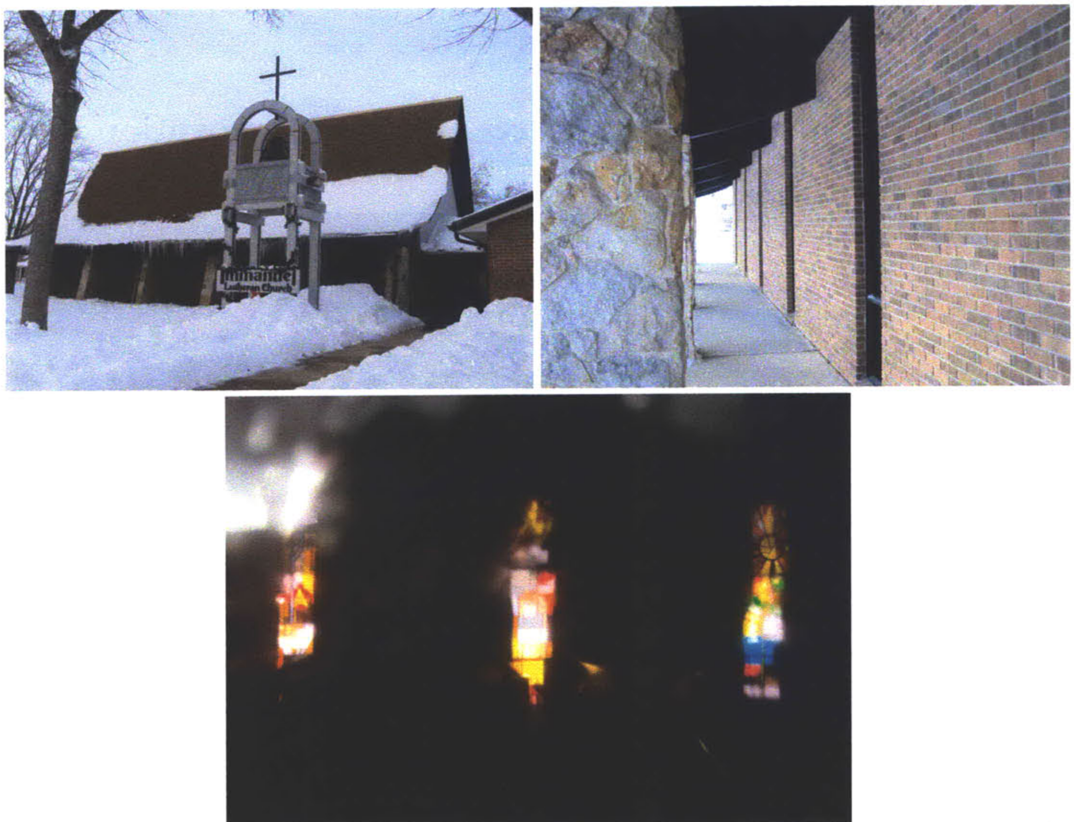


Figure 55. Logan Immanuel Lutheran Church in Logan, Iowa, constructed 1970; exterior view; view of glazing under the overhang; looking through a window to the other side of the church.

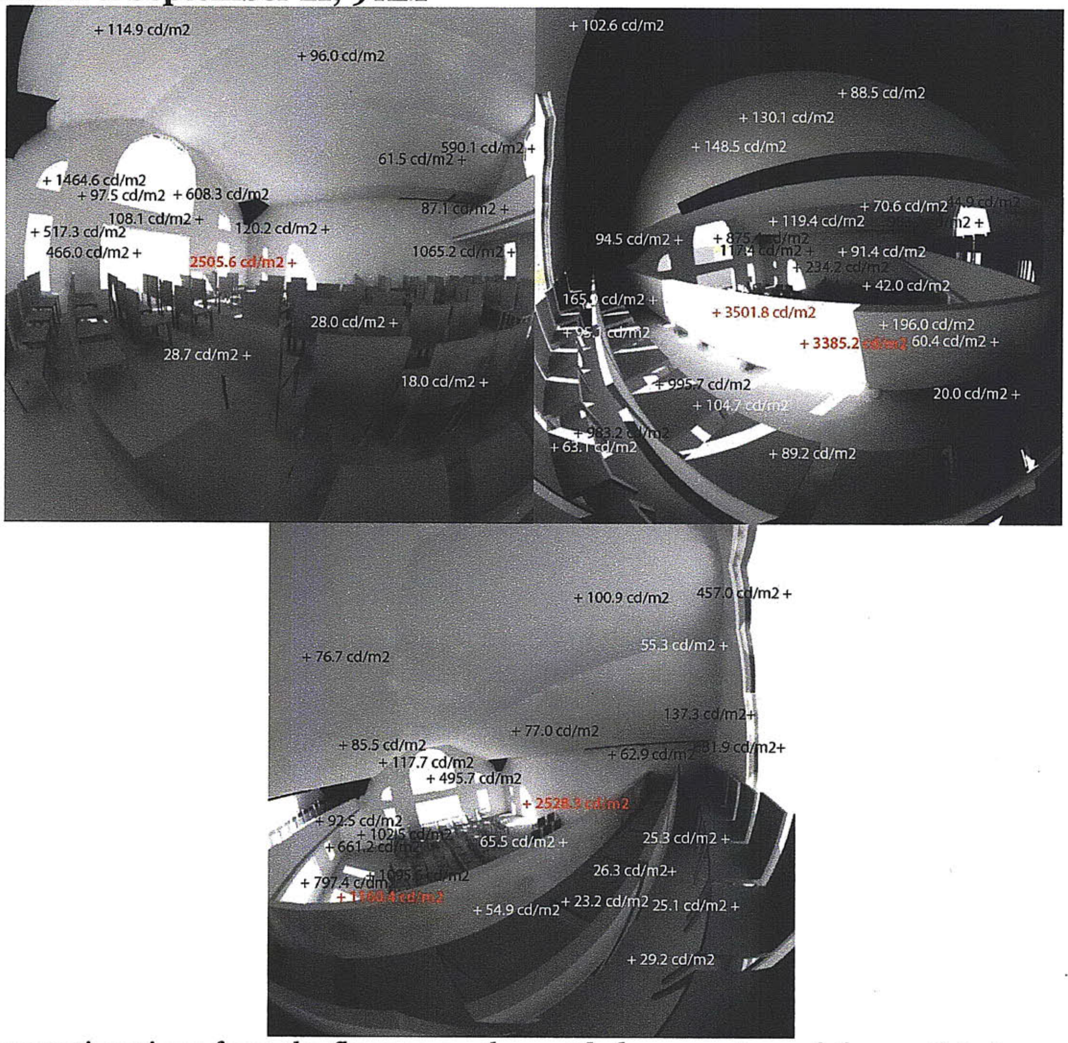
An interesting and compelling answer to these problems in the Immanuel Lutheran Church in Logan, shown in figure 55. This church was built in 1970, after installing air conditioning had become standard. Clearly the visual experience is a priority in this building, as can be seen by the installation of vibrantly colored stained glass and the unconventional form that gives a great deal of height in the sanctuary. However, the actual area of glazing is a fairly low percentage of the walls – a large part of the height of the building is given by its steeply pitched roof, possibly controlling the heat lost through conduction. The heavy overhangs address two other issues that trouble an air-conditioned church – overheating in the summer and glare. The shading would prevent undesirable solar gains in the summer months. The overhang would also prevent all but the very earliest morning light from penetrating the sanctuary directly, making glare unlikely to be a problem during morning services that start at 9:00 or 10:00 AM.

