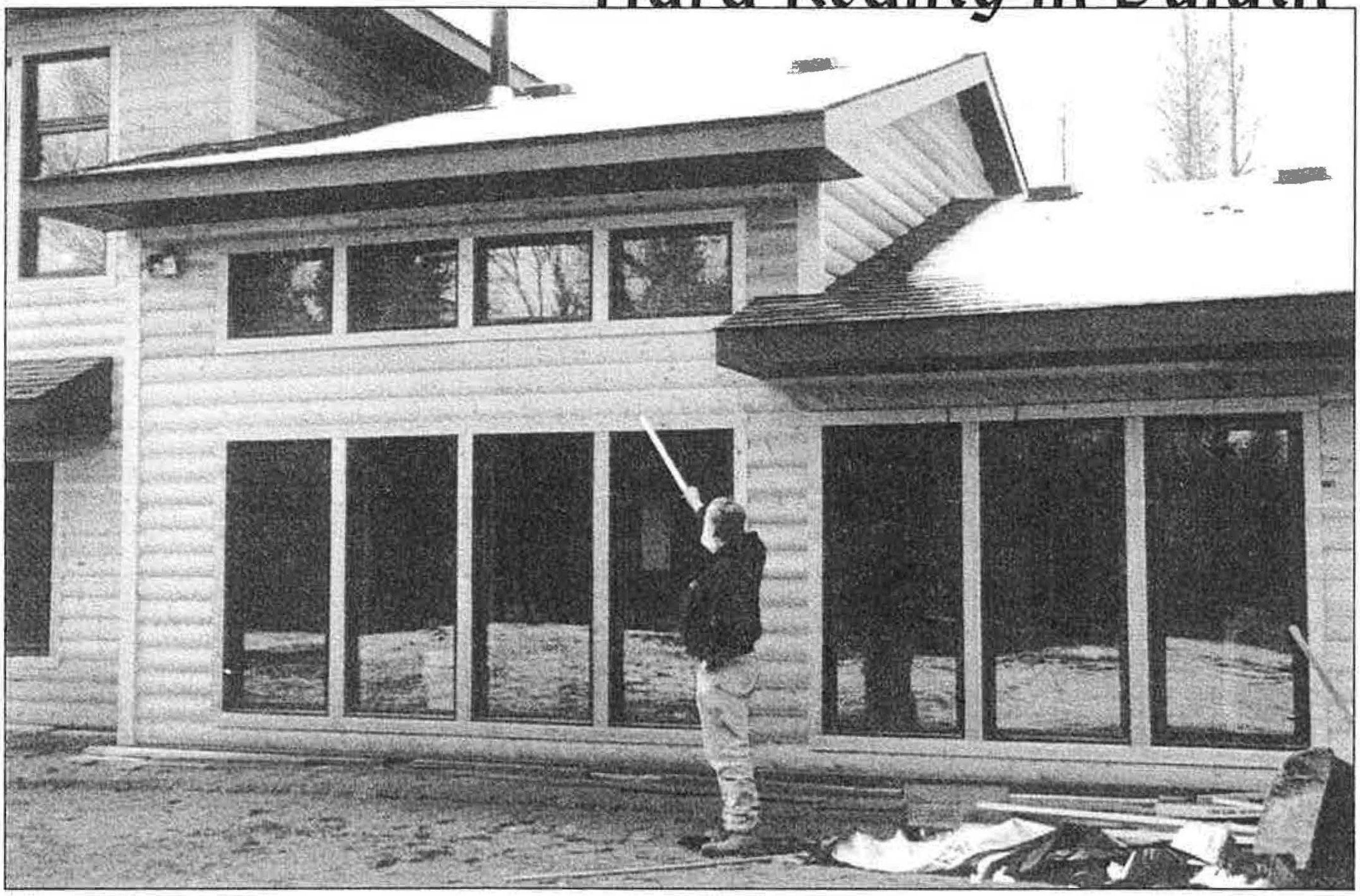
field notes

Dream Design, Hard Reality in Duluth



BRUCE MARSHALL

by Colleen Turrell

Don't say "No" to what you don't understand, for the times they are a'changing .... Bob Dylan, "Blowing in the Wind"

Designers and architects are often criticized for not incorporating proven energy efficiency measures, such as passive solar design or high-tech windows. But what happens when such measures are part of the design, but the builder refuses to install them because they are "unfamiliar"?