The worry that the cost of climate control would eventually totally preclude the visual experience of daylight in a church is what made this thesis question interesting and important. In this thesis examined the historical evolution of churches in Harrison County, Iowa was examined from a period before active climate control into a period utilizing climate control extensively. Two case studies were done on the Missouri Valley Church of Christ and the Logan Christian Church examining the effects of extensive renovations done in the mid-20th century. Daylighting and thermal qualities were focused on and assessed which aspects of church design were sacrificed and which were prioritized. What this thesis has illustrated are realistic ways that church sanctuaries can coordinate comfort and exciting visual experience.

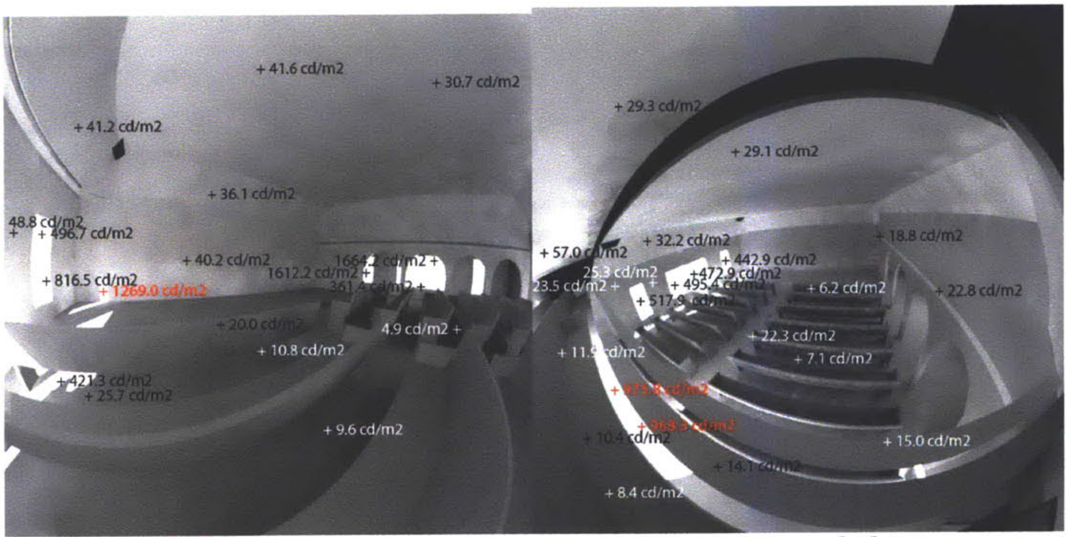
7.0 Appendix of Radiance Images

7.1 Missouri Valley Church of Christ Pre- and Post-Renovation

7.1.1. March 21 & September 21, 9 AM

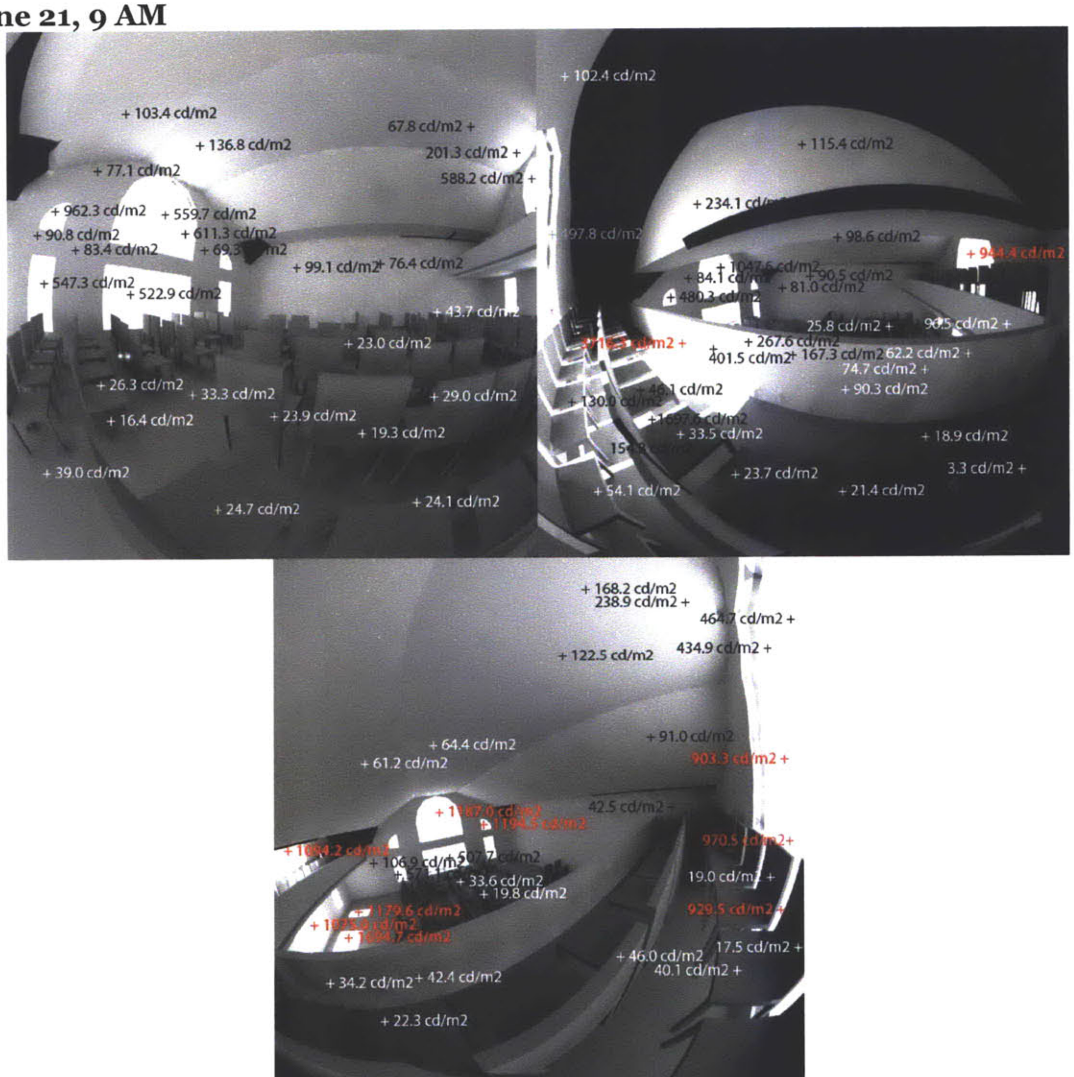


Pre-renovation views from the floor seats, the east balcony seats, and the north balcony seats