In 1999 residential designer Bruce Marshall designed a low energy house for clients in the Duluth, Minnesota, climate. But the builder didn't build the design, apparently because the concepts were unfamiliar to him. How this happened, and how to prevent it, is worth a close look.

Exemplary Design

Recognizing that more than one-third of the energy used in the United States goes to residential and commercial buildings, the National Renewable Energy Laboratory (NREL) in 1994 developed the Exemplary Buildings program to showcase low-energy building solutions. (The residential side of this program is now part of the Department of Energy's Building America program.) By "exemplary building" NREL means one that uses at least 70% less energy than a comparable house built to the 1995 Model Energy Code

(95MEC), which Minnesota adopted on April 15, 2000.

Marshall designed such a home for Roger and DeAnna Finifrock, of Barnum, Minnesota, in collaboration with NREL scientist Micah Sherman. The house's annual heating load was to be 78% less than for a comparable 95MEC house, according to Marshall's calculations using the building energy simulation software Energy-10. Conservation measures reduced the heating load by 70%, and solar gain reduced the remaining heating load 26%. Energy savings features were to cost about $3/ft^2 more than for a comparable 95MEC house. Annual heating cost for the Exemplary House was estimated at $234. Compare this to a 95MEC house whose heating cost would be $1,041, assuming propane costs of 69¢/gal (see "Exemplary House Design Performance Estimates," p.45).

Below the clerestory windows, on the interior of the home, there was to be a lightshelf to reflect glare off the floor and up onto the ceiling. The builder omitted this feature because it was unfamiliar to him.

Design Constraints

The house Marshall designed was not the house that used the least possible energy in the Duluth climate. Rather, it used a lot less energy while at the same time satisfying the constraints of site, budget, schedule, and owner preferences.

Duluth is cold and fairly cloudy in the winter and not hot in the summer. It has 9,901 heating degree-days and 150 cooling degree-days each year. The winter design temperature is -21°F; the summer design temperature is 82°F. At 47°N latitude, Duluth receives only 52% of its possible sunshine, due to heavy cloud cover.

The house is located off a county road in a small clearing in the woods. The site is level, with sandy soil; a swamp lurks nearby. Electricity and liquid petroleum gas are available to the site from local companies.

The Finifrocks, empty nesters in their 50s, wanted a house of approximately 2,000 ft^2, plus a garage and a three-season porch. On the ground floor, they wanted a master bedroom, a large master bathroom, a half bath, and a small office. From the living and dining areas, they wanted good views to the south and east. They wanted the kitchen to be situated in the northeast corner of the ground floor. On the second floor, they wanted two additional bedrooms served by an additional full bath and a sitting room.

They were not partial to any particular style. Roger didn't want the house to look too conventional; DeAnna didn't want it to look too unconventional. They wanted a durable house that they could leave to their children. Of course they wanted a healthy house. They were interested in having a low-energy, environmentally friendly, resource-efficient home, but they didn't want a house that shouted "techno wizard!" As far as costs go, they aimed for a budget of $35–$45/ft^2 for the house and porch, excluding the foundation and the garage, before taxes. (The foundation and garage were excluded from the cost estimate because this is how modular homes and manufactured homes are promoted in this area—they constitute around 25% of new houses. The Finifrock house was supposed to be an example of what could be done for people with that sort of a budget, so the figure was computed accordingly.)

Strategies for Low-Energy Space Heating

In Duluth's climate, 80% of the energy needed for a 95MEC house goes for space heating, according to Marshall's Energy-10 calculations. Therefore, in developing a low-energy house design for the Finifrocks, he focused on energy for space heating but without ignoring energy for cooling, lights, and plug loads, such as appliances.