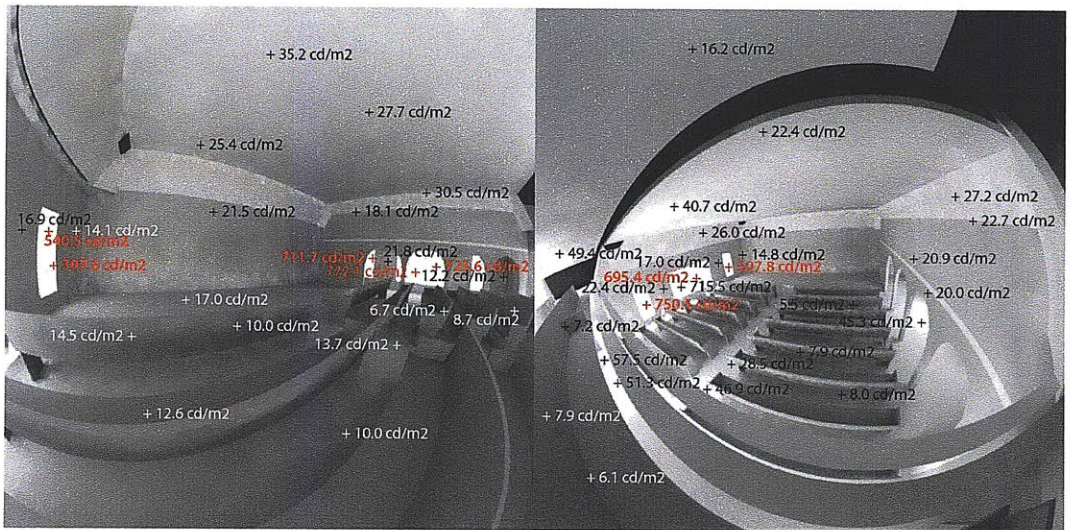


Post-renovation views from the floor seats and from the east balcony seats

7.1.2. June 21, 9 AM

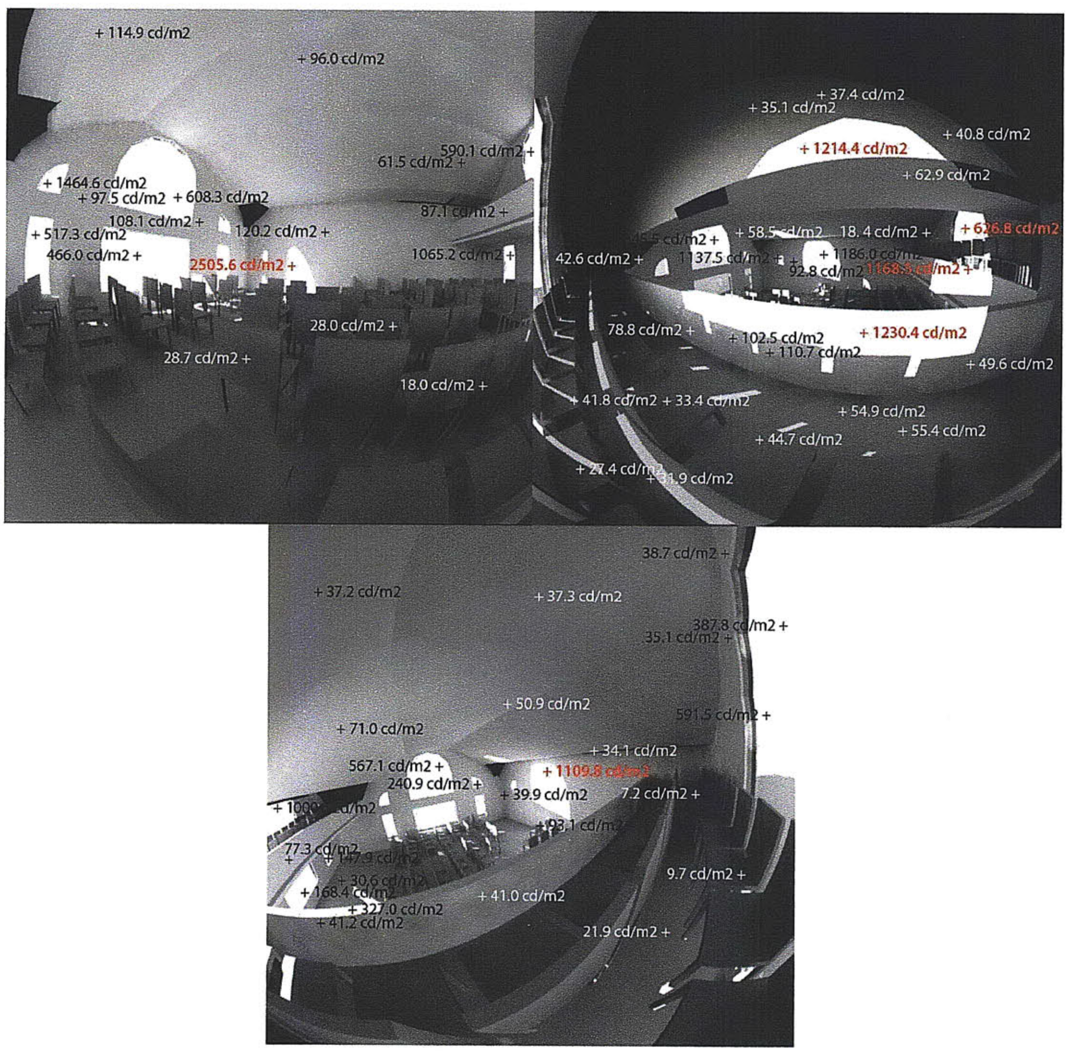


Pre-renovation views from the floor seats, the east balcony seats, and the north balcony seats