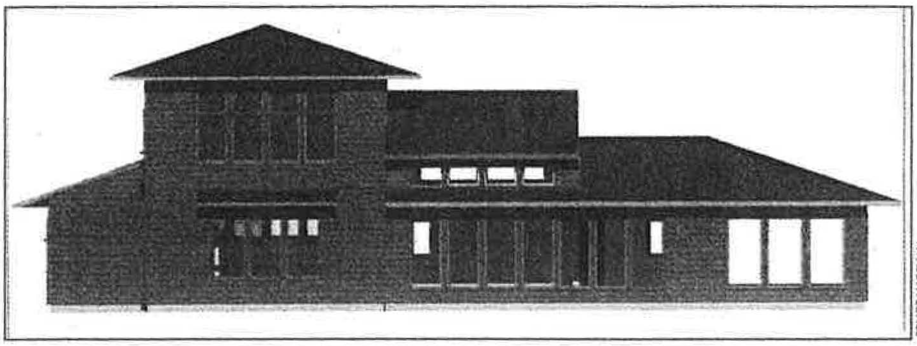
Four strategies for reducing the fossil fuel energy required for space heating have been identified by NREL's Doug Balcomb:

1. reduce losses by creating a compact, tight, well-insulated envelope;
2. recover heat from exhaust air;
3. make use of solar gain; and
4. select a highly efficient mechanical heating/cooling system.

The Envelope

Building a tight, well-insulated envelope is the strategy that makes the most difference in reducing the fossil fuel energy required for space heating in the Duluth climate, according to Marshall's Energy-10 studies. Following Marshall's design, the envelope of the Finifrock house would have reduced its heating load 63% compared to a 95MEC house.

Sherman studied the Duluth climate and came up with recommendations for insulation for the envelope. (About nine months later, almost the same



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The passive solar design offered views to the south and east, taking advantage of sunlight for heat and lighting.

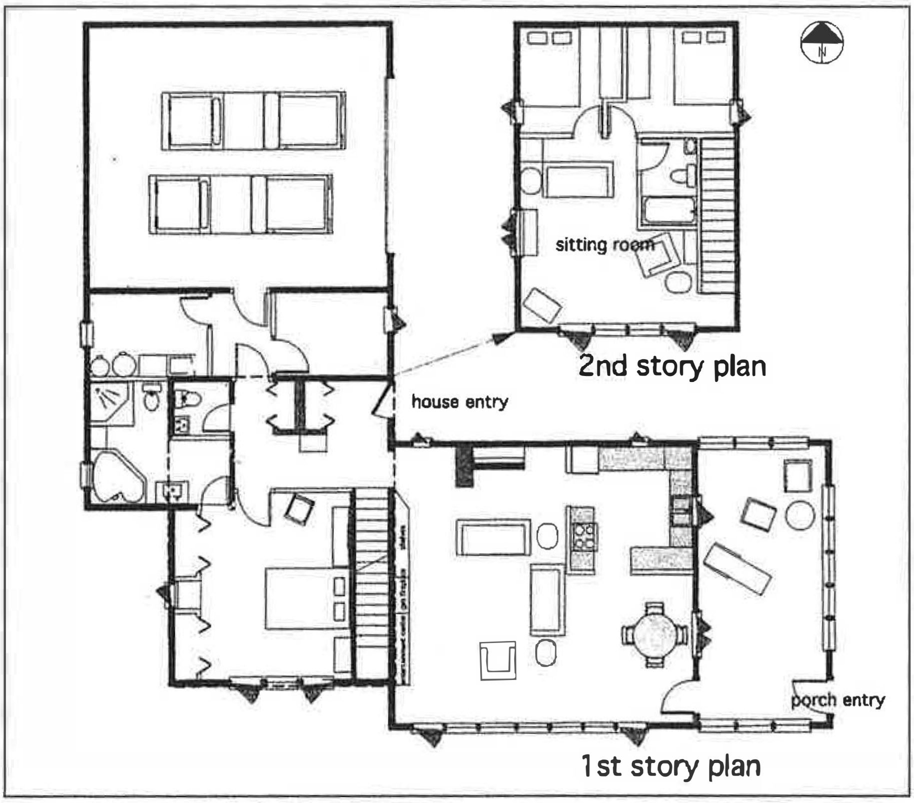

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Figure 1. The house was designed so that furniture was placed away from the windows in the upstairs sitting room, the living and dining areas, and the sun room. Walkways were placed in these areas instead, to direct the flow of traffic here.

envelope was proposed for this climate by the International Code Council, as can be seen in the *International Energy Conservation Code, 2000.*)

The home's whole-wall R-value is 25.5 (this includes framing). The ceiling R-value is 51. The roof has a 12-inch raised heel truss to better insulate over the exterior wall and thus prevent ice dams. The home's exterior doors have an R-value of 16.

Marshall wanted to minimize windows on any facade except the south facade (or a facade within 30° of south), where appropriate windows are net energy gainers. The Exemplary House design located 237 ft^2 of windows on the south facade. Note that south glazing can increase the cooling load in the summer; this increase, however, can be largely prevented by shading the south windows with an appropriately wide roof eave.

For the nonsouth facades, Marshall recommended double-glazed windows with one low-e coating and argon fill, in a vinyl frame; these operable windows have a total-unit U-value of 0.32. Fiberglass-framed triple-glazed windows with two low-e coatings and argon fill have an even lower U-value, but these did not fit the budget. For the south facades, he recommended fixed windows with a SHGC/U-value ratio of 1.9 and operable windows with a ratio of 1.5. The fixed windows had a total-unit SHGC of 0.6 and a total-unit U-value of 0.32; the operable windows had a total-unit SHGC of 0.5 and a total-unit U-value of 0.3.

The foundation has R-12.5 insulation. The insulation board is attached vertically to the sides of the concrete slab and horizontally under the slab. The use of subslab insulation is somewhat controversial—Sherman recommended it in this case because his energy analysis program, Sunrel, showed that it would help; Marshall's analysis, using Energy-10, showed that it did not help. An insulated concrete slab was the only type of foundation they seriously considered, given the low, wet site. Also, a concrete slab foundation can be an excellent fit with a passive solar system, since it offers ready-made thermal mass.

"Reducing air infiltration is the last great residential energy conservation frontier," Marshall says. Marshall's design aimed for a tight 0.1 ACH, to be checked by a blower door test. This step—reducing air infiltration from the 95MEC value of 0.5 ACH to 0.1 ACH—would have reduced the heating load by 39% compared to a 95MEC house, according to Marshall's Energy-10 calculations. One of his main techniques for achieving this was to have been a strapped wall, wherein all the electrical outlets are located inside the vapor retarder, significantly reducing penetrations.

Marshall praised the role Energy-10 played in the design process. "I was able to easily quantify the significance of reducing air infiltration with Energy-10," Marshall said. "It's a marvelous tool. With it you can easily quantify things–how significant is more of this or that. You move from guesses to numbers with a rational basis. I calculated that envelope improvements would reduce heating load by 63%. Well, 39% of that was to come from reducing air infiltration. So, you have a quantitative basis for the significance of tight construction." To introduce outdoor air, a whole-house ventilation system was specified for the house.

Solar Gain

Solar gain makes a difference, even in the relatively cloudy Duluth climate "Here's another way Energy-10 was useful in design," he said. "It allows the user to quantify the relative contribution of different players in getting to low energy. The 95MEC used 138.7 MBTU/year for heating. Going to the better envelope dropped it to 50.8 MBTU/year—a 63% reduction. Add heat recovery, a highly efficient boiler, programmable thermostats, and you get down to 42.2 MBTU/year—a 70% reduction. Now, if you add passive solar to this terrific package, you can get down to 31.2 MBTU/year. So what should we think about this reduction due to passive solar? Well, on the one hand, the absolute reduction is nearly a flyspeck compared to what envelope enhancements give you. But, on the other hand, if you've already gotten your heating load down to 42.2 MBTU, then you can reduce that load a further 26% by adding passive solar."

In designing the Finifrock house Marshall employed two methods of solar gain and paid particular attention to developing a glare strategy. He's quite exercised by the subject of glare. "It's not that difficult. Some sources get it right—the excellent *Designing Low Energy Buildings* booklet that comes with Energy-10, for example. But the message I get from the buildings I see is that few architects and builders understand glare problems. For example, go around Minnesota on a sunny winter day, and look at the south windows of all sorts of buildings—you'll see that in most cases, curtains or blinds have been drawn. On the inside, people are using artificial lights, and the heat is on. That is design failure. It occurs in new, multimillion dollar office buildings as well as in passive-solar homes of all vintages."

Many of the Finifrock builder's departures from Marshall's design stem, Marshall speculates, from the builder not appreciating glare problems.