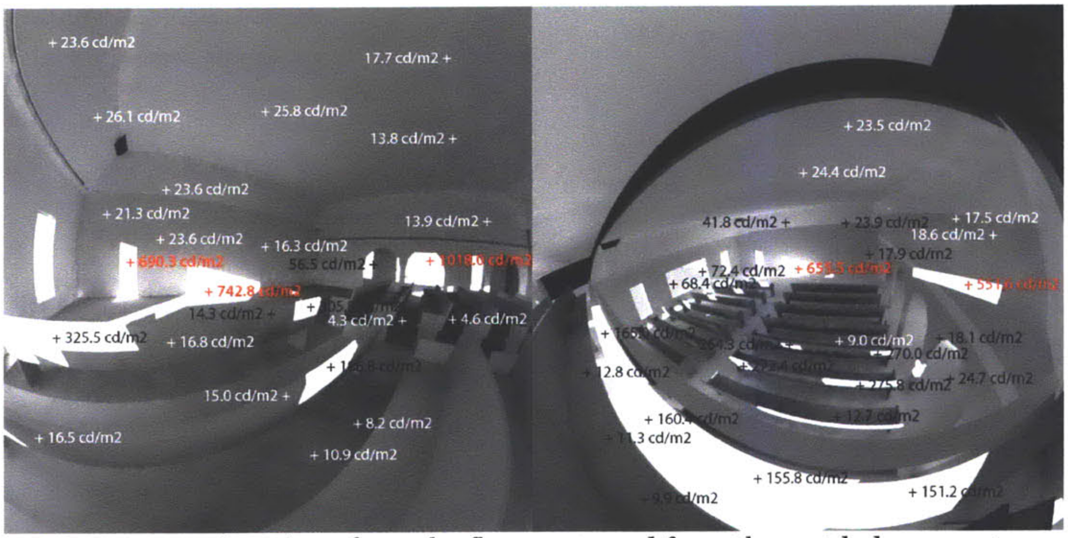


Post-renovation views from the floor seats and from the east balcony seats

7.1.3. December 21, 9 AM



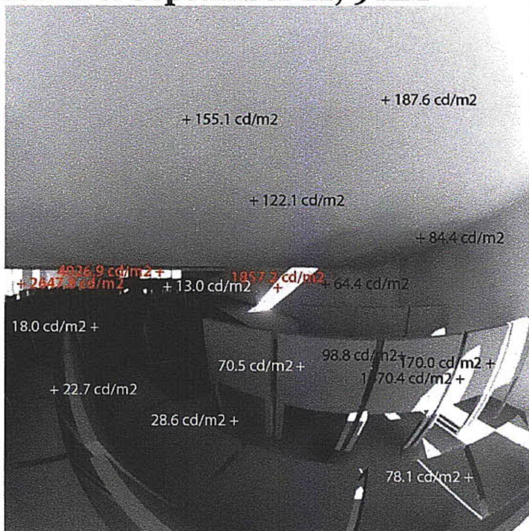
Pre-renovation views from the floor seats, the east balcony seats, and the north balcony seats

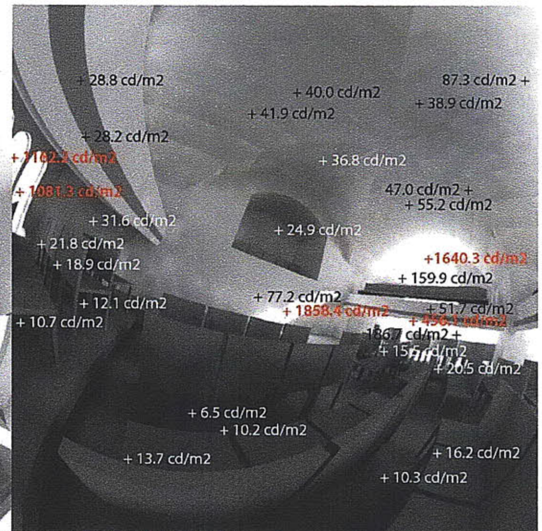


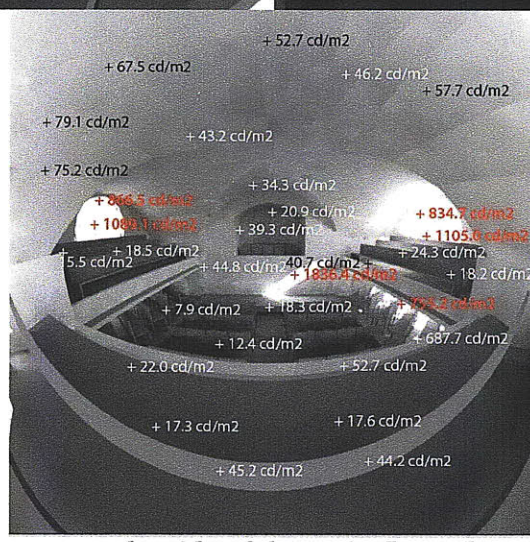
Post-renovation views from the floor seats and from the east balcony seats