Direct Gain

The passive-solar house design features east-west orientation and a compact, open floor plan to reduce heating load and to facilitate natural heat flow. The garage is located on the northwest corner of the house to break the winter wind. The design takes advantage of maximum solar heat gain from the south windows and minimum gain from the other windows.

Sunspace

The design included a sunspace in the form of a modified three-season porch. One side, with ample window openings, was to have faced south; the window openings could have been glazed or screened, depending upon the season. This feature would have reduced the heating load by 5% compared to the 95MEC.

Glare Strategy

The decision to go for solar gain has design consequences. South-facing windows can have a downside in winter, when low sun angles and highly reflective snow can cause glare and overheating in some rooms.

One way to avoid these problems is to locate many of the south windows along a hallway and an entryway, from which the heat but not the glare will naturally flow into living areas.

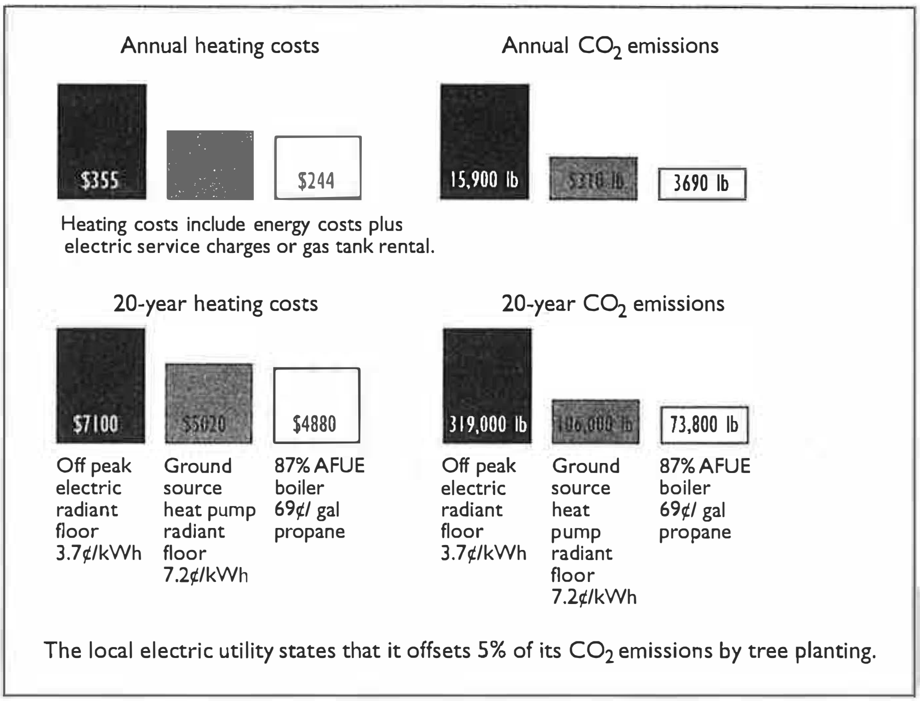

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Figure 2. The heating system Marshall chose offered both the lowest heating costs and the lowest CO_2 emissions of all the options that were considered.

Exemplary House Design Performance Estimate

- 2,168 ft² gross floor area = 2,000 ft² conditioned floor area. Estimated total cost $43/ft² (excluding foundation and garage) before taxes.
- Estimated $234 per year heating cost (with 69¢/gallon propane and 87% AFUE boiler) or 1.3 cords of black ash. Lowest lifetime heating cost-relative to 2000 MN Energy Code house or relative to Exemplary House with any other auxiliary heating system.
- Lowest CO_2 emissions. Avoided 12,700 lb CO_2 per year relative to 2000 MN Energy Code house.
- Solar gain reduces heating load by 26% relative to solar neutral Exemplary House.
- Energy-saving features cost less than $3/ft² more than a 2000 MN Energy Code house.

For the Finifrock design Marshall developed a different glare strategy, using space planning, occasional use of curtains, and light shelves. He says, "For the living/dining areas, I located a traffic circulation area (walkway) next to the south windows (see Figure 1). This would keep furniture grouping (and people) out of direct sun as well as away from windows, where people will feel cold in the winter. Still, to prevent disabling glare on sunny winter days, the sun has to be blocked out with curtains, blinds, or shades. When that happens, you still want ample natural light. So, I provided south and north clerestory windows, as well as an east window. And, Roger and DeAnna agreed to living room furniture placement that give them the option of seats facing away from south sunlight. I also provided a light shelf for the south clerestory windows, to redirect sunlight from the floor to the ceiling."