7.2 Logan Christian Church Pre- and Post-Renovation

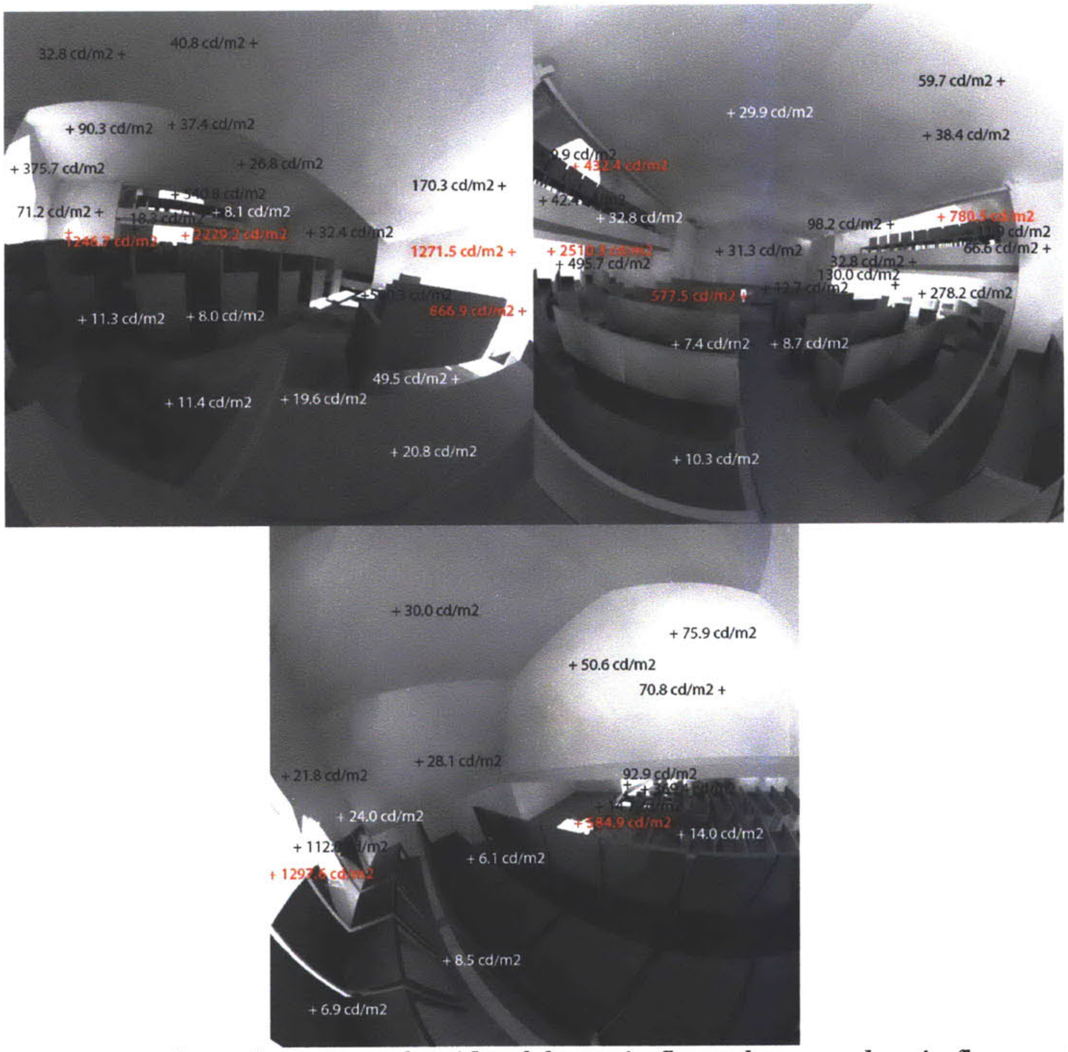
7.2.1. March 21 & September 21, 9 AM





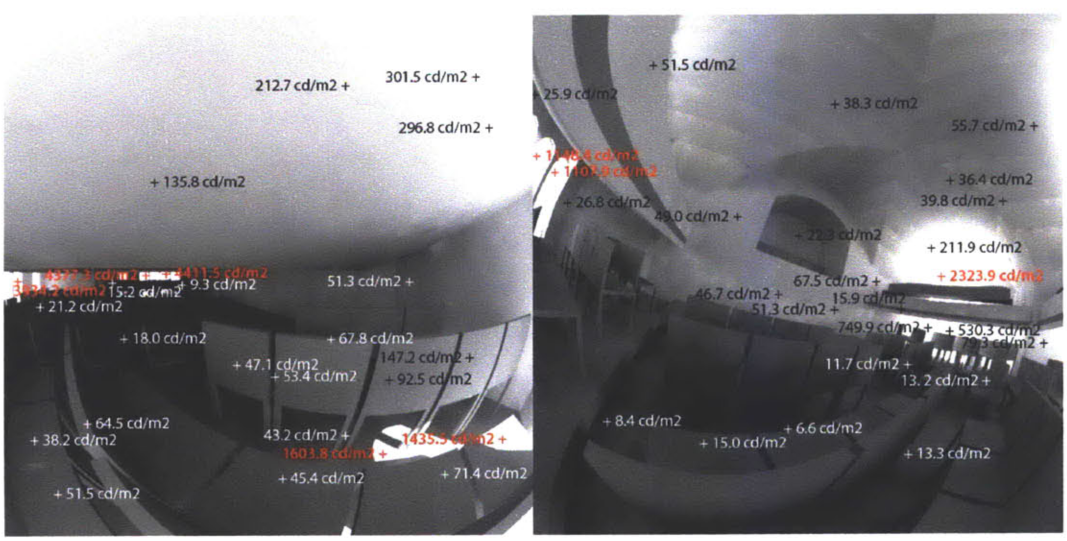


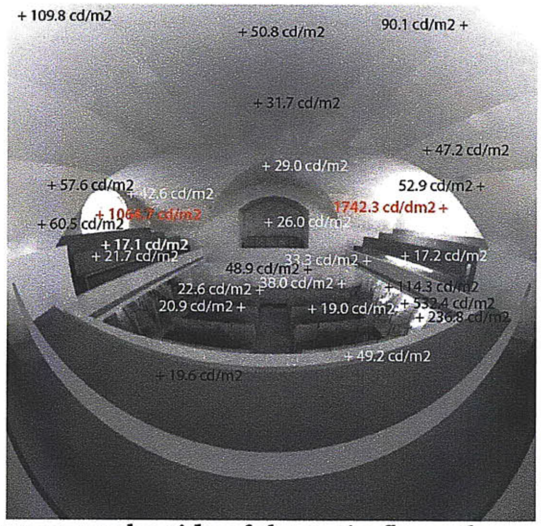
Pre-renovation views from the seats at the side of the main floor, the central main floor, and the south balcony