Mechanical Heating and Cooling

A heat-recovery whole-house ventilation system would pay for itself in about five years, according to Marshall's calculations. After careful attention to the envelope, heat recovery from exhaust air, and solar gain, the remaining heating load was calculated to be quite low, according to the design team of Marshall, Sherman, and heating contractor Art Korhonen. The design team analyzed many mechanical heating systems for comfort, reliability, cost (life cycle analysis), and environmental impacts (see Figure 2). They selected an 87% annualized fuel utilization efficiency (AFUE), sealed-combustion boiler (Amitrol Wh7-Hot Water Maker) with baseboard convectors, with an advanced controller to cycle multiple zones to preset thermostatic setpoints daily and weekly. Marshall also specified a well-insulated propane water heater, Energy Star appliances, and compact fluorescent lamps, where possible.

The design team determined that mechanical air conditioning would not be necessary to achieve thermal comfort. The cooling load can usually be satisfied—after excluding most summer sun with roof overhangs—with ventilation, thermal mass, occasional night-time flushing of hot air in the house, and ceiling fans. Windows and their placement (to secure air movement) are critical to this strategy.

Snatching Victory

"We had this lovely, low-energy design," Marshall says. "The owners liked it; NREL liked it. I drew up construction documents and gave a trial set of them to the builder. The builder, the owners, and I sat down to discuss them. He had some questions and suggestions. I told him why the design was as it was. I then left the country for three weeks. When I returned, the house had been framed up, with numerous, important departures from the design."

The departures mostly related to solar features or envelope innovations, according to Marshall. He listed some of the departures: "A roof eave was omitted, so the living room will now overheat in the summer; all light shelves were omitted, so now the living and sitting rooms will suffer winter glare; the south windows of the sunspace were omitted, redefining it to a so-called three-season porch, less usable (too cold) in spring and fall and making no contribution to dampening winter heat loss from the house; dining area space planning was altered, so now the dining table and chairs will be located in punishing winter sun. For the exterior wall, the strapped wall with studs at 24 inches OC was not built, rather a 2 x 6 wall with approximately equivalent R-value was built. But R-value is not the big player here–infiltration is. The strapped wall is a star at preventing that."

> ***"When it comes to a complex project, how do you snatch victory from the jaws of defeat ?"***

How did it happen that important aspects of the design were not built? "I'm not absolutely sure, although I discussed it with the parties," Marshall says. "Here's how I put it together. The builder was a very old and trusted friend of the owner. The builder does good work. Dare I say the builder has a high opinion of his opinions? My guess is, as he studied the plans carefully, when he came to something that was unfamiliar to him, he told the owner something like, 'This is not how it's usually done. I want to do it the way I've always done it.' And the owner went along. I think if I had been around, we could have talked it all out. But, maybe not."

For the Finifrocks, their house will still be a low energy house, though not as low as designed. But it will be less comfortable and enjoyable to live in, Marshall believes, because of preventable glare, local overheating, and less spring and fall use of the three-season porch.

How to prevent this from happening another time? "You are perhaps more of an optimist than I, when you say 'prevent,'" says Marshall. "I have only four ideas how to snatch victory from the jaws of defeat when it comes to a new or complex project:

1. Make it simpler. So, use more panels, modules, factory housing, etc. Of course, this has its own set of disadvantages.
2. Make it the law. That is, enact a low energy code.
3. Develop enough clean, safe, renewable energy so we can safely waste energy.
4. In the meantime, we've got to try to understand one another–all the parties involved–and work together. If you don't understand, ask a second question. Don't assume you understand what the other is saying, as he or she understands it. Seek confirmation. Seek understanding."

Colleen Turrell is associate editor of Home Energy. This article is based on an original work by Bruce Marshall.

For more information:

Bruce Marshall
Sunwise Design
4919 County Road 6
Kettle River, MN 55757
Tel:(218)389-6140
E-mail: marshall@cp.duluth.mn.us.