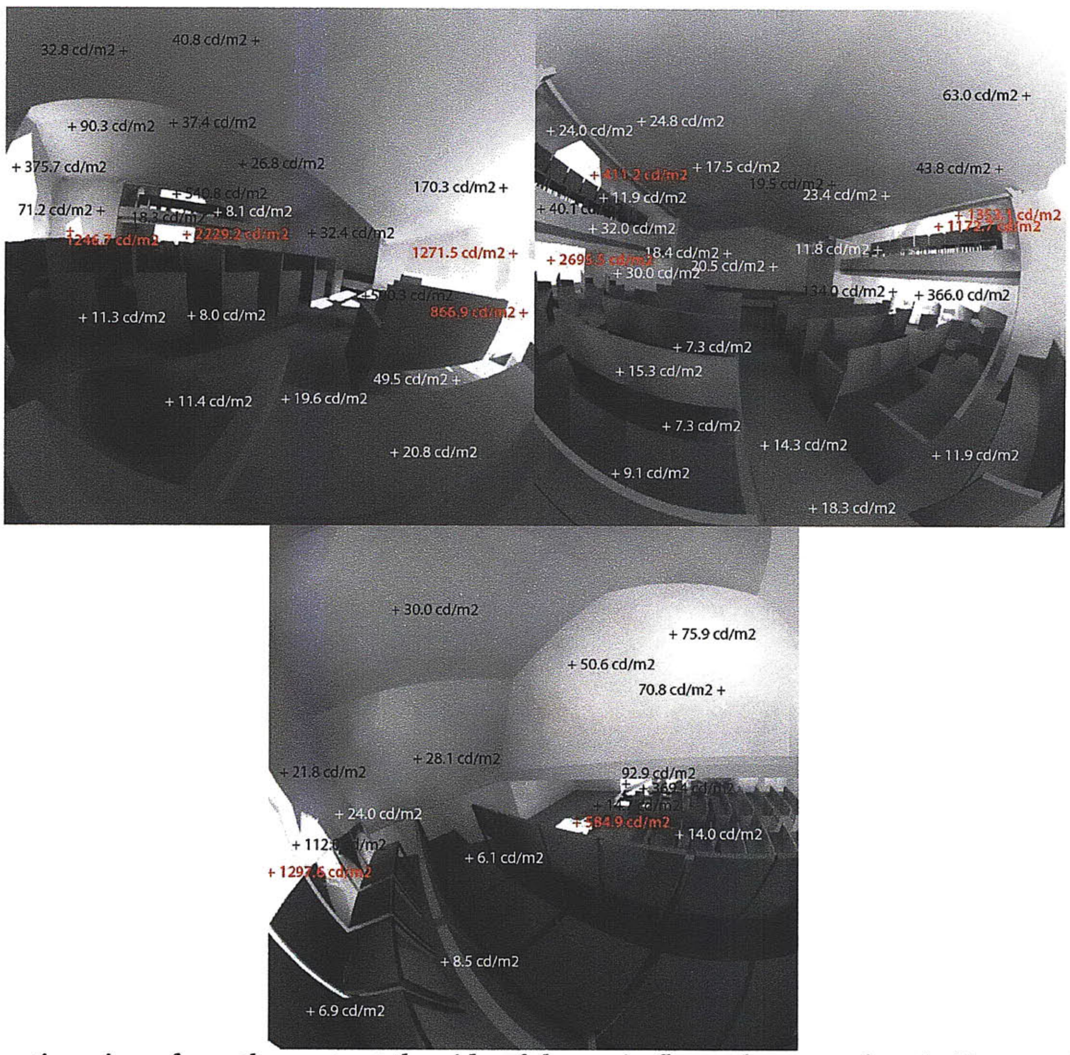
Post-renovation views from the seats at the side of the main floor, the central main floor, and the west balcony

7.2.2. June 21, 9 AM



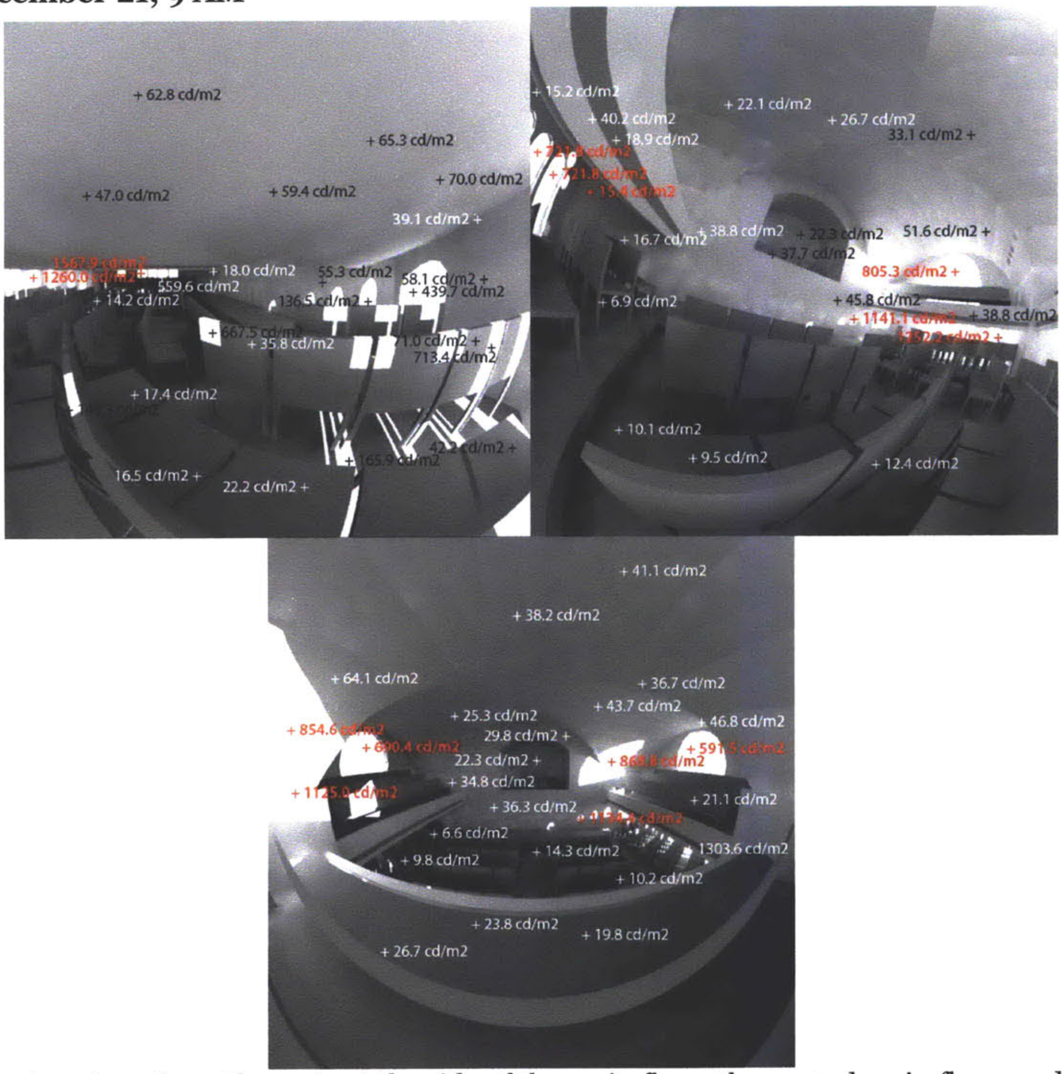


Pre-renovation views from the seats at the side of the main floor, the central main floor, and the south balcony

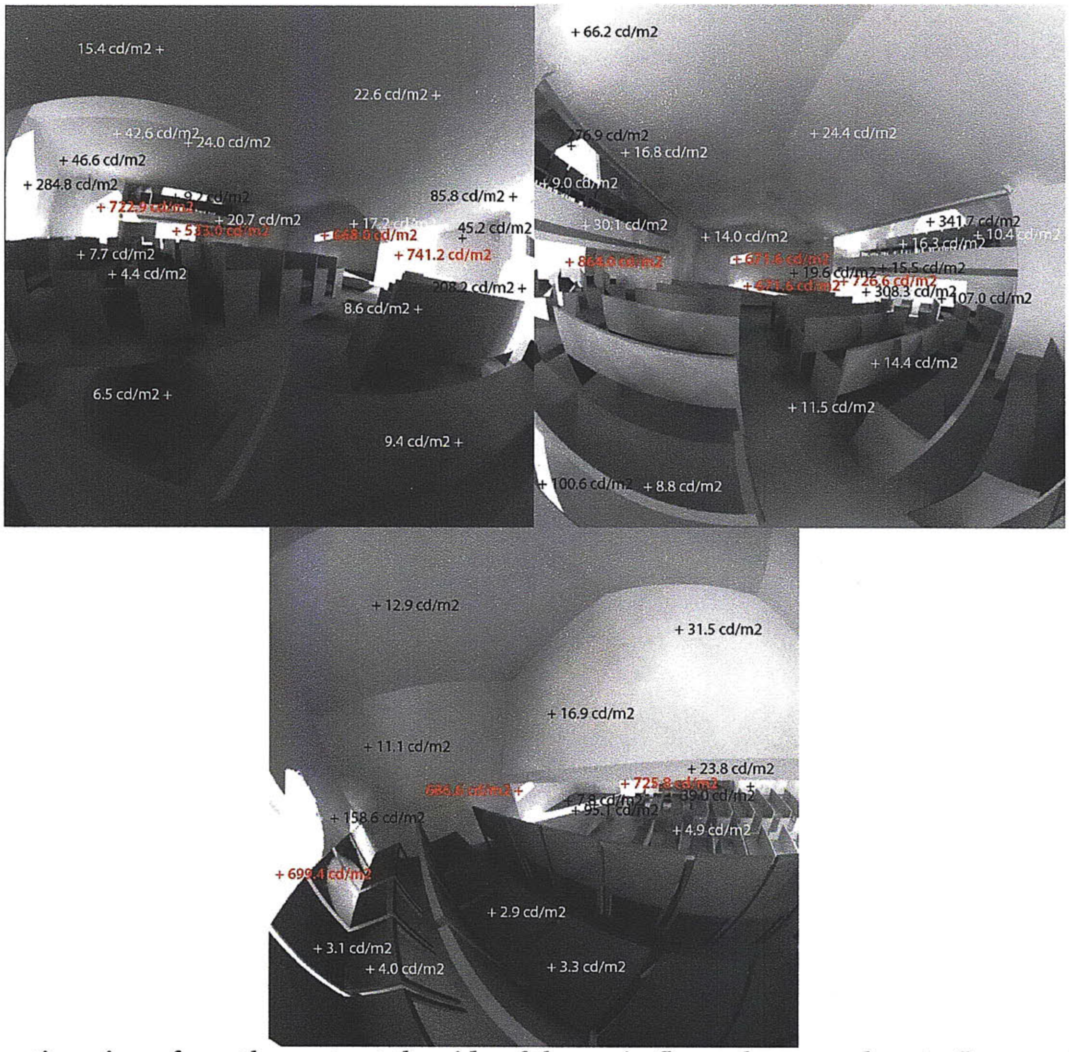


Post-renovation views from the seats at the side of the main floor, the central main floor, and the west balcony

7.2.3. December 21, 9 AM



Pre-renovation views from the seats at the side of the main floor, the central main floor, and the south balcony



Post-renovation views from the seats at the side of the main floor, the central main floor, and the west balcony

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